EUROPEAN SYNCHROTRON RADIATION FACILITY

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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:** Physical simulation of Plasma Transfer Arc cladding (PTA) for additive manufacturing	**Experiment number**: ME-1388
Beamline: ID22	**Date of experiment**: from: 24/07/2017 to: 26/07/2017	**Date of report**: 05/09/2017
Shifts: 6	**Local contact(s)**: Andy Fitch	*Received at ESRF:*

Names and affiliations of applicants (* indicates experimentalists):

Hadi Moztarzadeh* (main proposer)

Dr Darren J Hughes*

Conor Caffola*

Dr Hoda Amel

Prof Richard J Dashwood

Report:

Diffraction techniques (neutron and synchrotron X-ray) are known as non-destructive methods to determine residual stresses in crystalline materials. The concept is based on directing a beam on a component and measuring the angular distribution of the radiation diffracted from the material. The relatively high energies involved lead to very low scattering angles, typically ranging from about 10° at moderate energies (25 keV) to about 4° at higher energies (~80 keV). This leads to the formation of an elongated diamond shape gauge volumes as opposed to the (almost) cubic gauge volume in neutron diffraction. Therefore, the synchrotron X-ray diffraction is considered as a complementary technique to other non-destructive (and even destructive) methods to evaluate residual stresses.

The basic concept underlying the non-destructive measurement of residual strains (residual stresses) by synchrotron X-ray diffraction is fundamentally the same as for other diffraction techniques. The method utilises the Bragg's law to identify the relationship between the d-spacing (dhkl) of certain lattice planes to the diffraction angle (2θhkl), at which the radiation is scattered coherently and elastically for a given wavelength of the radiation.

$n\lambda=2\theta\_hkl.\sin\theta\_hkl$

According to the Planck-Einstein equation for photon energy, the wavelength can be calculated:

$E=h.f$

$E=(h.c)/\lambda$

Where E is the photon energy, h is the Planck's constant (h = 6.626×10-34 J.s = 4.136×10-15 eV.s), f is the wave frequency, c is the speed of light in vacuum (c=3×108 m/s) and λ is the photon's wavelength.

$E\ (eV)=1.2398/(\lambda\ (\mu m))$

When the frequency is expressed in terms of radians per second (instead of cycles per second or hertz) the angular frequency is used which includes a factor of 2π into the Planck's constant. The resulting constant is called the reduced Planck's constant or Dirac constant:

$\bar{h}=h/2\pi$

Therefore, the values of the reduced Planck's constant are: 1.546×10-34 J.s/rad or 6.582×10-16 eV.s/rad.

This experiment was designed as part of the research towards understanding the effect of Plasma Transferred Arc (PTA) cladding on the evolution of residual stresses in parts made in an additive-layer process. The main aim was to obtain a thorough understanding of the stress distrbution in parts made by Ti-6Al-4V alloy and investigate the effect of process parameters.

The high energy synchrotromn X-ray was used at ID22 to scan PTA AM parts made out of Ti-6Al-4V on the subtsrate of the same material grade. The parts were scanned along multiple horizontal and vertical scanlines to gain an understanding of the stress distribution. The PTA AM parts and the scanlines are schematically shown in Figiure 1. Each scan point was scanned in two directions to determinie strain in two in-plane directons.

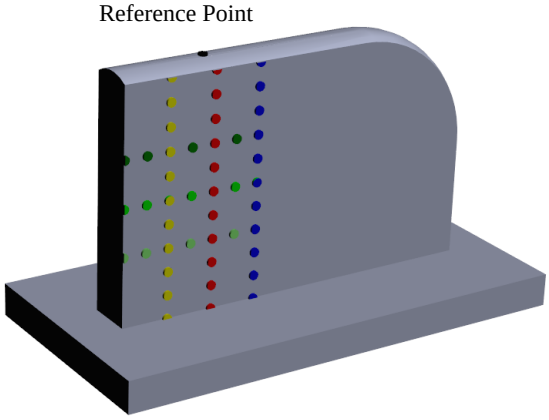

Figure 1 – Schematic of the samples and the scanlines for the synchrotron X-ray diffraction

The energy of the X-ray beam was 60 KeV which gave a wavelenght of 0.20678 Å. The unit cell parameteres for α and β phases are given in Table 1.

Table 1 – Unit cell parameters

	a (Å)	b (Å)	c (Å)	alpha (º)	beta (º)	gamma (º)
α-crystal structure	2.9500	2.9500	4.6600	90.000	90.000	120.000
β-crystal structure	3.3200	3.3200	3.3200	90.000	90.000	90.000

The α (101) peak has shown the strongest diffraction peak. This can be checked by considering the position of the α (101) peak in X-ray diffraction pattern from Cu-Kα (2θCu-Kα= 40.2035°), the position of the same peak, α (101), in synchrotron X-ray is determined to be 2θsync. X-ray=5.2846°.

Therefore, the scanning for each point was performed from 2θ=5.23° to 5.4° with a step angular displacement of 0.5°. Scanpoints were scanned from 5.10º to 5.40º to capture the α(101) peak. Figure 2 shows the sample set-up and the schematic of the matchstick gauge volume acrsoss bthe width of the samples.

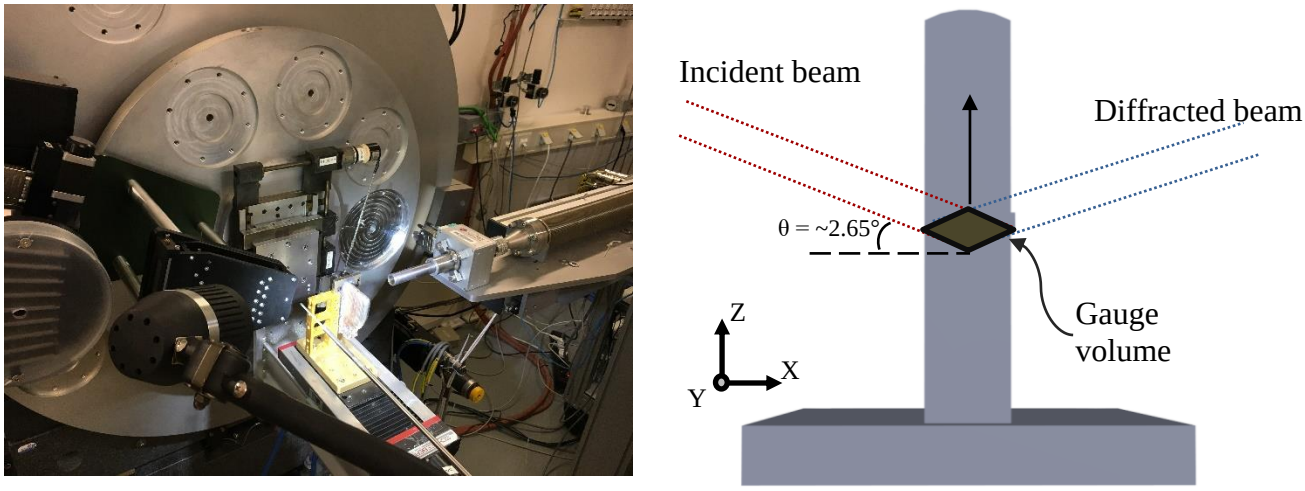

Figure 2 – (a) the sample set-up on the Synchrotron X-ray beamline at ID22, ESRF and (b) the geometry of the gauge volume of the incident and diffracted beams throughout the width of the PTA AM samples

In total, 6 samples were scanned, to study the cobination of the effects of process parameters. In this experiment, three main process parameters were considered to manufacture the samples; the energy input, the dwell time and the deposition strategy. The experiment investigated the distribution of residual strain/stress within the PTA Am parts manufactures using a set of different process parameters.