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Development of piezoelectric ceramics driven fatigue testing machine for small specimens

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Abstract

A new fatigue testing machine with piezoelectric ceramics actuators was developed and a prototype was manufactured for high-cycle fatigue tests with small specimens. The machine has a simple mechanism and is compact. These features make it easy to set up and to maintain the machine in a hot cell. The excitation of the actuator can be transmitted to the specimen using a lever-type testing jig. More than 100 μm of displacement could be *prescribed* precisely to the specimen at a frequency of 50 Hz. This was sufficient performance for high-cycle bend fatigue tests on specimens irradiated at the SINQ target in Paul Scherrer Institute. The relationship of a displacement applied to the specimen and the strain of the necking part were obtained by experimental methods and by finite element method (FEM) calculations. Both results showed good agreement. This fact makes it possible to evaluate the strain of irradiated specimens by FEM simulations.

1. Introduction

Many years ago, the small specimen technology (SST) has been developed to investigate mechanical properties of nuclear materials. However, further development and improvement of SST are needed [1]. For instance, in fast neutron source facilities for fusion materials research [2,3] or in proton beam irradiation facilities [4], the irradiation volumes are very small and the irradiated specimens are highly activated. To use effectively the irradiation volume and to decrease the radiation dose, SST is an indispensable procedure. In the spallation target irradiation program (STIP) at the SINQ target in Paul Scherrer Institute (PSI), some smaller specimens are employed. The purpose of the program is to study irradiation effects on structural materials for an accelerator-driven spallation neutron source. The system is composed of a high-intense proton accelerator and a heavy metal spallation target. High-flux fast neutrons will be generated by a spallation reaction of high-energy protons and heavy metals. As target materials, heavy liquid metals (mercury, led–bismuth, etc.) are promising candidates. The container of the liquid metal target will be subjected not only to proton/neutron irradiation and liquid metal corrosion but also to a 50 Hz pressure wave with pulse injection by a high-energy proton beam [5,6]. To evaluate effects of the pressure wave on lifetime of the container materials, high-cycle fatigue tests of the irradiated materials will be needed. Out of the numerous material test methods with small specimens, fatigue testing is one of the most difficult methods. Conventional testing machines with hydraulic-type or electromagnetic-type actuators cannot provide low loads and small displacements with sufficient precision. A supersonic-type actuator can generate high frequencies but the test specimen will be heated by supersonic vibration. So, a special testing machine for high-cycle fatigue tests with small specimens is needed. JAERI and the Yonekura MFG Co. Ltd. have developed a new fatigue testing

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machine and manufactured a prototype employing piezoelectric ceramics actuators.

2. Design concept and specifications of the machine

2.1. Design concept of the machine

The fatigue testing machine was designed to satisfy the following requirements:

(1) To perform high-cycle fatigue tests with small specimens. The small fatigue specimen used in this study is shown in Fig. 1. A small displacement (± 100 μm) must be prescribed precisely to the specimen with at a frequency of 50 Hz.
(2) To have a simple mechanism and a compact system. The machine has to be set in a hot cell and operates by remote handling. A simple mechanism make it easy to set up and to maintain the machine. It has preferably to be compact sized and light weighted.

Fig. 2 shows the prototype of the fatigue testing machine with piezoelectric ceramics actuators. The size of the machine is 200×600 mm^2, and is 120 mm high. Its weight is about 20 kg.

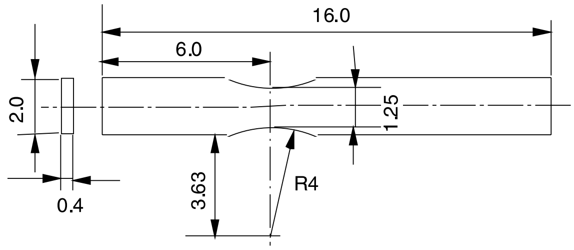
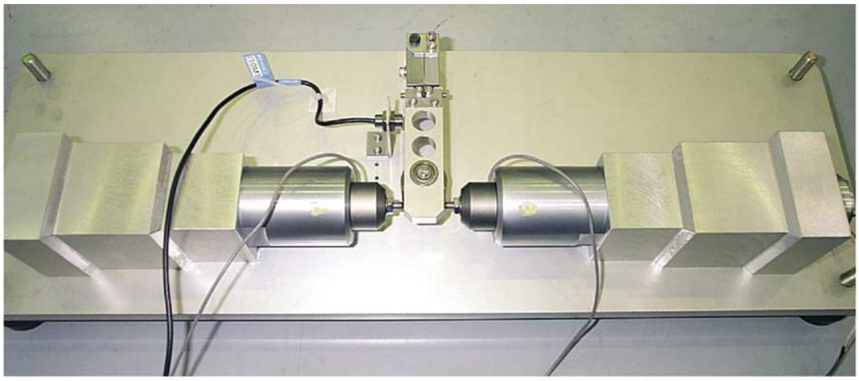


Fig. 1. Test specimen for bend fatigue tests, dimensions in mm.

2.2. Piezoelectric ceramics actuator and specimen loading apparatus

The piezoelectric material converts the mechanical pressure to an electric field. Conversely, an applied electric field generates lattice strain [7]. The lattice strain deforms the ceramics. An actuator can be made of a multilayered ceramics disk. The advantages of the actuator are high sensibility to an applied voltage and high positional accuracy. For these reasons, piezoelectric ceramics actuators are suitable for driving a small fatigue testing machine.

The machine has two actuators (Tokin Co. Ltd.), which are mounted on opposite sides of the testing jig.



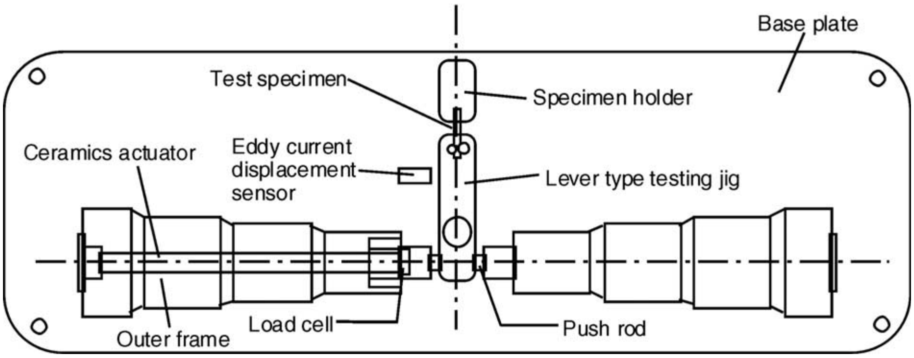


Fig. 2. Prototype of the piezoceramic actuators driven fatigue testing machine.

The maximum amplitude of the actuator itself is about 120 μm. The displacement of the actuator can be transmitted to the specimen using a lever-type testing jig. The jig presently installed has a lever ratio of 1:3. The maximum amplitude of the specimen is about 360 μm at 26 Hz. The frequency may be varied in the range between 26 and 108 Hz. It will be possible to perform tests at lower frequencies by changing the controller unit. The upper limit of the test frequency is determined by the resonance frequency (3 kHz) of the actuator and the following capability of the testing jig.

2.3. Control system

Two actuators are installed in the machine. An anti-phase sine wave voltage is prescribed to the actuators in order to repeat alternatively expansion and contraction. The expanding actuator, however, does *not* shrink *as* rapidly. Because the multilayered piezoelectric ceramics actuator act as a condenser, the hysteresis behavior of the actuator prevents the ceramics from contracting quickly. To resolve the problem, small load cells are fitted between the actuators and the pushing rod. The voltages are controlled such that the load difference of the load cells is to be zero. Namely, a voltage higher than sine-wave is prescribed to the expanding side and the actuator on the shrinking side is forced to shrink by the expansion side.

Fatigue tests can be performed at present only under the displacement control mode. In future, load control mode tests will be possible by installing a load cell at the specimen holder. The displacement of the jig is measured using an eddy-current type displacement sensor.

2.4. Specimen and specimen holder

The specimen used in this study is shown in Fig. 1. The specimen was originally developed at ORNL [8] and modified for a proton irradiation program at PSI [9]. The testing jig is composed of a lever jig and a specimen holder. The specimen is put into the slit of the specimen holder and fixed. At the lever jig side, the specimen is clamped by rollers. An electric current is applied to the specimen. The interruption of the current indicates the specimens rupture.

The relationship between the displacement applied to the specimen and the strain of the necking part were determined by experimental methods and finite element method (FEM) simulations. A digital micrometer and a specimen with a adhered strain gauge at the necking part were used for the experimental method. The FEM code ABAQUS was used for the FEM simulation.

3. Results and discussion

3.1. Waveform

The oscillation of the lever jig was measured by an eddy-current type displacement sensor. Fig. 3(a) shows the waveform of the maximum amplitude (240 μm) at 26 Hz, Fig. 3(b) the waveform at the maximum frequency (100 Hz). Both waveforms are approximately sine-curves. The maximum amplitude of the specimen is 1.5 times larger than that of measured at the position of the eddy-current type displacement sensor.

3.2. Displacement and strain

Fig. 4 illustrates the strain distribution of a solution-annealed (SA) Japan Primary Candidate Material (JPCA) specimen as simulated by FEM. The loading point was at 3 mm off the shoulder part of the specimen. The results indicate that the maximum strain is observed slightly of the holder side of the necking part.

Fig. 5 shows the relationship of an applied displacement and a strain at the necking part of the SA-JPCA specimen. The loading points were at 3 and 5 mm off the shoulder part. The open circles and the crosses show the experimental data and results of the FEM calculation, respectively. Both values evidence good agreement. A displacement can be converted to a strain by use of these

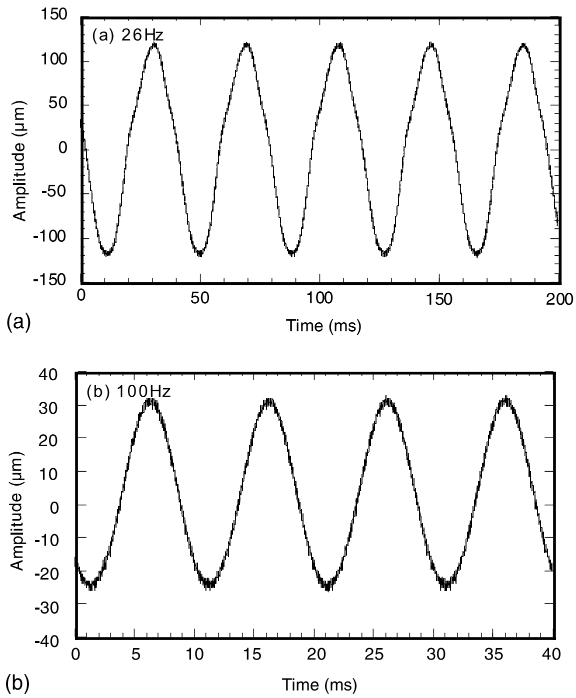


Fig. 3. Wave form of (a) the maximum amplitude at 26 Hz and (b) the maximum frequency (100 Hz).

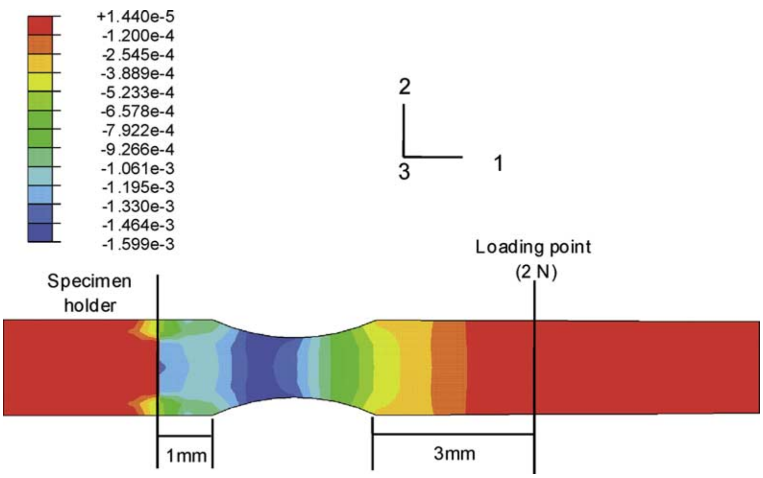


Fig. 4. Strain (ε11) distribution of the SA-JPCA specimen simulated by FEM.

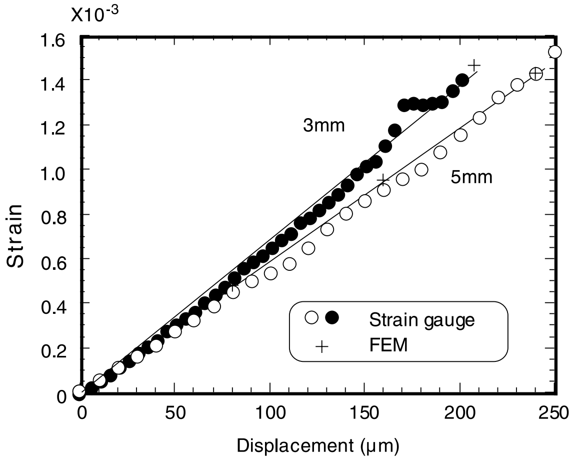


Fig. 5. Relationship of an applied displacement and the strain at the necking part of a SA-JPCA specimen.

relationships. However, it is difficult to obtain the relationship for irradiated materials by this experimental method. The relationship of irradiated materials must be evaluated by FEM simulation, exclusively.

4. Conclusion

The results obtained from this study are as follows:

(1) A new fatigue testing machine with piezoelectric ceramics actuators was developed and a prototype was manufactured. The machine has a simple mechanism and is compact. These features make it easy to set up and to maintain the machine in a hot cell.
(2) More than 100 μm of displacement could be prescribed precisely to the specimen at a frequency of 50 Hz. This is a sufficient performance for high-cycle fatigue tests on specimens irradiated at the SINQ target.
(3) The relationship of a displacement applied to the specimen and the strain of the necking part were obtained by experimental methods and by FEM calculations. Both results showed good agreement. This fact makes it possible to evaluate the strain of irradiated specimens by FEM simulations.

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References

[1] P. Jung, A. Hishinuma, G.E. Lucas, H. Ullmaier, J. Nucl. Mater. 232 (1996) 186.
[2] K. Noda, K. Ehrlich, S. Jitsukawa, A. Moeslang, S. Zinkle, J. Nucl. Mater. 258–263 (1998) 97.
[3] T.E. Shannon, R.A. Jameson, H. Katsuta, H. Maekawa, M. Martone, A. Moeslang, V. Teplyakov, M.J. Rennich, J. Nucl. Mater. 258–263 (1998) 106.
[4] P. Marmy, M. Daum, D. Gavillet, S. Green, W.V. Green, F. Hegedus, S. Proenecke, M. Victoria, Nucl. Instrum. and Meth. B 47 (1990) 37.
[5] M. Futakawa, K. Kikuchi, H. Conrad, H. Stechemesser, Nucl. Instrum. and Meth. A 439 (2000) 1.
[6] K. Kikuchi, H. Nakashima, S. Ishikura, M. Futakawa, R. Hino, J. Nucl. Sci. Technol. 37 (2000) 113.
[7] B. Jaffe, W.R. Cook, H. Jaffe, Piezoelectric Ceramics, Academic Press, New York, 1971.
[8] G.R. Rao, A. Rowcliffe, B.A. Chin, J. Nucl. Mater. 179–181 (1991) 438.
[9] Y. Dai, G.S. Bauer, J. Nucl. Mater. 296 (2001) 43.