Transactions of the Korean Nuclear Society Spring Meeting
Jeju, Korea, May 23-24, 2019

Porosity measurement in 3D printed SS316 using neutron dark-field imaging

Jongyul Kim [a*], Byoungil Jeon [a], TaeJoo Kim [a], Youngju Kim[b], Seung Wook Lee[b], and D. S. Hussey[c]
[a]*Neutron Science Center, Korea Atomic Energy Research Institute, Daejeon*
[b]*School of Mechanical Engineering, Pusan National University, Pusan*
[c]*Neutron Physics Group, National Institute of Standards and Technology, Gaithersburg, USA*
[*]*Corresponding author: kjongyul@kaeri.re.kr*

1. Introduction

3D printing applications in aerospace and automotive industries are growing. For property improvement of 3D printed objects, microstructure information such as porosity, crack, and so on is important [1]. To get microstructure information in 3D printed object, one way is to use neutron dark-field imaging by grating interferometry that is one of advanced neutron imaging techniques [2]. In this paper, pore size and volume fraction of 3D printed samples made of Stainless Steel 316 were measured using neutron dark-field imaging.

2. Methods and Results

In this section, neutron dark-field imaging technique, experiment and analysis results are described.

2.1 Neutron dark-field imaging

Neutron dark-field signal based on neutron scattering can be obtained using Talbot- Lau neutron grating interferometer, and the schematics of Talbot- Lau neutron grating interferometer is shown in Fig. 1.

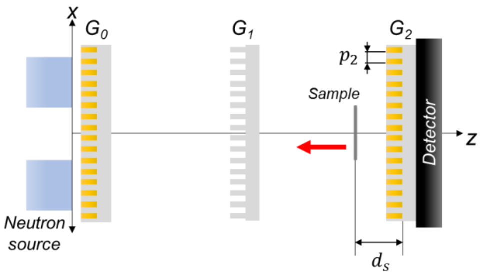

Fig. 1. . The schematics of symmetric Talbot-Lau neutron grating interferometer consists of a source grating (G_0), a phase grating (G_1), and an analyzer grating (G_2)

The dark-field signal is defined by the ratio of visibility of the modulation induced by the Talbot-Lau interferometer with the sample (V_s) and without the sample (V_r). The dark-field imaging (DFI) signal is expressed as a function of correlation length by

$$\mathrm{DFI}(\xi) = V_s/V_r = e^{\Sigma_s t(G(\xi)-1)}, (1)$$

where Σ_s is the total small angle neutron scattering cross-section, t is the sample thickness, ξ is correlation length, and $G(\xi)$ is the correlation function describing the scattering structure. The total neutron scattering cross-section and correlation function are determined by the scattering structure and materials. The correlation length is a systemic parameter of the grating interferometer and it is expressed by

$$\xi = \lambda d_s/p_2, (2)$$

where λ is the wavelength, d_s is the sample to G_2 distance, and p_2 is the period of G_2.

2.2 Experiment and analysis results

The Experiment of neutron dark-field imaging was conducted at cold neutron imaging facility (NG6) of National Institute of Standards Technology (NIST), as shown in Fig. 2 [3]. Neutron imaging system at NG6 consisted of a LiF neutron scintillator and lens coupled scientific CMOS camera that is made up of 2560x2160 pixels with 6.5 µm pixel pitch.

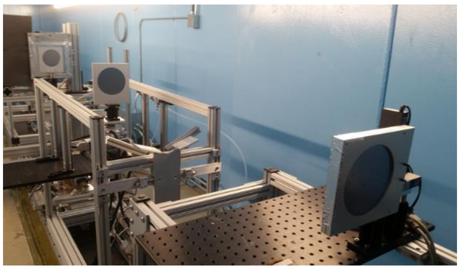

Fig. 2. The neutron dark-field imaging setup at NG6

Three samples made of SS316 using Direct Energy Deposition (DED) method, Selective Laser Melting (SLM) method, and casting method were prepared for neutron imaging experiment. The neutron transmission image, dark-field image, and phase-contrast image of these prepared samples were obtained as shown in Fig. 3. It is confirmed that the samples have different intensities in neutron dark-field image although they have similar intensities in neutron transmission image.

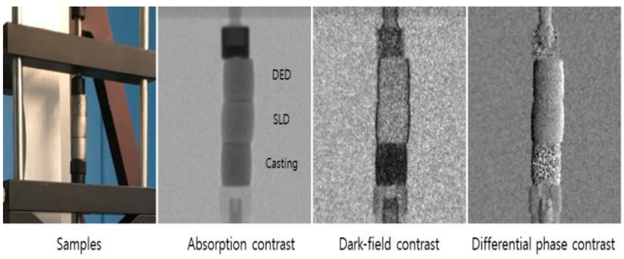

Fig. 3. SS316 sample photo and neutron images

Dark-field signals of each sample were obtained as autocorrelation length by equation (2) changes as shown in Fig. 3. The information of pore size and volume fraction could be obtained using an isolated sphere model, and the correlation function is expressed by

$$G(\xi) = e^{-\frac{9}{8}\left(\frac{\xi}{r}\right)^2}, (3)$$

where r is the radius of sphere. In this case, the total neutron scattering cross-section can be expressed by

$$\Sigma_s = \frac{3}{2}\lambda^2 \Delta\rho_0{}^2 \varphi_V r, (4)$$

where φ_V is the volume fraction, and $\Delta\rho_0$ is the difference of neutron scattering length density.

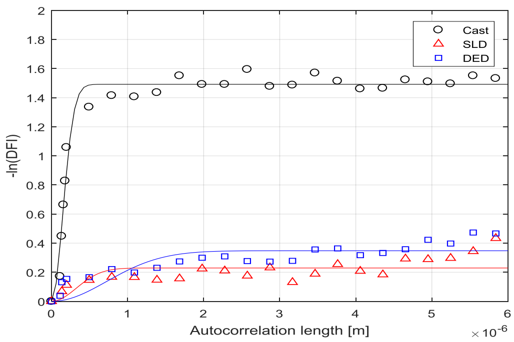

Fig. 3. Dark-field contrast in accordance with autocorrelation length

After fitting dark-field signals of each sample using equations, the pore size and volume fraction of each sample are shown in Table I. It is confirmed that the SS316 sample by SLD method is denser than the sample by DED method.

Table I: Pore size and volume fraction of 3D printed SS316

Case	Pore size [㎛]	Volume fraction
Cast	0.219	0.2541×10^{-2}
SLD	0.487	0.1752×10^{-3}
DED	1.087	0.1191×10^{-3}

3. Conclusions

3D printed SS316 samples were measured using neutron dark-field imaging to get microstructure information nondestructively. We could obtain pore size and volume fraction data of prepared samples using dark-field image signal and some fitting model. It is confirmed that neutron dark-field imaging can be useful tool for evaluation of 3D printed objects.

REFERENCES

[1] A. Haghshenas and M.M. Khonsari, Evaluation of fatigue performance of additively manufactured SS316 via internal damping, Manufacturing Letters 18 (2018) 12-15.

[2] A. J. Brooks et al, Porosity detection in electron beam-melted Ti-6Al-4V using high-resolution neutron imaging and grating-based interferometry, Prog Addit Manuf (2017) 2:125-132.

[3] D.S. Hussey et al, A New Cold Neutron Imaging Instrument at NIST, Physics Procedia 69 (2015) 48 – 54.