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Application News

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EPMA-8050G Electron Probe Microanalyzer, USF-2000A Ultrasonic Fatigue Testing System

Observation and Analysis of Fractured Surfaces of Metal Materials through Ultrasonic Fatigue Testing

With metal materials in general, internal inclusions may become an origin of a fatigue fracture. To evaluate the fatigue strength of metal materials, we need to use a technique to detect inclusions in metal materials which may lead to an internal fracture and to identify the elements of such inclusions. In order to detect inclusions, the best way is to actually carry out a fatigue test.[1)]
In this experiment, we detected inclusions in SNCM439 specimens using the USF-2000A ultrasonic fatigue testing system and observed the inclusions and identified their elements using the EPMA-8050G electron probe microanalyzer (hereinafter referred to as EPMA).

T. Ono, F. Yano

Observation of the Fractured Surface

We used an optical microscope and EPMA to observe the fractured surface of metal materials following a fatigue test. Fig. 1 and Fig. 2 respectively show a photo (optical microscope) of the entire fractured surface on specimen #1 and enlarged observation images (secondary electron images by EPMA) of the area near the inclusions. The fracture was originated from the internal inclusion.

Fig. 1 Photo of the Fractured Surface (Optical Microscope)

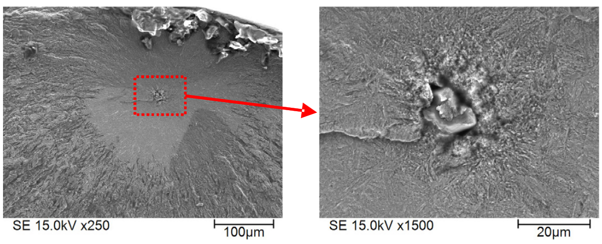

Fig. 2 Observation Image of an Inclusion in Specimen #1 (Secondary Electron Image)

Analysis of the Inclusion

We performed a mapping analysis to determine the composition of the inclusion. The results of analyzing the inclusion of specimen #1 are shown in Fig. 3, where image (a) is a secondary electron image showing the profile of the inclusions and image (b) is a backscattered electron image, in which the larger the mean atomic number the brighter it appears, and therefore provides the relative information of the composition. Images (c) to (f) are respective distribution images of O, Al, S, and Mn, indicating that these elements are contained in the inclusion at high concentrations.
Next, we performed a state analysis with the EPMA to identify the chemical bonding state of Al. We compared the peak waveforms of the Al Kb and K satellite lines of the inclusions (enclosed with a yellow circle on image (b) in Fig. 3) and standard samples (Al and Al_2O_3), and found that the inclusion was Al_2O_3 (Fig. 4). From these results, we determined that the inclusions were alumina (Al_2O_3) and manganese sulfide (MnS).

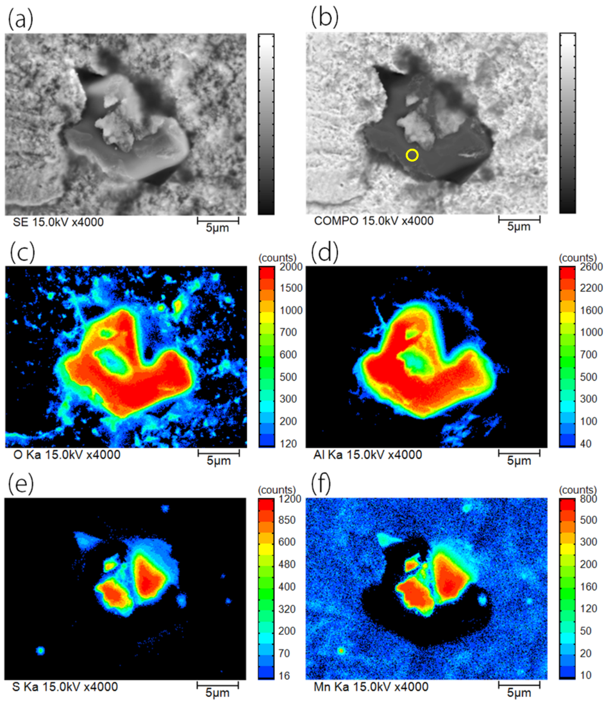

Fig. 3 Mapping Analysis Results of Specimen #1
(a) Secondary Electron Image,
(b) Backscattered Electron (Composition) Image,
(c) O-distribution Image, (d) Al-distribution Image,
(e) S-distribution Image, (f) Mn-distribution Image

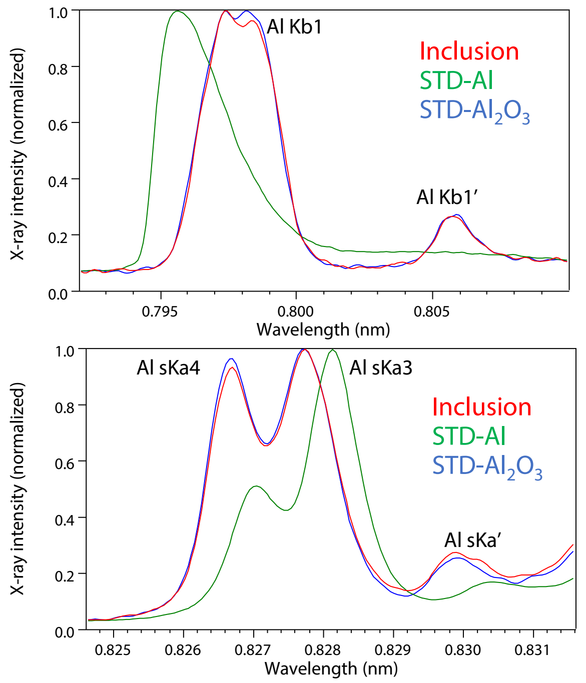

Fig. 4 Al State Analysis (Upper: Al Kb Lines, Lower: Al sKa Lines)

Inclusion Detection through Ultrasonic Fatigue Testing

Generally it is known that with most structural metal materials the fatigue strength lowers until a load is applied 10^6 times, and from 10^7 times onward the fatigue limit is reached, at which no fatigue fracture will occur. However, it is also revealed that with high-strength metal materials that are hardened or surface treated, internal inclusions become an origin of a fatigue fracture and cause a fracture even at 10^8 to 10^9 cycles. It is considered that when a fracture occurs from the inside, the fatigue strength is dependent on the size and elements of internal inclusions. Consequently, to evaluate the fatigue strength of high-strength metal materials, it is indispensable to know the size and elements of inclusions present in the metal materials.

In order to detect inclusions which lead to an internal fracture, the best way is to actually carry out a fatigue test; however, a fatigue test exceeding 10^9 loading cycles at 10 Hz will take approx. 3.2 years. The ultrasonic fatigue testing system used in this experiment enables testing at a frequency of 20 kHz, achieving a test with 10^9 cycles in about 14 hours. Such a system is very effective to detect internal inclusions through actual fatigue testing.

Using the USF-2000A ultrasonic fatigue testing system, we detected inclusions in three SNCM439 specimens. Fig. 5 shows the testing system configuration, and Table 1 and Table 2 give the testing system equipment and the test conditions.

We assumed the stress amplitude that could cause an internal fracture to be 900 MPa based on a previous report.[2] The test results are listed in Table 3. The number of cycles to failure was in the range of 2.91×10^7 to 6.27×10^8, indicating a difference of more than tenfold at the maximum. All fractures were originated from internal inclusions.

In addition to Fig. 2 (on the previous page) of specimen #1, Fig. 6 and Fig. 7 show respective observation images (secondary electron images) of the fractured surfaces and inclusions on specimens #2 and #3. On all specimens, the fracture was developed from internal inclusions, indicating that inclusions are the origin of fatigue fractures. The sizes (major diameter) of the inclusions obtained from the images are listed in Table 4. Judging from Table 3 and Table 4, the larger the inclusion size is, the smaller the number of cycles to failure, suggesting that fatigue strength is affected by the size of the inclusions.

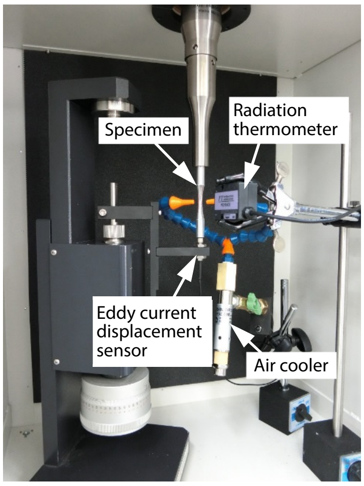

Fig. 5 Picture of the Test

Table 1 Testing System

Testing System	:	USF-2000A ultrasonic fatigue testing system
Thermometer	:	Radiation thermometer
Displacement Meter	:	Eddy current displacement sensor

Table 2 Test Conditions

Specimen	:	SNCM439
Stress Amplitude	:	900 MPa
Maximum Cycles	:	1×10^{10}
Number of Specimens	:	n = 3
Stress Ratio	:	−1
Frequency	:	20 kHz
Intermittent Operation	:	Oscillation time: 300 ms, non-oscillation time: 200 ms

Table 3 Test Results

Specimen	Stress Amplitude [MPa]	Number of Cycles to Failure
1	900	6.27×10^8
2	900	1.06×10^8
3	900	2.91×10^7

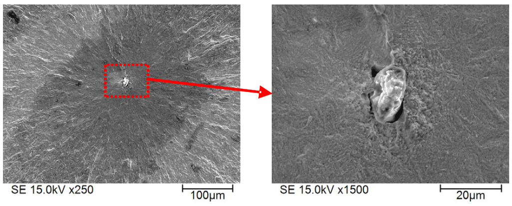

Fig. 6 Observation Image of an Inclusion in Specimen #2 (Secondary Electron Image)

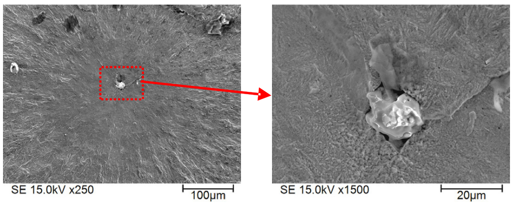

Fig. 7 Observation Image of an Inclusion in Specimen #3 (Secondary Electron Image)

Table 4 Size of Inclusions

Specimen #	Specimen #1	Specimen #2	Specimen #3
Size (Major Diameter) of Inclusions	16 µm	20 µm	22 µm

Conclusion

We detected inclusions in metal materials using an ultrasonic fatigue testing system. Actual fatigue testing is the best means for detecting inclusions which may cause an internal fracture and an ultrasonic fatigue testing system is an effective means to drastically shorten the testing time. In addition, we analyzed the inclusions using an electron probe microanalyzer, and we not only determined the size and the distribution of elements of the inclusions but also identified the compound. From the results, we found that the size of inclusions may be affecting the variations in the number of cycles to failure and that observation of the fractured surface is indispensable in ultrasonic fatigue testing.

References

1) Yoshiyuki Furuya, Saburo Matsuoka, Takayuki Abe: Tetsu-to-Hagane, Vol. 88 (2002) No. 10 (in Japanese)
2) Application News No. i258

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