Application News

Tabletop Dynamic and Fatigue Testing System Servopulser™ EHF-L Series
High-Temperature Fatigue Testing Machine with Scanning Electron Microscope SEM Servopulser
Electron Probe Microanalyzer EPMA™ -8050G

Three-Point Bending Fatigue Tests of Welded Material Using the SEM Servopulser

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User Benefits

- The SEM Servopulser and EPMA can perform three-point bending fatigue tests of welded material and analyze the factors causing failures.
- The SEM Servopulser can also be used to observe fatigue cracks.
- High-accuracy dynamic control can be achieved with the Servo Controller 4830.

■ Introduction

Welding is used extensively in industries such as construction, transport vehicles including automobiles and aircraft, and in the electronic and electrical industries, where it is indispensable. However, when a welding defect causes an accident, it can have serious or even devastating effects. Therefore, the evaluation of the long-term reliability and durability of welds is very important.

This article describes the preparation of test specimens with two types of ferrous metal welded in the center and three-point bending fatigue tests performed on them using the Servopulser tabletop dynamic and fatigue testing system. After the tests, the fracture surfaces of the test specimens were observed using the electron probe microanalyzer (EPMA). In addition, the extension of cracks during the fatigue tests was observed using the SEM Servopulser, a high-temperature fatigue testing machine with a scanning electron microscope.

■ Test Specimen Information and Measurement System

The test specimen information and photos are shown in Table 1 and Fig. 1, respectively. The dimensions of the test specimens were length 18 mm × width 4 mm × thickness 3 mm. They were made of Type 304 stainless steel and SS400 structural steel and were TIG welded. At the welded part, a C1 chamfer was formed, which was welded all round.

The tests were performed using the Servopulser EHF-L tabletop dynamic and fatigue testing system, the SEM Servopulser high-temperature fatigue testing machine with a scanning electron microscope, and the EPMA electron probe microanalyzer. The test equipment configuration is shown in Table 2. First, the welded test specimen S-N curve was created using the EHF-L. Then the fatigue testing conditions were set on the SEM Servopulser based on the S-N curve obtained, and the cracking process was observed. After the test, the fracture surface of the test specimens were observed using the EPMA.

Table 1 Test Specimen Information

Test Specimen:	Type 304 stainless steel, SS400 structural steel
Welding Method:	TIG welding (TG308 stainless steel welding rod Φ1.2 mm)
Dimensions:	Length 36 × width 4 × thickness 3 mm

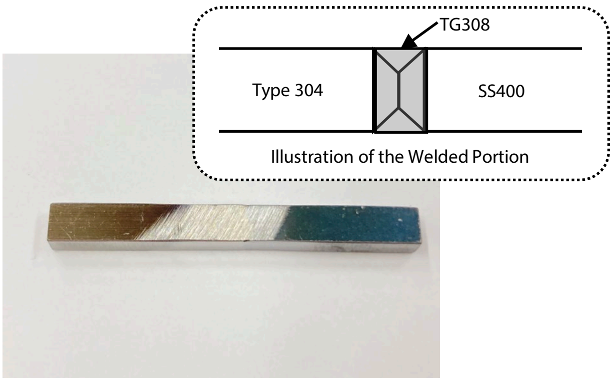

Fig. 1 Photograph of Test Sample

Table 2 Equipment Configuration

Device:	EHF-L, SEM Servopulser, EPMA-8050G
Load Cell:	10 kN
Test Jig:	Three-point bending test jig
Control Device:	Servo Controller 4830
Software:	Windows software for 4830

■ Static Three-Point Bending Test Results

To set the conditions in the fatigue tests, static three-point bending tests were performed. The test conditions are shown in Table 3, and the bending stress-stroke curves are shown in Fig. 2. The mean value of the flexural strength in the static three-point bending tests was 881 MPa (standard deviation 63.8 and coefficient of variation 7.2). The loading conditions in the fatigue tests were based on this value. The test setup is shown in Fig. 3.

Table 3 Test Conditions

Test Speed:	1 mm/min
Number of Tests:	n = 3

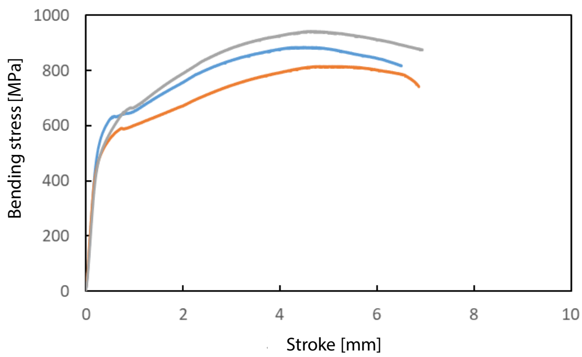

Fig. 2 Bending Stress - Stroke Curves

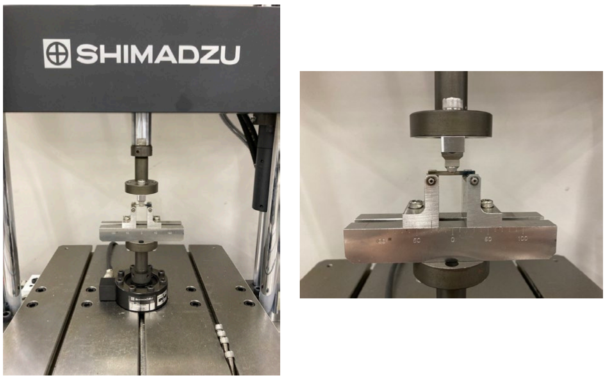

Fig. 3 Test Setup

■ Three-Point Bending Fatigue Test Results

The loading conditions in the three-point fatigue tests were 46 to 80 % of the static three-point flexural strength. The test conditions are shown in Table 4, and the S-N curves are shown in Fig. 4. Since failure at a location other than at the welded portion was confirmed only for the maximum loading stress of 650 MPa, the test was performed twice on specimens A and B. More information is provided in the observation and element analysis by the EPMA in the next section.

Table 4 Three-Point Bending Fatigue Test Conditions

Maximum Loading Stress:	405, 418, 499, 546, 593, 650, 700 [MPa] (46 to 80 % of the static flexural strength)
Stress Ratio:	0.1
Frequency:	20 Hz
Number of Tests:	n = 1 (n = 2 for 593 MPa only)
Distance between Supports:	30 mm
Indenter/Support Point:	R2

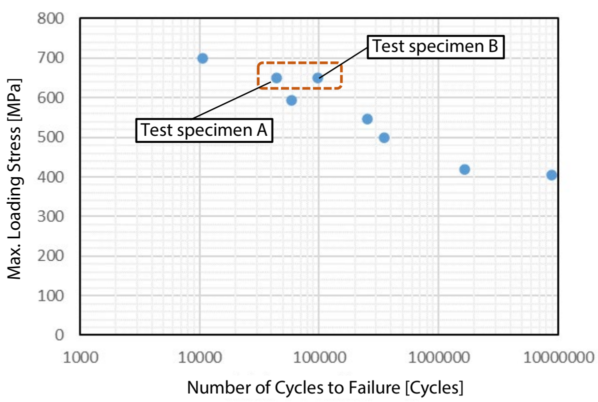

Fig. 4 S-N Curve
(Each blue point is one fatigue test result.)

■ Observation and Element Analysis Using the EPMA

First, element mapping of the test samples was performed before the fatigue test. The test specimens consisted of Type 304 and SS400 with a TG308 weld in the center, so differences in Ni, Cr, etc. were found. Fig. 5 shows a backscattered electron image and an element mapping analysis image for Ni and Cr. The boundaries between Type 304, TG308, and SS400 could be clearly determined, as shown in Fig. 5 (2) and (3).

Next, element mapping analysis was performed by the EPMA on the SS400 side of the test specimens A and B . Fig. 6 shows a photograph of the test specimens after the tests. The failure of specimen A occurred virtually in the center, while test specimen B failed on the SS400 side. Fig. 7 shows images observed using the EPMA of the fracture surface of test specimen A on the SS400 side. Fig. 7 (3) and (4) show that in the center of the test specimen, the Ni and Cr content was low, but around it, the Ni and Cr components were high. This was probably because the SS400 welding surface and the welding rod TG308 components were detected.

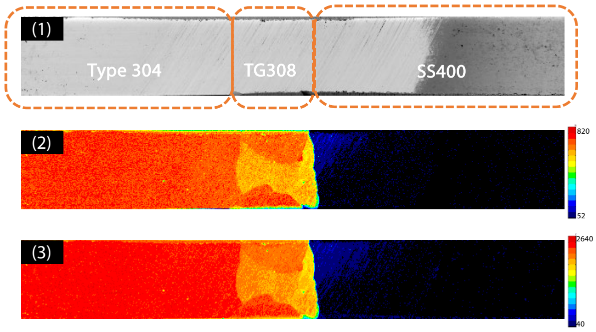

Fig. 5 Observation Images Using EPMA
(1) Backscattered electron image (2) Ni (3) Cr

Fig. 6 Test Specimens A and B after the Fatigue Tests

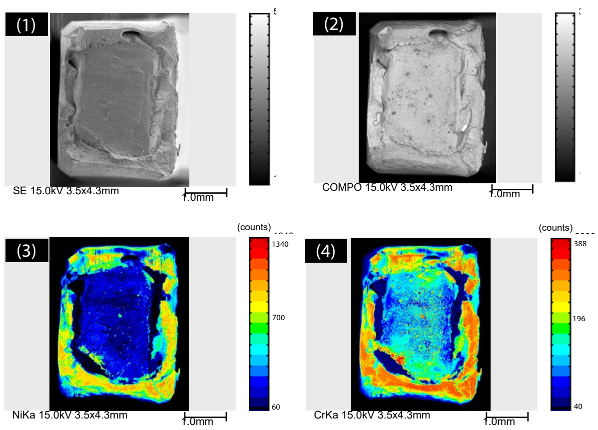

Fig. 7 Observation Images of Test Specimen A Fracture Surface (SS400 Side) Using EPMA
(1) Secondary electron image (2) Backscattered electron image (3) Ni (4) Cr

Fig. 8 shows images observed using the EPMA of the fracture surface of test specimen B on the SS400 side. From Fig. 8 (3) and (4), there was almost no Ni and Cr detected. This was probably because the fracture surface of test specimen B was on the SS400 side. From this, the strength of the weld in test specimen B was higher, so the fatigue failure occurred in the parent metal SS400, and the number of cycles to failure was higher than for test specimen A.

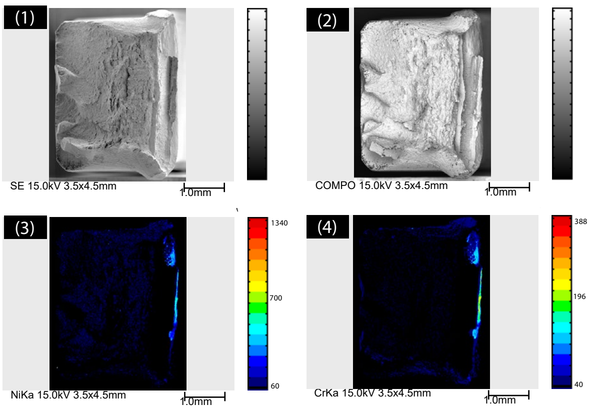

Fig. 8 Observation Images of Test Specimen B Fracture Surface (SS400 Side) Using EPMA
(1) Secondary electron image (2) Backscattered electron image (3) Ni (4) Cr

■ Observations Using the SEM Servopulser

The SEM Servopulser combines a scanning electron microscope (SEM) with a fatigue testing machine (Servopulser). This enables the extension of cracks to be observed in detail during tests. In this case, observations using the SEM Servopulser were performed up to a maximum loading stress of 700 MPa. Fig. 9 shows a photo of the SEM Servopulser.

Fig. 10 shows images observed using the SEM Servopulser, and Fig. 10 (1) shows an image of the test specimen and the indenter when the number of cycles was 1000. From Fig. 10 (1), a crack can be seen slightly to the right side of the center of the test specimen. Fig. 10 (2) shows an image of the right side of the crack in Fig. 10 (1) observed with a magnification of 1000. It can be seen that from the crack tip observed in Fig. 10 (1) the crack extends further, as indicated by the white arrow in the figure. Fig. 10 (3) shows an image of the crack observed with a magnification of 300 after 8000 cycles, and Fig. 10 (4) shows an image of the right side of the crack observed with a magnification of 500. It can be seen that compared with Fig. 10 (2), the crack has extended further.

Fig. 9 SEM Servopulser™

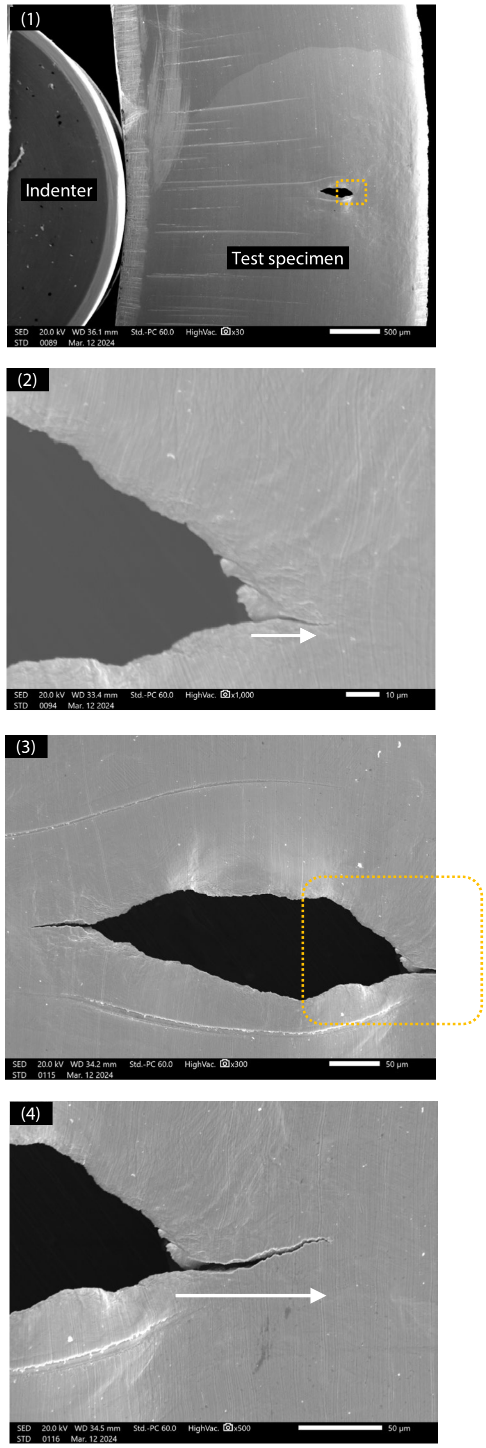

Fig. 10 Examples of Observation Using the SEM Servopulser
(1) 1000 cycles, magnification ×30 (2) 1000 cycles, magnification ×1000
(3) 8000 cycles, magnification ×300 (4) 8000 cycles, magnification ×500

■ Conclusion

Bending fatigue tests were performed on welded specimens using the Servopulser, and the S-N curve was obtained. Element analysis was performed using the EPMA on two test specimens that had different numbers of cycles to failure. It was found that failure occurred in different locations, that is, in the welded portion and in the parent metal.

Then the conditions were set on the SEM Servopulser based on the S-N curve obtained, and the cracking process in the test specimen was observed during measurement. By changing the magnification on the SEM, it was possible to observe the cracks in detail in the test specimens. And, as the tests progressed, it was possible to clearly observe how the cracks extended. In this way, this equipment demonstrated it is useful for the evaluation of fatigue properties of welded materials.

Related Applications

1. Three-Point Bending Fatigue Tests of Carbon Fiber Reinforced Plastic Using the SEM Servopulser
   Application News No. 01-00793
2. Three-Point Bending Fatigue Test and Crack Observation of Cracked Specimens Using SEM Servopulser
   Application News No. 01-00794

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