EUROPEAN SYNCHROTRON RADIATION FACILITY

INSTALLATION EUROPEENNE DE RAYONNEMENT SYNCHROTRON

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*

Deadlines for submission of Experimental Reports

Experimental reports must be submitted within the period of 3 months after the end of the experiment.

Experiment Report supporting a new proposal ("relevant report")

If you are submitting a proposal for a new project, or to continue a project for which you have previously been allocated beam time, you must submit a report on each of your previous measurement(s):

- even on those carried out close to the proposal submission deadline (it can be a *"preliminary report"),*
- even for experiments whose scientific area is different form the scientific area of the new proposal,
- carried out on CRG beamlines.

You must then register the report(s) as "relevant report(s)" in the new application form for beam time.

Deadlines for submitting a report supporting a new proposal

- 1st March Proposal Round - **5th March**
- 10th September Proposal Round - **13th September**

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.

Instructions for preparing your Report

- fill in a separate form for each project or series of measurements.
- type your report in English.
- include the experiment number 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:** Ultrasound Microstructural Control during DED Additive Manufacturing	**Experiment number**: MA-5497
Beamline: ID19	**Date of experiment**: from: 9/2/2023 to: 13/2/2023	**Date of report**: 1/3/2023
Shifts: 12	**Local contact(s)**: Alexander Rack, Partha Paul, Yunhui Chen	*Received at ESRF:*

Names and affiliations of applicants (* indicates experimentalists):

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Dr Kai Zhang*	University College London
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Ms. Maureen Fitzpatrick*	ESRF
Dr Catherine Tonry*	University of Greenwich

Report:

Introduction

Using the unique blown powder manufacturing process replicator (BAMPR-II), shown in figure 1, we performed in-situ radiography of Directed Energy Deposition Additive Manufacturing (DED-AM) on an ultrasonic (US) sonotrode. The experiments are a first of their kind, and initial analysis shows strong effects of the ultrasound including evidence of cavitation and the small parameter space where it occurs. This initial report has been compiled shortly after the beamtime and further details will be added as the results are studied in more detail.

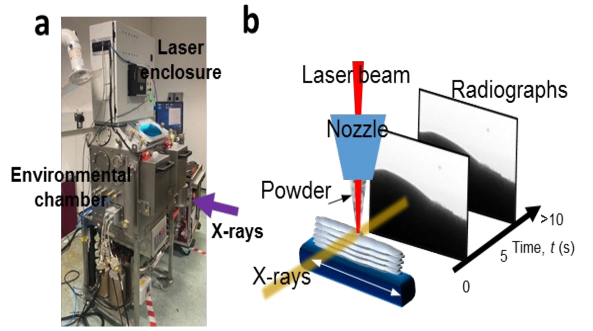

Fig. 1. (a) New BAMPR-II rig with built in ultra-fast IR imaging, (b) preliminary synchrotron X-ray results (DLS).

Methodology

For the experimental work, we printed directly on a ultrasonic sonotrode made from Titanium. Experiments were performed using both Ti-6242 and RR1000 alloys. The material was directly deposited and melted in tracks directly onto the sonotrode. A parameter space was studied looking at the effect of the ultrasonic amplitude of the probe, position on the probe, the laser power, scan speed and powder material. Tests were also performed without powder to demonstrate the effect on welding. The amplitude of the vibration changes along the probe length, allowing us to fine tune the amplitude by 'building' on different positions of the probe.

Results

Results have demonstrated that there is a small operating window to obtain a good build. If the ultrasound amplitude is too high, the melt pool can be ejected. This is dependent on surface tension and so there was more success with a smaller melt pool.

Figure 2 shows the effect of an increase in the ultrasound intensity. All processing parameters are the same, except for the US amplitude. 2(a) shows a normal build without US. 2(b) a build with a 20% probe amplitude far from the tip (low amplitude) and 2(c) shows the same amplitude but near to the tip (high amplitude). The figure shows how the change in the US amplitude has an extreme effect. The build without US shows the typical DED melt pool shape. With a low intensity US, the top surface of the melt pool changes dramatically leading to a shallower melt pool. A high intensity build shows ejection of the melt pool, leading to the laser penetrating deep into sonotrode and creating a 'key-hole' like effect. In the low amplitude case, "non-inertial" cavitation was observed, where the bubbles pulse but don't seem to implode as would be seen in full "inertial cavitation". This is shown in Figure 3, where bubbles oscillate between large and small radii due to the changing acoustic pressures.

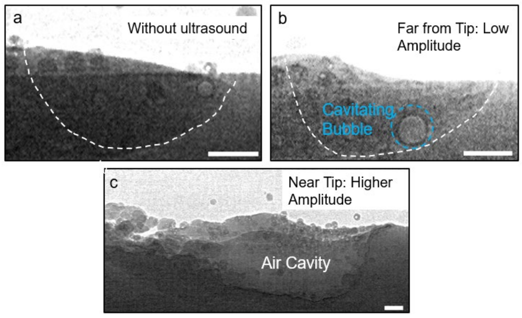

Figure 2: Effect of ultrasound and the position on the probe. (a) no ultrasound, (b) far from the tip of the probe and (c) near the tip of the probe

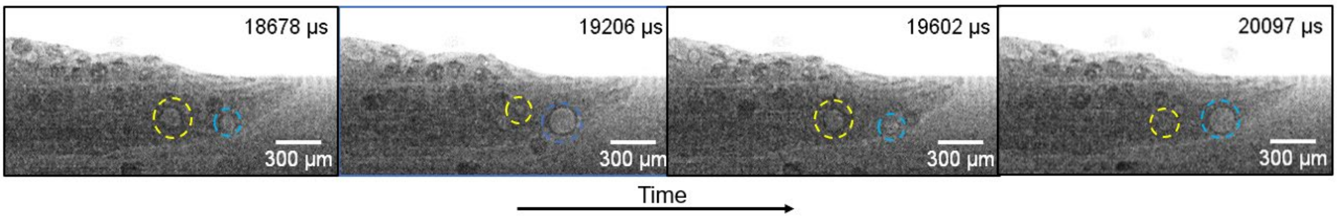

Figure 3: Bubbles pulsating due to US pressures, demonstrating cavitation.

We also performed a study of laser welding where inertia ejects the melt allowing the laser to penetrate deeper. These results are yet to be plotted and will be added to this report in future.

Unfortunately, having been let down by our supplier for our primary design of the US equipment, we had to fall to back to a secondary plan at short notice. This secondary plan was to use an existing US generator that had geometric, amplitude and power constraints compared to our primary design. This restricted the parameter space that we could explore and while we have achieved impressive results, it has raised a significant number of key research questions. With improved equipment we could detail more cavitation events and test with further materials.

Future Plans

We intend to publish at least one high impact journal paper from results so far on the US welding study. A further paper on the evidence of cavitation could be published based on our findings thus far, but it would not be as high impact as the scientific findings warrant. We are therefore applying for a further beamtime to study this phenomenon in more detail with new and refined equipment including finely tuneable US amplitude, orientation of US excitation and varying materials. With this new equipment we will demonstrate full inertial cavitation and show the desired degassing and grain refinement. As we study the existing results in more detail, we anticipate there will be other avenues for publication and exploration.