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ESRF

Experiment Report Form

The double page inside this form is to be filled in by all users or groups of users who have had access to beam time for measurements at the ESRF.

Once completed, the report should be submitted electronically to the User Office via the User Portal:

https://wwws.esrf.fr/misapps/SMISWebClient/protected/welcome.do

Reports supporting requests for additional beam time

Reports can be submitted independently of new proposals – it is necessary simply to indicate the number of the report(s) supporting a new proposal on the proposal form.

The Review Committees reserve the right to reject new proposals from groups who have not reported on the use of beam time allocated previously.

Reports on experiments relating to long term projects

Proposers awarded beam time for a long term project are required to submit an interim report at the end of each year, irrespective of the number of shifts of beam time they have used.

Published papers

All users must give proper credit to ESRF staff members and proper mention to ESRF facilities which were essential for the results described in any ensuing publication. Further, they are obliged to send to the Joint ESRF/ ILL library the complete reference and the abstract of all papers appearing in print, and resulting from the use of the ESRF.

Should you wish to make more general comments on the experiment, please note them on the User Evaluation Form, and send both the Report and the Evaluation Form to the User Office.

Deadlines for submission of Experimental Reports

- 1st March for experiments carried out up until June of the previous year;
- 1st September for experiments carried out up until January of the same year.

Instructions for preparing your Report

- fill in a separate form for each project or series of measurements.
- type your report, in English.
- include the reference number of the proposal to which the report refers.
- make sure that the text, tables and figures fit into the space available.
- if your work is published or is in press, you may prefer to paste in the abstract, and add full reference details. If the abstract is in a language other than English, please include an English translation.

ESRF	**Experiment title: X-ray diffraction measurements of 3D residual stress fields below surface anomaly in a Nickel-base superalloy**	**Experiment number**: MA-3647
Beamline: ID22	**Date of experiment**: from: 22 November 2017 to: 28 November 2017	**Date of report**: 1st March 2018
Shifts: 18	**Local contact(s)**: Mr. Andy Fitch	*Received at ESRF:*

Names and affiliations of applicants (* indicates experimentalists):

Besnik SADRIJI* – PhD student at LMT, Ens-Paris-Saclay, CNRS, Université Paris-Saclay

Karine LAVERNHE* – Assistant Professor at LMT, Ens-Paris-Saclay, CNRS, Université Paris-Saclay

Yoann GUILHEM* – Assistant Professor at LMT, Ens-Paris-Saclay, CNRS, Université Paris-Saclay

Report:

Context and objectives

A synchrotron X-ray diffraction experiment, MA-3647, has been carried out at the ESRF on ID22, in order to measure the residual stress field below V-type dents. In fact, current models consider surface anomalies, like dents, as initiated cracks of similar depth and propagating from the first cycle. Besides giving shorter propagation life compared to experimental data, preliminary studies showed that induced compressive residual stress field beneath the anomaly influences the first stages of crack propagation and thus are responsible for conservative results. In order to develop a new crack growth model accounting for initial residual stress fields and their evolution, it is necessary to measure them. For more precision about the context see the proposal for the ma3647 experience.

Objects of interest

The experiment focuses on V-shaped dents of three different depths: 200μm, 150μm and 100μm. Two types of samples have been studied, the "non-relaxed" ones and the "relaxed" ones. The "non-relaxed" ones are the specimens that just contain the flaw itself. So that the initial gradients and multiaxial state of residual stress fields are characterized. The "relaxed" ones are the specimens that have been subjected to pre-cycle fatigue under temperature, giving information about how the residual stress fields evolve both in terms of gradients and multiaxial state.

Two kinds of samples have been extracted from the specimens in order to access all the components of the residual stress field see Fig.1. With sample A (Wall), ε_{yy} and ε_{zz} are determined and with sample B (Column) all the components are measurable. The results on sample B give us an idea of the stress release induced by the extraction.

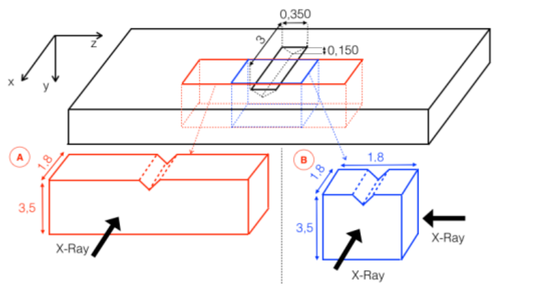

Fig.1 – Fatigue sample geometry with dent (3x0.350x0.150). Sample A for two components and sample B for all the components and comparison with the extraction.

Experimental technique

The material of interest is a Ni-base superalloy INCO718 DA which is used as bulk material for disc components of aero-engines. Its mean grain size is ~10µm and contains 4 phases: the γ matrix (FCC) and three types of precipitates (γ', γ'' and δ). The monochromatic beam at λ=0.1771 Å with energy 71 keV allowed us to measure the lattice spacing of the (111) plane of the γ matrix. The nine-channel crystal analyzer is used to detect the diffracted x-rays and for our material the best compromise scan-time/quality of the scattering angle window is $2\theta_{111} \in [4.84, 4.94]$ see Fig.2.

The nominal gauge volume is 0.05 (Y direction) x 0.15 (Z direction) x 1 (X direction) millimetres so that the volume contains enough grains that diffract.

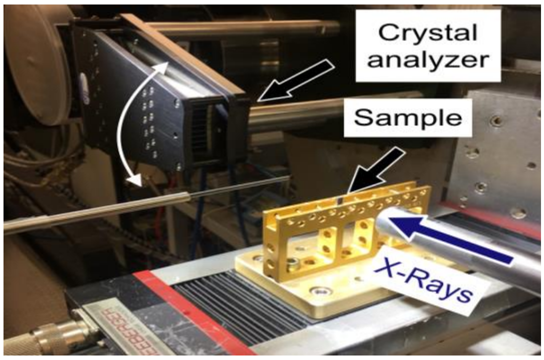

Fig.2 – Set-up with the nine-channel crystal analyzer

In order to correctly place the samples in front of the beam and scan the region of interest, two procedures of surface and flaw detection have been set.

Measurements

Measurements have been made on 9 samples representing the 3 depths, the "non-relaxed" and "relaxed" states and the three components of the residual stress field for a total of 19 scans see Table 1. "Wall" and "column" appoint respectively for sample A and sample B. The component along X was not measurable with wall samples. To access all the different components, the samples were put in different positions see Fig.3.

Sample	ε^{Wall}_{XX}	ε^{Wall}_{YY}	ε^{Wall}_{ZZ}	$\varepsilon^{Column}_{XX}$	$\varepsilon^{Column}_{YY}$	$\varepsilon^{Column}_{ZZ}$
Dent 200μm		x	x (2 scans)	x	x	x
Dent 200μm Relaxation 1		x	x	x		
Dent 150μm		x	x	x (2 scans)		
Dent 150μm Relaxation 1		x	x	x		
Scratch 100μm		x	x (2 scans)			

Table.1 – Exhaustive list of the scans made with the different depths and samples

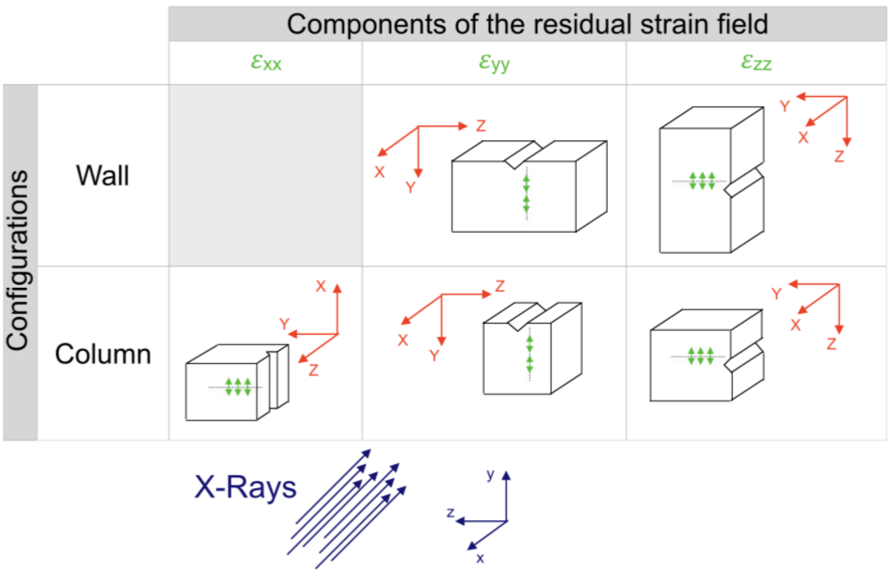

Fig.3 – Positions of the sample to access all the components

The first scan took about 8 hours. It was important to get a full map of the residuals stress fields before adjusting it to our needs. At the end the scans lasted about 5 hours, installation of the sample included.

Results

Thanks to this experiment, the residual strain fields are quantitatively described in terms of gradients, multiaxial state and relaxation. It is then possible to determine the residual stress field thanks to a constitutive law of the material of interest. An overview of the results is shown in Fig.4.

Fig 4.a depicts the deformation ε_{zz} map beneath the 200μm V-dent. As expected, there is a compressive region in the first 500μm under the flaw. Then, the residual strain field goes in tension in order to maintain "equilibrium" in the material. This grid allows us to characterize the residual strain field in an extended zone around the flaw. Fig 4.b illustrates the multiaxial state and the relaxation of the residual strain field. It gathers the deformations ε_{yy} and ε_{zz} of the 200μm deep V-dent at the center of the flaw and along the depth of the non-relaxed and relaxed states. The extreme values of deformation reached ε_{zz} = -0.0042 and ε_{zz} = 0.0022 respectively correspond to σ_{zz} ~ -830 MPa and σ_{zz} ~ 430 MPa according to an isotropic elastic law and are consistent with the simulations, besides finding the same evolutions. It is also shown that the residual stress field is multiaxial and that the relaxation occurs as it is expected. The results on other depths, 150μm and 100μm show the same evolutions but at a lower rates in absolute terms, as expected.

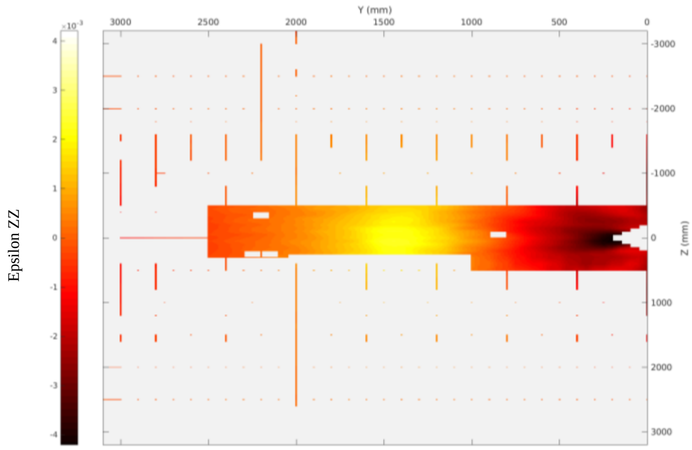

Fig.4a – EpsZZ map beneath the 200μm V-dent

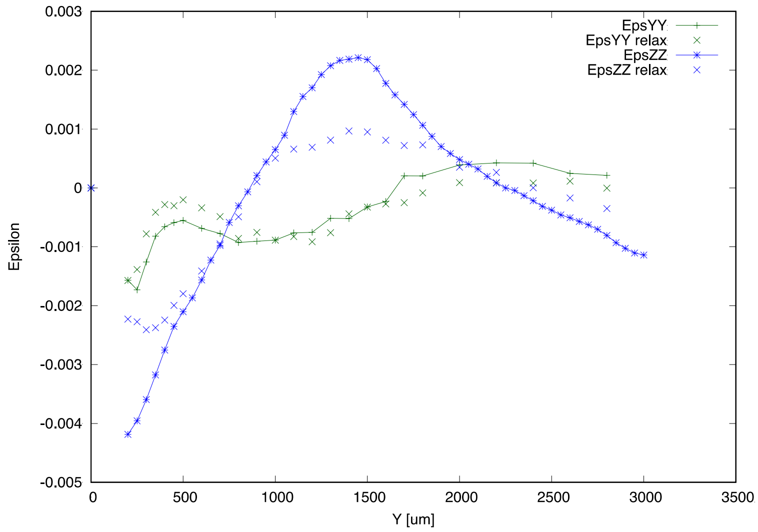

Fig.4b – EpsYY and EpsZZ beneath 200μm V-dent for the normal and the relaxed state at Z=0 (in the middle of the flaw)

<u>**Conclusions & perspectives**</u>

The MA-3647 experience was very stimulating, first by the process of sample preparation and especially at the ESRF. We took some time to take over the system, then try some scans to find the best time-analysis/quality ratio. In the meantime, procedures to have a "live" post-processing of the datas have been set so that the results can be analyzed to adapt our needs. Among the specimens studied, some flaws have been submitted to a cyclic loading under temperature in order to characterize the relaxation of the residual stress field. The results of this experiment are very satisfying as they first quantitatively describe the gradients, the multiaxial state and the relaxation of the residual stress field, and second go along with what was expected.

Thanks to these measurements, considerations have gone further concerning the investigation of the multiaxial state of the residual stress field. The flaws considered for the relaxation were orthogonal to the anomaly whereas their orientation may differ in real life. In order to have a representative measurement of the residual stress field under a "non-orthogonal to the loading direction" flaw we could consider, for example, dents turned of 45° from the loading direction. Also, another type of flaws, like scratches, introduces an initial non-symmetric multiaxial residual stress in the material. These flaws are part of the proposal for the end of the year as a continuation of the MA-3647 experience. Studying the 45°-dent and the scratch would allow us treating general cases and how the multiaxial state of the residual strain field evolves.

In the meantime, an innovative numerical simulation procedure is developed in order to reproduce the flaw introducing and the cyclic loading. These results are the reference for the procedure consistency.