

Analysis and Testing solutions for Additive Manufacturing

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Abstract. Additive Manufacturing contributes to reducing environmental impact through initiatives such as creating a circular economy. Furthermore, since it is possible to control the microstructure and crystallographic texture, it is expected to be applied as a variety of high-performance materials such as biomaterials. However, to ensure AM product quality, conventional analysis and testing methods alone are insufficient, and new methods are also required. In this paper, Analysis and Testing solutions for evaluation material powder used in Powder Bed Fusion, a typical AM method, as well as product microstructure and fatigue evaluation are introduced.

1 Introduction

Efforts to reduce greenhouse gas emissions and transition to the circular economy are being promoted around the world in order to prevent global warming and realize a nature positive. Additive Manufacturing (hereafter referred to as AM) is a technology that reduces environmental impact by significantly reducing the amount of raw materials used and waste, and also makes it possible to re-pulverize used products and reuse them in AM, making it a technology that greatly contributes to the circular economy. Although various research and development efforts are underway to implement AM in society, there are still many issues in terms of cost and quality assurance. In order to accelerate the social implementation of AM, it is necessary to improve the efficiency of analysis and testing and use big data to ensure quality. In this paper, a new analysis method specific to powders used in AM, examples of evaluation of the correlation between surface hardness and microstructure, and a test method that allows fatigue evaluation to be performed in a short time are introduced.

2 Analysis of AM powder

AM product quality also depends on the quality of the raw material powder. High-quality metal powder is essential to obtaining high-quality metal AM products. Powder that has been spheroidized is used, but there is a possibility that powder with a distorted shape and satellite powder with other particles still attached may also exist. Distorted powder and satellite powder can cause cracks to occur and strength to decrease. It may also affect liquidity. Therefore, it is important to evaluate the particle size distribution and shape of the raw material powder used, and it is desirable that the amount of powder to be evaluated be as large as possible. This section introduces an example in which two types of powder were analyzed using the Dynamic Particle Image Analysis System iSpect DIA-10 of Shimadzu Corporation.

2.1 Powder sample

Powder that had been atomized and not been atomized were used as samples shown in Fig. 1 and Fig. 2. Tens of thousands of powders can be fed into the analysis system at once.

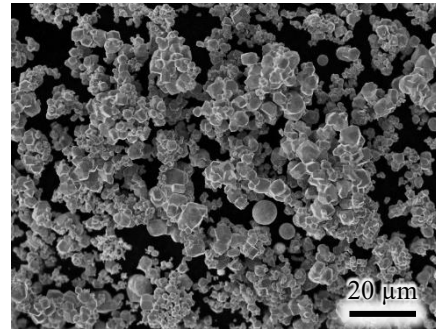


Fig. 1. Powder A (before atomization)

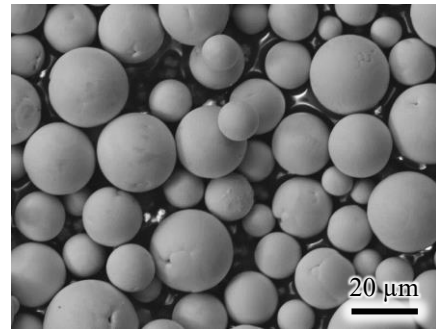


Fig. 2. Powder B (plasma atomization)

2.2 Analysis results and discussion

It is possible to obtain not only the particle size distribution but also images of each particle. The resulting images of Powder A and Powder B are shown in Fig. 3 and Fig. 4.

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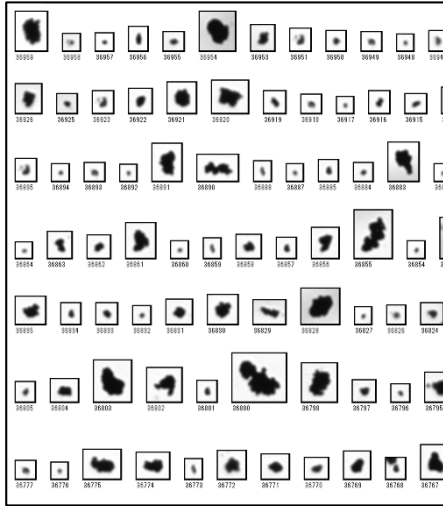


Fig. 3. Particle image detected in Powder A

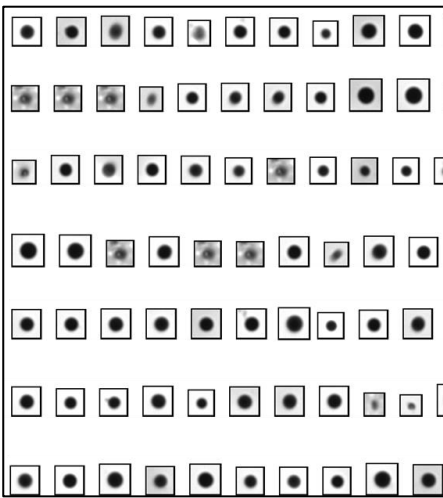


Fig. 4. Particle image detected in Powder B

In powder A, many distorted shape particles and satellite particles were detected. In atomized powder B, almost spherical particles were detected.

As an example of how the quality of powder affects the quality of AM products, data on the density after printing with powder A and B are shown in Fig.5 and Fig.6. It is obvious that products made with Powder A have many defects and have low density.

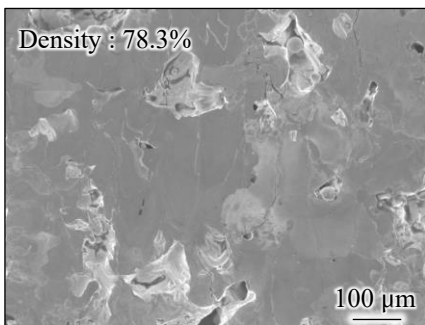


Fig. 5. Density image of product (Powder A)

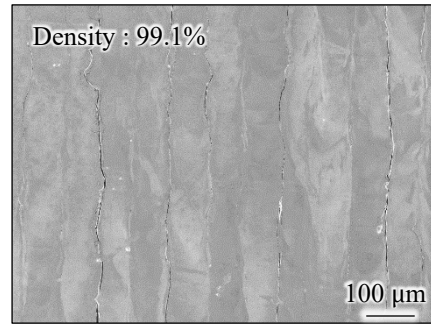


Fig. 6. Density image of product (Powder B)

This analysis system iSpect DIA-10 used this time can detect more than 90% of the particles in the input powder in a short time. It also has a function that prevents false detection of bubbles and a function that measures the size of satellites, making it possible to evaluate AM powder efficiently and accurately.

3 Surface hardness

Surface hardness is also an important parameter for quality control of AM products. Even if processing control is carried out to ensure quality, there is a risk that the structure and hardness distribution will not be as expected, depending on the state of the melt pool and the formation of the microstructure. On the other hand, a major feature of PBF type AM is that it allows for microstructure control in each location, and research is progressing on its application to biomaterials such as bone. Therefore, in terms of quality assurance, it is desirable to evaluate the microstructure and hardness distribution over as wide a range as possible. This section introduces an example in which the correlation between microstructure and hardness was evaluated using a sample created by microstructure control. For hardness measurement, Shimadzu micro-Vickers hardness tester HMV-31G was used to measure the hardness distribution fully automatically.

3.1 Vickers hardness distribution result

The Vickers hardness distribution result is shown in Fig. 7. Afterwards, the microstructures of areas with high hardness (A) and areas with low hardness (B) were observed, and the results are shown in Fig. 8 and Fig. 9.

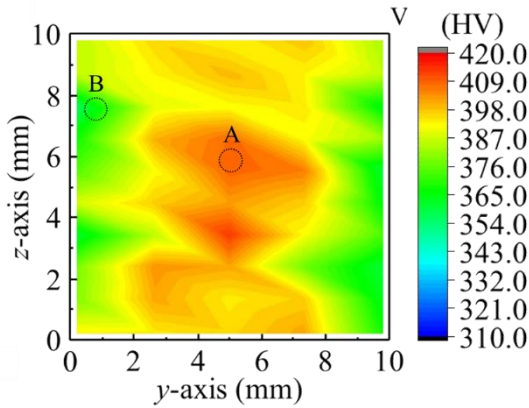


Fig. 7. Vickers hardness distribution

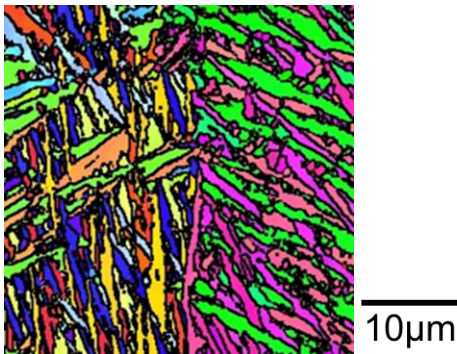


Fig. 8. Microstructure observation results of area with high hardness (A)

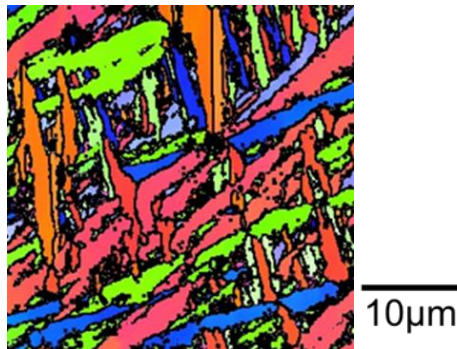


Fig. 9. Microstructure observation results of area with low hardness (B)

3.2 Discussion

A dense structure was observed in the area with high hardness (A). On the other hand, the area with low hardness (B) has a coarse structure. This sample was created by microstructure control, so that the hardness near (A) is high and the near (B) is low, so it means the results as designated were obtained.

On the other hand, if the product is designed to have uniform hardness and this result occurs, it will be judged as a quality defect. By building a large database of correlations between hardness and microstructure observation, we can expect that it will even become possible to predict microstructures from hardness measurements.

4 Fatigue evaluation

In ensuring quality, especially safety, evaluation of fatigue durability is also essential. AM products tend to exhibit more internal voids (trapped gas or lack of fusion). For this reason, to enhance the reliability, the correlation between the characteristics of internal defects (distribution, size, position, etc.) with the fatigue strength must be analyzed.

Testing for fatigue durability evaluation (life evaluation) requires an enormous amount of time, so there is a need to shorten test times in order to accelerate research and development. This section introduces an example of a fatigue test conducted using the Ultrasonic fatigue testing machine USF-2000 of Shimadzu Corporation that can perform fatigue test at higher speed.

4.1 Test specimens

The shape and size of the test specimens is shown in Fig. 10. Firstly, a cylindrical sample with a radius of 10mm was created with the electron beam PBF (Powder Bed Fusion), and then machined to obtain the final shape. The shape of the sample has been determined according to the specifics of the Ultrasonic testing machine. A total of 6 specimens have been used in this test.

The material of specimen is titanium alloy Ti6Al4V.

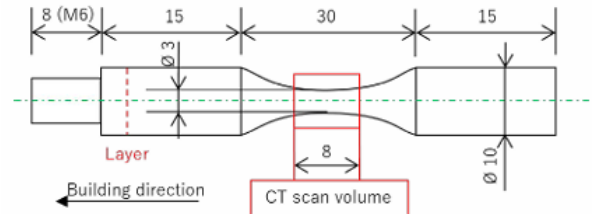


Fig. 10. Specimen shape and dimensions (in mm)

Before fatigue test, the CT scan was conducted on a volume including the central section of the specimen, taken at ± 4 mm from the centre of the specimen (Fig. 10 red frame). The CT scan was conducted on the central section as it is the volume with the highest probability of developing a fatigue crack.

Although there were some voids inside the specimen, the void distribution was similar for each specimen. Fig. 11 shows a cross-sectional view of the specimen including internal voids. Most of the voids were spherically shaped, although some elongated voids (crack like defects) were also present. Voids were observed both inside of the specimen and on the surface.

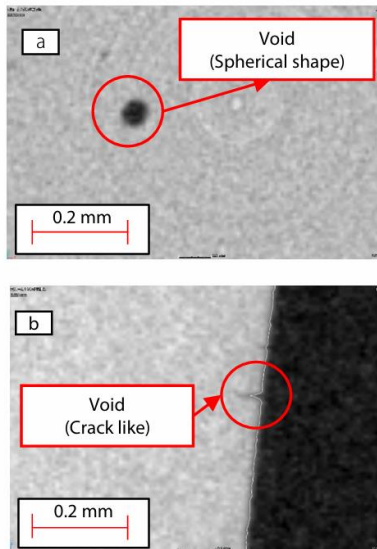


Fig. 11. Cross section image of specimen including voids (a) Spherical void, (b) Crack like void

4.2 Fatigue test and test results

As shown in Table 1, fatigue tests were conducted on 6 specimens under two types of stress loads. The number of cycles at which each specimen broken is shown in Table 1 and Fig. 12.

Table 1 Test condition and results

Specimen	Stress (MPa)	Cycle to break
1	350	6.42×10^5
2	350	4.50×10^8
3	350	6.65×10^5
4	300	1.19×10^8
5	300	3.56×10^9
6	300	3.50×10^5

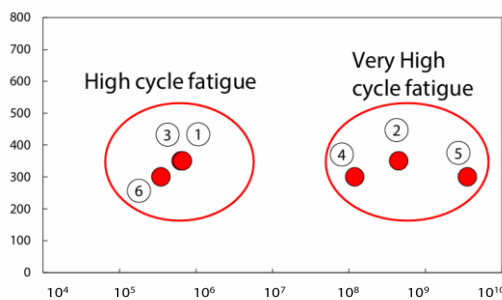


Fig. 12. Relationship between stress and number of cycle to break

4.3 Discussion

The results clearly show that the number of cycles to break can be divided in two macro areas: 10^5 ~ 10^6 cycles (high cycle fatigue) for specimens 1, 3 and 6 and 10^8 ~ 10^9 cycles (very high cycle fatigue) for specimens 2, 4 and 5. The results show that there is not a correlation between the applied stress load and the number of cycles to break.

When the fracture surface of each specimen was observed, it was found that the crack initiation site in the specimen in the high cycle fatigue region was located on

the specimen surface. On the other hand, the crack initiation site in the specimen in the very high cycle fatigue region was an internal void. These results indicate that the position of the voids has a significant effect on fatigue life [1].

In addition, when conducting 10^9 fatigue tests using a general fatigue testing machine (10Hz), as in test specimen number 5, it takes about three years to complete the test. The USF-2000 used this time can perform tests at 20kHz, so completed 10^9 tests in just 14 hours.

5 Conclusion

Examples of evaluations of raw material powder for AM, hardness and fatigue after AM were introduced in this paper. By acquiring and analysing a wide variety of data with high precision and in massive quantities, the quality of AM product will further improve, and its social implementation will further accelerate. By performing faster and more efficient analysis and test, development speed will also be accelerated.

Hope this paper will be some help to person involved in Additive Manufacturing.

References

1. J. Günther, D. Krewerth, T. Lippmann, S. Leuders, T. Tröster, A. Weidner, H. Biermann, T. Niendorf, Fatigue life of additively manufactured Ti-6Al-4V in the very high cycle fatigue regime, International Journal of Fatigue, **94 Part2**, 236-245 (2017)

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