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Application News

Dynamic and Fatigue Testing Machines Servopulser
Microfocus X-Ray CT system

Observation of Crack Propagation Process in Aluminum Alloy Specimen Using Air-Servo Microfocus X-Ray CT System

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User Benefits

- The Air-Servo Microfocus X-Ray CT System enables observation of crack propagation in three dimensions and over time.
- Microfocus X-Ray CT system enables nondestructive observation of the interior of materials.
- High-precision dynamic control is possible with the Servo Controller 4830.

■ Introduction

Many structural failures are caused by fatigue failure resulting from repeated loading. In fatigue failure, cracks initiate from microdefects in the material, internal voids, inclusions, and other features, and then propagate under repeated loading until final fracture occurs. To evaluate this sequence of processes, it is effective to observe defects and crack propagation nondestructively.

Traditionally, crack observation has focused on visual inspection and microscopic observation, but these methods are limited to information near the surface. To sufficiently capture the three-dimensional shape and changes in cracks propagating inside a material, observation of the fractured specimen after failure has generally been used. In contrast, X-ray CT can nondestructively visualize internal defects and cracks in three dimensions, making it possible to evaluate in detail changes in crack morphology, including in the interior.

Accordingly, using the “Air-Servo Microfocus X-Ray CT System,” which combines X-ray CT with a fatigue testing machine, repeated tests were performed in which loading was stopped at fixed cycle intervals and imaging was carried out. This article introduces the resulting process of crack initiation and propagation in the same specimen.

■ Specimen Information

Fig. 1 shows a schematic of the specimen used in this article. The specimen is made of Al-5052 and has a notch at the center in the longitudinal direction.

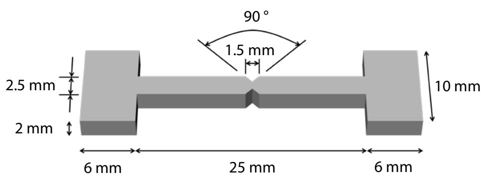

Fig. 1 Schematic of the Specimen

■ Acquisition of the S-N Diagram

Measurement System

Before observation by X-Ray CT, an S-N curve was obtained to investigate the fatigue properties of the specimen. Table 1 shows the equipment configuration, Fig. 2 shows the servo pulser EHF-LV used, and Fig. 3 shows the test setup.

Table 1 Equipment Configuration for S-N Diagram Acquisition

Fatigue Testing Machine:	Servopulser EHF-LV020k1A
Load Cell:	2 kN
Jig:	Manually Tightened Tensile Test Jig
Controller:	Servo Controller 4830
Software:	Windows Software for 4830

Fig. 2 Dynamic and Fatigue Testing Machine Servopulser EHF-L

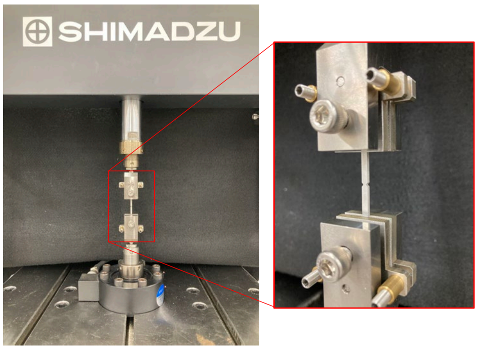

Fig. 3 Test Setup

Static Test

To set the conditions for the fatigue test, static tensile tests were performed using the EHF-LV. The test speed was set to 1 mm/min. Fig. 4 shows the test force-displacement diagram. As a result of measurements with N = 5, the average maximum test force was 486.9 N.

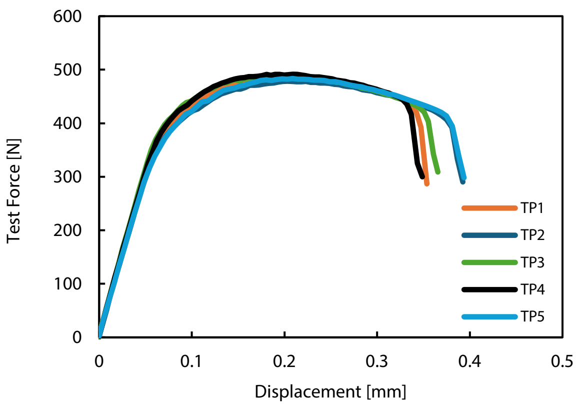

Fig. 4 Test Force-Displacement Diagram

Fatigue Test

Based on the maximum test force measured in the static test, the maximum load test force during the fatigue test was set. The fatigue test conditions are shown in Table 2. The obtained S-N Curve is shown in Fig. 5.

Table 2 Fatigue Test Conditions

Maximum Load Test Force:	195, 243, 292, 341, 389, 438 N (40 % to 90 % of the Static Maximum Test Force)
Stress Ratio:	0.1
Maximum Number of Cycles:	1.0×10^6
Frequency:	10 Hz
Number of Tests:	N = 2

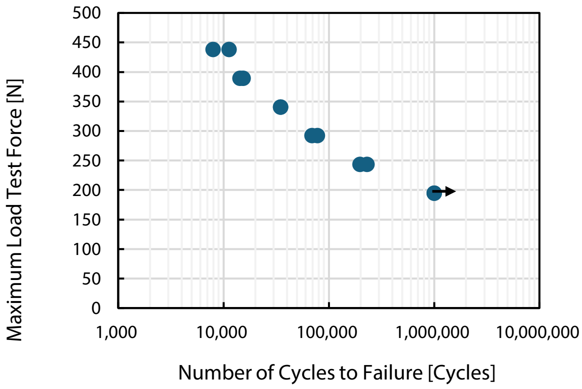

Fig. 5 S-N Diagram

■ Observation of Cracks by the Air-Servo Microfocus X-Ray CT System

Using the Air-Servo Microfocus X-Ray CT System, the status of cracks propagating during the test was observed.

The system is designed to be compact with light weight, making it easy to transport. After fatigue tests, the specimens can be transported inside the X-ray CT system while still attached. Furthermore, by applying static loading inside the CT system, imaging can be performed with the crack held open, allowing the crack tip to be observed more clearly.

Measurement System

Table 3 shows the equipment configuration of the Air-Servo Microfocus X-Ray CT System. Fig. 6 shows the test and imaging setup, and Fig. 7 shows the test force-time waveform. From Fig. 5, the condition was set so that the maximum test load test force was 70 % of the static maximum test force. Fig. 7 shows that control with a good sine wave was achieved.

Table 3 Equipment Configuration of
the Air-Servo Microfocus X-Ray ST System

Fatigue Testing Machine:	Air-Servo Mini
X-Ray CT:	inspeXio SMX-225CTS
Load Cell:	1 kN
Controller:	Servo Controller 4830
Software:	Windows Software for 4830

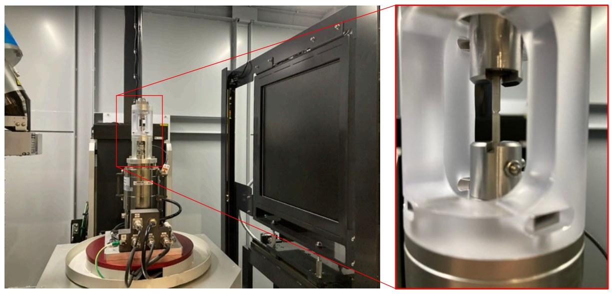

Fig. 6 Test and Imaging Setup

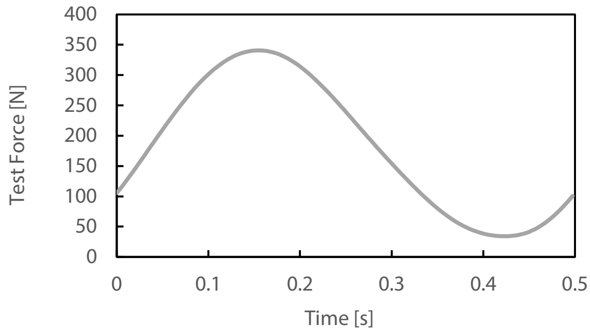

Fig. 7 Control Waveform

Crack Observation

Under the condition in which 70 % of the static maximum test force was used as the maximum load test force for obtaining the S-N diagram, the displacement increased sharply after 30,000 cycles. Therefore, during X-ray CT imaging, imaging was performed every 1,000 cycles after 30,000 cycles, and after 35,000 cycles, imaging was performed when the displacement increased sharply. Fig. 8 shows cross-sectional images of the notch region of the specimen obtained by X-ray CT, and Fig. 9 shows the average amplitude of displacement at each cycle. In Fig. 8(1), no crack can be confirmed up to 30,000 cycles, but in Fig. 8(2), a crack was observed for the first time at 31,000 cycles. After that, the crack gradually propagated and led to fracture at 36,392 cycles in Fig. 8(6).

Fig. 10 shows a three-dimensional representation of the cross-section at fracture in Fig. 8(6). It was found that crack propagation in the width direction was greater on the left side than on the right side.

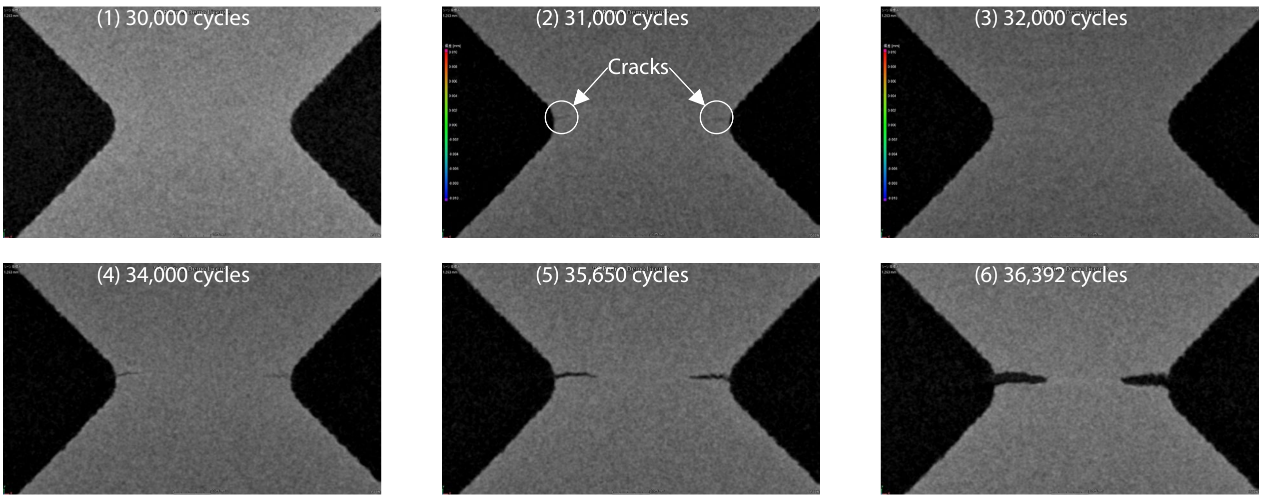

Fig. 8 Continuous Cross-Sectional Images of the Notch Region

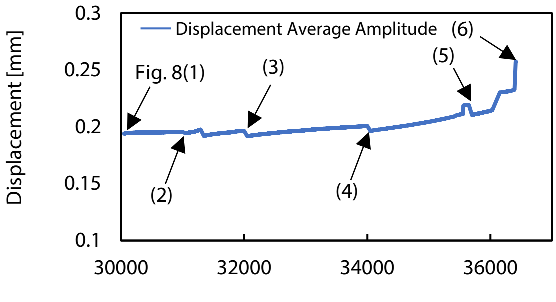

Fig. 9 Average Displacement Amplitude for Each Cycle

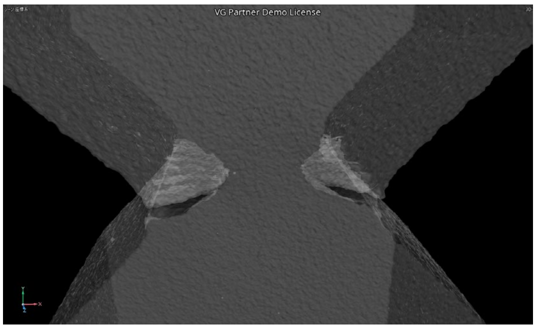

Fig. 10 3D Image of the Notch Region at Fracture

Fig. 11 shows 3D images of the specimen generated from X-ray CT images. Each image is color-scaled according to the amount of deformation relative to 30,000 cycles in Fig. 11(1), and shows the displacement relative to three surfaces: the two white-hatched surfaces in Fig. 11(1) and the rear surface. Focusing on the lower right surface outlined in white in Fig. 11(1), the color gradually changes to red, indicating movement in the X-axis direction. It is considered that the larger crack propagation on the left side in the width direction increased the opening on the left side, causing the lower right surface of the specimen to move to the right. This is also supported by Fig. 10, which shows that the crack on the left side ultimately propagated more extensively.

Focusing on the cracks in Fig. 11, no noticeable change is seen up to 34,000 cycles in Fig. 11(4), but in Figs. 11(5) and 11(6), the crack has widened enough to be visible from the front, and the region between the left and right cracks in the notch was observed to neck down.

■ Conclusion

Using the Air-Servo Microfocus X-Ray CT System, cracks propagating from the notch region of an aluminum alloy specimen were observed. First, static tests and fatigue tests were performed using the servo pulser EHF-LV, and a S-N diagram was obtained. Based on the obtained S-N diagram, the fatigue test conditions for the Air-Servo Microfocus X-Ray CT System were determined, and X-ray CT imaging was performed. The process of crack propagation according to the number of cycles was observed in cross-sectional images and 3D images. In addition, by visualizing the displacement from a specific cycle onward, it was also confirmed that the specimen necked down just before fracture.

Using the measurement system introduced in this article, it is possible to observe changes in specimen shape over time while the specimen remains mounted in the jig. Therefore, not only the crack propagation process of a specimen during fatigue testing, but also material deformation behavior and the process of shape change can be observed*.

*In the measurements described in this article, the servo pulser EHF-LV020k1A was used to obtain the S-N diagram, and a series of measurements and imaging were made possible by using the Air-Servo Microfocus X-Ray CT System.

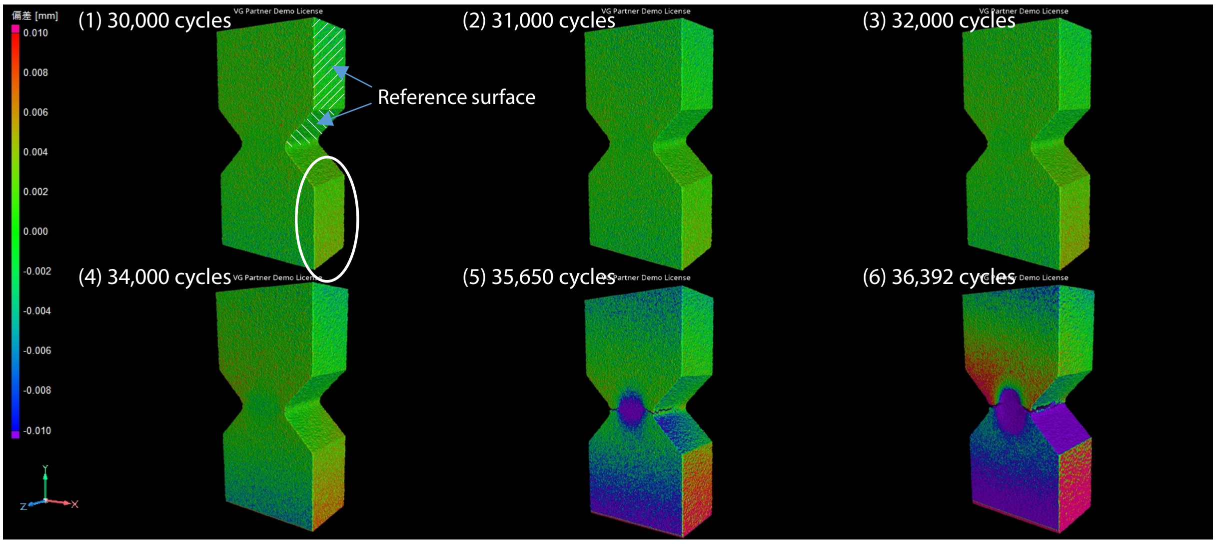

Fig. 11 3D Images Showing the Displacement Relative to 30,000 Cycles

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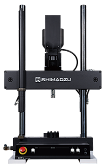

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