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Data Article

Small dataset for hot cracking susceptibility of Al alloys and Ni alloys using dynamic X-ray radiography (DXR) technique

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X-ray application

A B S T R A C T

Hot cracking as the major concern in the manufacturing process of metal alloys is detrimental to part performance and can lead to catastrophic failure. However, current research in this field is restricted to the scarcity of the relevant hot cracking susceptibility data. Here, using the DXR technique provided at 32-ID-B beamline of Advanced Photon Source (APS) at Argonne National Laboratory, we characterized the hot cracking formation in Laser Powder Bed Fusion (L-PBF) process for ten commercial alloys (Al7075, Al6061, Al2024, Al5052, Haynes 230, Haynes 160, Haynes X, Haynes 120, Haynes 214, and Haynes 718). The extracted DXR images captured the post-solidification hot cracking distribution and allow the quantification of the hot cracking susceptibility of those alloys. We further exploited this in our recent effort on hot cracking susceptibility prediction [1] and established a hot cracking susceptibility dataset posted on Mendeley Data for the purpose of facilitating the relevant research in this field.

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Specifications Table

Subject	Materials Science
Specific subject area	*This dataset focuses on evaluating the hot cracking susceptibility of a variety of commercial Al and Ni alloys in additive manufacturing.*
Type of data	Image Chart (in excel)
How the data were acquired	A miniature device that replicates the L-PBF process was established together a DXR characterization technique at the 32-ID-B beamline of Advanced Photon Source (APS) at Argonne National Laboratory. The laser source used here is ytterbium fiber (IPG 10 YLR-500-AC, IPG Photonics, Oxford, Massachusetts, USA), operating at a wavelength of 1070 nm with maximum power output of 520W with a Gaussian beam profile. The integrated galvo scanner (IntelliSCANde 30, SCANLAB GmbH, Puchheim, Germany) allows the laser to scan across the sample surface up to 2m/s. The spot size of the laser beam is determined by the foal plane offset distance. This custom-made laser system normally operates at 50 µm offset distance to allow a 100 µm spot size, which simulates the spot size in EOS M290 L-PBF machine. Throughout the test, the evaluated sample is placed in a stainless-steel chamber filled with 1 atm Argon gas. During the characterization, a high-flux polychromatic x-rays with harmonic energy of 24.2-24.9 KeV generated by a short-period undulator transmit through the sample. The formation of hot cracking will induce difference in the local density of the sample. This generates contrast in the x-ray transmittance. A 100 µm thick Lu2Al5O12: Ce scintillator is placed behind the sample to convert the transmitted x-ray signal into light signals, which pass through a 45° reflection mirror, are expanded by an objective lens and finally captured with a high-speed camera. The high-speed camera used in this setup is Photron FastCam SA-Z (Photron Inc., Japan), which was operated at frame rates in the range 30 - 50 kHz. The objective lens uses a 10X magnification which yields a spatial resolution of 2 µm/pixel in the DXR imaging.
Data format	Raw Analyzed
Description of data collection	10 commercial alloys were evaluated in this dataset: Al7075, Al6061, Al2024, Al5052, Haynes 230, Haynes 160, Haynes X, Haynes 120, Haynes 214, and Haynes 718. Two laser processing conditions were surveyed: 520 W - 0.2 m/s and 520 W - 0.3 m/s. The frame rate of the high-speed camera was set to 50kHz and the exposure time is set to 1 µs throughout the entire experiment.
Data source location	• *Institution: Advanced Photon Source at the Argonne National Laboratory (processed at* Carnegie-Mellon University) • *City/Town/Region: Chicago (*Pittsburgh) • *Country:* United States
Data accessibility	Repository name: Mendeley Data Data identification number: 10.17632/tcmd6wnyyg.3 Direct URL to data: https://data.mendeley.com/datasets/tcmd6wnyyg/3
Related research article	Tang, Guannan, et al. "An Updated Index Including Toughness for Hot-Cracking Susceptibility." *Metallurgical and Materials Transactions A* 53.4 (2022): 1486-1498. https://doi.org/10.1007/s11661-022-06612-6

Value of the Data

- This dataset offers a fast and direct visualization of hot cracking events in a wide variety of alloys processed by laser melting which emulates laser powder bed fusion (LPBF) additive manufacturing. Such data is not readily available in the literature. Conventional hot cracking susceptibility measurements such as the Varestraint test are only able to evaluate the hot cracking on the external surfaces of the test material and cannot see the hot cracking inside the material. However, our dataset is based on the DXR technique, which provides direct imaging of the hot cracking events throughout the entire sample and is therefore a more accurate measurement of hot cracking susceptibility.

- Hot cracking is a notorious defect that is not only affects the field of additive manufacturing but also the welding community and even the broader metallurgy community. This dataset offers direct insight into the distribution of hot cracking events and their 2D morphology, i.e., in projection. People in relevant fields can gain a better understanding of hot cracking formation through this and can use this dataset for validation of their theoretical work.
- The main purpose of this dataset is to provide a validation basis to theoretical works in hot cracking formation. Through image analysis, this dataset can be used to rank hot cracking susceptibility, which can in turn be used to evaluate hot cracking prediction models. This further enables data analytics for assessing relationships between properties and parameters used in additive manufacturing. It provides information about how laser process parameters affect hot cracking in a variety of alloys with varying material properties. We expect that the data will also be useful for industrial production optimization and reduction in cost.

1. Objective

The main reason behind the establishment of this dataset is to provide the validation data for our modelling work published as DOI:10.1007/s11661-022-06612-6. Aside from this, we realized that the data of hot cracking susceptibility related to Additive Manufacturing is scarce which is an obstacle to studies of hot cracking. Consequently, we aim to facilitate relevant hot cracking research.

The long-term goal related to this dataset is to include more alloys with different properties and also a wider range of processing parameters so as to increase its statistical importance.

2. Data Description

Fig. 1 gives the DXR-based average hot cracking susceptibility for all 10 alloys evaluated in this article. Each data value in Fig. 1 is an average of the original measurements. Fig. 1 was also stored in Mendeley Data in the formation of an Excel (Named: "Measured Severity.xlsx"). The individual raw measurements were also included in "Measured Severity.xlsx". Aside from this,

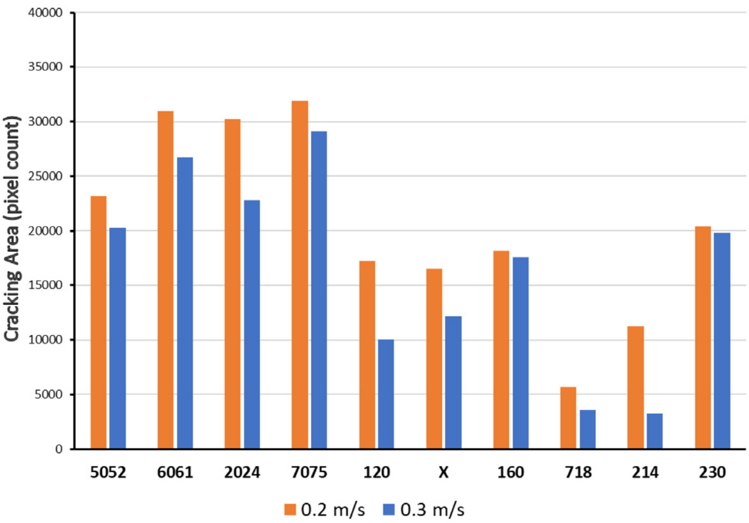

Fig. 1. DXR-based average hot cracking susceptibility for alloys evaluated in this article.

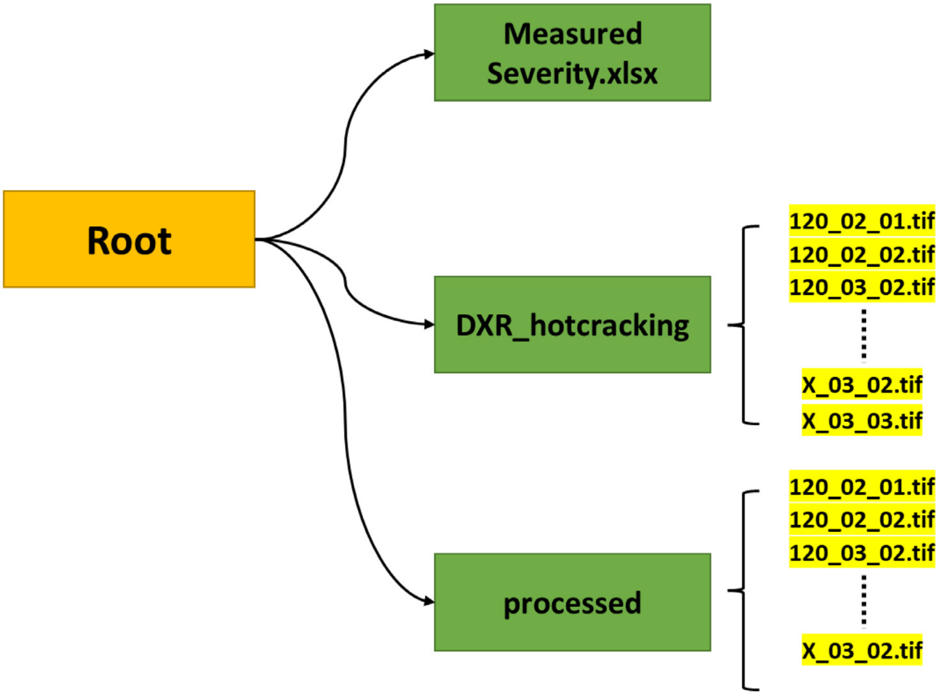

Fig. 2. The flowchart shows the hierarchy of the data repository.

the data repository also stores the original DXR images for hot cracking and the corresponding images post our image processing. Within the folders, the file name is formatted by (alloy name)_(laser scan speed m/s)_(Measurement number). Note that our two test conditions use the same laser powder 520 W and therefore it is only necessary to inspect the laser scan speed for each image file. For example, within the folder "DXR_hotcracking", the first file "120_02_01" tells that this is the 1st measurement on Haynes 120 alloy processed by laser speed of 2 m/s. Fig. 2 illustrates the hierarchy within the data repository. Under the root, there are two folders and one Excel file. The Excel file summarized the measured hot cracking susceptibility. All the raw image data are stored under the folder "DXR_hotcracking". The processed images were stored under the folder "processed".

3. Experimental Design, Materials and Methods

The experiments to collect the images in the dataset described in this document is realized via Dynamic X-ray Radiography (DXR) hosted by Advanced Photon Source (APS) at Argonne National Laboratory [2]. The 32-ID-B beamline of APS has recently developed an experimental setup using high-speed synchrotron x-ray to imaging the solidification process representative of Laser powder bed fusion [3]. Combined with a high speed camera, this technique allows in-situ characterization of the laser/metal interactions occurred in L-PBF process. A detailed schematic of this experimental setup can be found in our recent publication [1]. As indicated, a scanning laser system is incorporated in the x-ray imaging beamline. The laser source is ytterbium fiber (IPG 10 YLR-500-AC, IPG Photonics, Oxford, Massachusetts, USA), operating at a wavelength of 1070 nm with maximum power output of 520W with a Gaussian beam profile. The integrated galvo scanner (IntelliSCANde 30, SCANLAB 12 3.1. SINCHROTRON-BASED X-RAY TECHNIQUES 13

GmbH, Puchheim, Germany) allows the laser to scan across the sample surface up to 2 m/s. The spot size of the laser beam is determined by the foal plane offset distance. This custom-made laser system normally operates at 50 µm offset distance to allow a 100 µm spot size, which simulates the spot size in EOS M290 L-PBF machine. During the printing process, a high-flux polychromatic x-rays with harmonic energy of 24.2-24.9 KeV generated by a short-period undulator transmit through the sample. The melting and solidification process will induce difference in the local density of the sample. This will lead to a contrast in the x-ray transmittance. A 100 µm thick Lu2Al5O12: Ce scintillator is placed behind the sample to convert the x-ray transmittance signal into light signals, which pass through a 45o reflection mirror, get amplified by an objective lens and are finally received by a high-speed camera. The high-speed camera used in this setup is Photron FastCam SA-Z (Photron Inc., Japan), which can operate at a frame rate of 30 - 50 kHz. The objective lens uses a 10X magnification to allow a spatial resolution of 2 µm/pixel in the DXR recording. During the experiment, a metal cuboid sample with a dimension of 50 mm long, 3 mm tall and 0.5-1 mm thickness (depending on the alloy type) will be placed in a stainless-steel chamber filled with 1 atm Argon gas. As the laser impinges on the sample's top surface, the synchrotron X-ray simultaneously will penetrate through the thickness of the sample. The laser continues to scan across the long edge of the sample under the illumination of X-ray. The corresponding dynamic melt pool will be reflected in the change of X-ray signal absorption and captured eventually by a high speed camera. The frame rate is normally set to 50 kHz and the exposure time is set to 1 µs throughout the most of our experiments.

DXR technique allows the characterization of the post-solidification hot cracking morphology in the format of a 2D static image. Using this technique, we surveyed 10 different alloys: Al7075, Al6061, Al2024, Al5052, Haynes 230, Haynes 160, Haynes X, Haynes 120, Haynes 214, and Haynes 718. Two processing conditions (520 W 0.2 m/s and 520 W - 0.3 m/s) were evaluated. Each test sample for each test condition has at least two measurements to reduce scatter in the cracked area measured per unit length (except for the case of Haynes 230, which only had one measurement per test condition). The experiment yielded 49 DXR images in total. Using the software ImageJ, we were able to isolate the hot cracking affected area in each of the DXR image and measure the pixel count for each image. The total pixel count value for each image represents the overall 2D size of the formed hot crack and indicates the hot cracking susceptibility. This method allows the direct measurements of the hot cracking susceptibility for all 10 alloys evaluated here. The original images and ImageJ-processed images were stored in Mendeley Data (DOI: 10.17632/tcmd6wnyyg.3) [4].

Ethics Statements

Our work meets all ethical requirements for publication in Data in Brief. Our work current work does not involve human subjects, animal experiments, or any data collected from social media platforms.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data Availability

Hot Cracking Susceptibility (DXR) for Al alloys and Ni alloys Measured by Dynamic X-ray Radiography (Original data) (Mendeley Data).

CRediT Author Statement

Guannan Tang: Conceptualization, Methodology, Software, Data curation, Formal analysis, Writing – original draft; **Benjamin J. Gould:** Methodology, Data curation; **Anthony D. Rollett:** Writing – review & editing.

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