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Application News

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

Detection of Inclusions in Metal Materials Using an Ultrasonic Fatigue Testing System

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. When a fracture occurs from the inside, it is considered that the fatigue strength depends on the size and kind of internal inclusions. Consequently, to evaluate the fatigue strength of high-strength metal materials, it is important to know the size and kind of inclusions present in the metal materials. There are some methods for inclusion detection, such as mirror polishing and observing the surface of the specimen; however, no one can tell whether a fatigue fracture starts from the detected inclusion. Therefore, to detect inclusions which lead to an internal fracture, it is best to actually carry out a fatigue test[*1]. However, a fatigue test exceeding 10^9 loading cycles at 10 Hz will take approx. 3.2 years. The ultrasonic fatigue testing system used for 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.

In this experiment, we performed the detection of inclusions in an SNCM439 specimen using the ultrasonic fatigue testing system, USF-2000A, and observed the inclusions using the electron probe micro analyzer, EPMA, to identify their elements.

F. Yano, T. Ono

Inclusion Detection by Ultrasonic Fatigue Testing

Fig. 1 shows the testing system configuration. Table 1 gives the testing equipment used and Table 2 gives the test conditions. The stress amplitude that could cause an internal fracture was assumed to be 900 MPa based on the previous report[*2]. The testing 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. For reference, a photo (optical microscope image) of the fractured surface of specimen #3 is shown in Fig. 2. In the case of a fracture originating from an inclusion, a condition referred to as a "fish eye"[*3] is observed on the fractured surface, which indicates the progression of fracture in a circular pattern with the inclusion at the center.

Table 1 Testing System

Testing system	:	Ultrasonic Fatigue Testing System USF-2000A
Thermometer	:	Radiation thermometer
Displacement meter	:	Eddy current displacement sensor

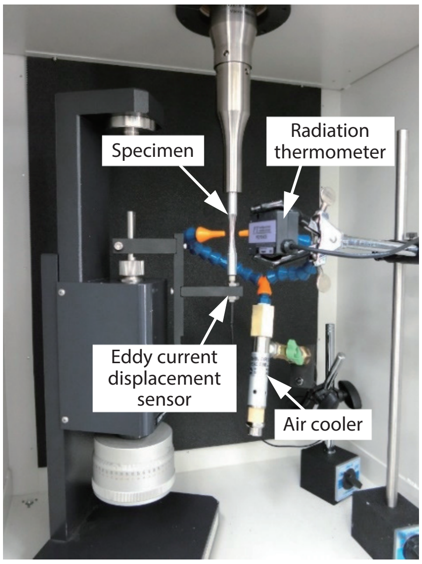

Fig. 1 Picture of the Test

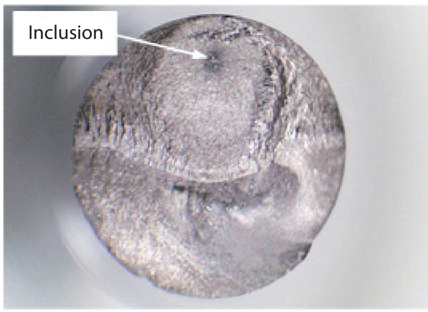

Fig. 2 Photo of the Fractured Surface (Optical Microscope)

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

Observation and Analysis of Inclusions with an Electron Probe Micro Analyzer

To examine the fractured surface condition as well as the size and kind of inclusions in metal materials after a fatigue test, we used the electron probe micro analyzer, EPMA-8050G. Fig. 3, Fig. 4 and Fig. 5 show respective observation images (secondary electron images) of the fractured surfaces and inclusions on specimens #1, #2 and #3. On all specimens, the fracture was developed from an internal inclusion, indicating that inclusions are the origin of fatigue fractures. The size (major diameter) of the inclusion obtained from the images is listed in Table 4. Table 3 and Table 4 together indicate that 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 inclusion.

Following the above observation, we performed a mapping analysis to determine the constituent elements of inclusions on the specimens. The mapping analysis results of the inclusion of specimen #1 are shown in Fig. 6. Image (a) in Fig. 6 shows the secondary electron image which is suitable for grasping the profile of the inclusion. Image (b) helps to understand the relative composition of constituent elements. In this backscattered electron image, the smaller the mean atomic number the darker it appears and the larger the brighter. Images (c) to (f) show the distribution images of O, Al, S, and Mn and indicate that these elements are contained in inclusions at high concentrations. From these results, the inclusions proved to be alumina (Al_2O_3) and manganese sulfide (MnS). Inclusions in specimens #2 and #3 were also found to be mainly alumina and manganese sulfide.

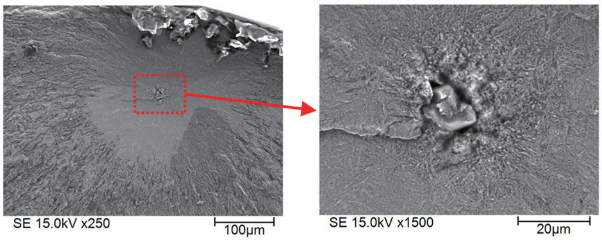

Fig. 3 Observation Image of an Inclusion in Specimen #1 (Secondary Electron Image)

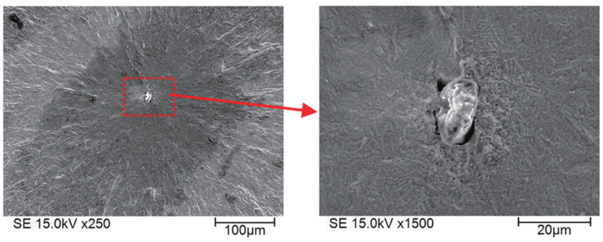

Fig. 4 Observation Image of an Inclusion in Specimen #2 (Secondary Electron Image)

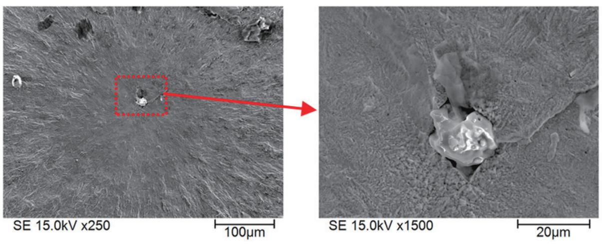

Fig. 5 Observation Image of an Inclusion in Specimen #3 (Secondary Electron Image)

Table 4 Size of Inclusions

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

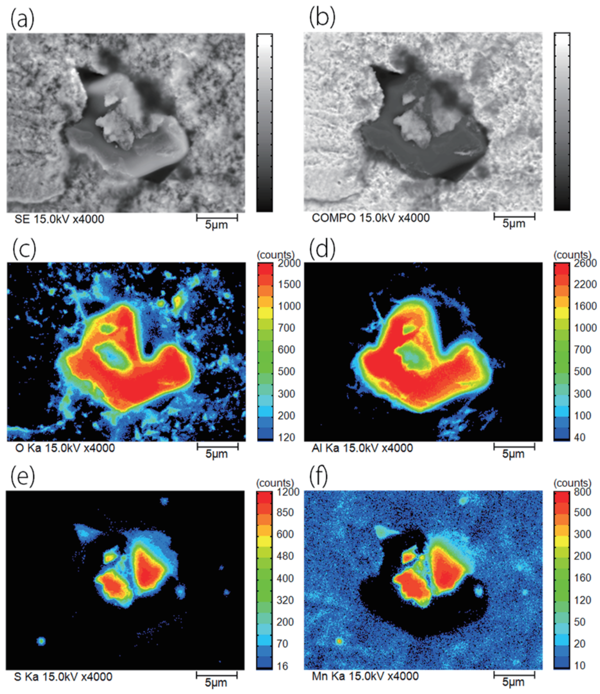

Fig. 6 Mapping Analysis Results of Specimen #1
(a) Secondary Electron Image,
(b) Backscattered Electron (Composition) Image,
(c) O-distribution Image, (d) Al-distribution Image,
(e) S-distribution Image, (f) Mn-distribution Image

Conclusion

In this experiment, we performed the detection of inclusions in metal materials using an ultrasonic fatigue testing system. Actual fatigue testing is the best way 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 micro analyzer to determine the size and constituent elements of each inclusion. From this, we confirmed that the size of inclusions may be affecting the variation 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
*3 Yoshiaki Akiba, Keisuke Tanaka, Akira Nakatsu: Transactions of the JSME (Part A) Vol. 70 No. 695 (2004-8) (in Japanese)

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