COMPUTER-CONTROLLED DEVICE FOR IN-SITU SEM STUDY OF THE FATIGUE BEHAVIOUR OF METALS AND CERAMICS

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ABSTRACT

This paper describes a computer-controlled fatigue test device with a special unit designed for placement in the specimen chamber of a scanning electron microscope (SEM). The test unit inside the SEM is fed with sinusoidally pulsating pressurized oil from an external hydraulic system. The resulting amplitude and mean loading of the test specimen are controlled by feedback control systems. The special test unit can also be used outside the SEM without any modifications. This gives the opportunity of testing identical test specimens in the same test unit under vacuum, as well as atmospheric conditions.

KEYWORDS

Test device, scanning electron microscope (SEM), fatigue, in-situ SEM study, computer-controlled.

INTRODUCTION

This paper describes an improved computer-controlled fatigue test device with a special unit designed for placement in the specimen chamber of an SEM (Philips SEM 505). The supporting structure for test specimen, loading mechanism and load transducers form the test unit for attachment to the commercial stage inside the vacuum chamber of the SEM. The specimen can be subjected to cyclic tension loading . The cyclic loading can be combined with single overloads to study the effect of load-overload sequences.

An earlier version of the fatigue test device without computer-controlled feedback has been used for testing metallic and ceramic materials (Mouritsen, O. Ø. and Karihaloo, B. L., 1993; Møller et al., 1994; Andreasen et al., 1995) and has performed very satisfactorily. Experience has shown however that both the amplitude and mean value of cyclic loading on the test specimen change slightly during the test. These variations are unavoidable due to changes in crack length, temperature of the test device as a whole, etc. Consequently both the amplitude and mean value of cyclic loading must be constantly adjusted during the test. To avoid this tiresome manual adjustment job, computer-controlled feedback systems have been built into the improved fatigue test device.

FATIGUE TEST DEVICE

Test runs have shown that cyclic tension loading can be applied to the test area of the specimen with a maximum frequency of up to 15 Hz. Cracks down to a length of about 0.5 μm can be detected and their growth to a length of almost 7 mm in steel specimens can be monitored. The maximum displacement in the test area can reach about 2 μm, allowing the response of the specimen to be constantly monitored and recorded on a videotape during cyclic loading. A careful study of the videotape permits one to identify the crack growth and/or retardation mechanisms under cyclic loading, combined if desired with single overloads.

The principal components of the improved computer-controlled fatigue device (Fig. 1) are: (i) test specimen; (ii) supporting structure for test specimen and load cell; (iii) load cell; (iv) load transducers; (v) vacuum chamber port lid; (vi) hydraulic pressure supply; (viii) computer-controlled feedback control systems.

The fundamental demand on the test unit that is to be placed inside the vacuum chamber was to minimize the displacements of the area under investigation. The principle of structural symmetry has been used to fulfil that demand during loading. The same principle must also hold for structural displacements and inertial forces.

In practice it is impossible to achieve perfect symmetry in frictional conditions. Consequently, slide bearings had to be avoided. Therefore, all displacements in the test unit are due to elastic deformations only.

Furthermore, all parts of the device placed inside the vacuum chamber must meet strict requirements as to their dimensions, accuracy, cleanliness, applicability to a wide variety of materials, etc.

The vacuum chamber unit of the fatigue device can be used outside the SEM without any modifications. This gives the opportunity of testing identical test specimens in the same test unit under vacuum, as well as atmospheric conditions.

The computer-controlled feedback systems are required to be
- accurate (better than 1%);
- quick in response time;
- stabile; and
- safe.

These requirements have (except for the accuracy) mainly been based on:
- a maximum crack growth rate of 10^{-6} m/cycle;
- a corresponding rate of change of the test specimen compliance found by finite element calculations; and
- experience with the manual adjustment of both the amplitude and mean value of cyclic loading during experiment with the earlier version of the device.

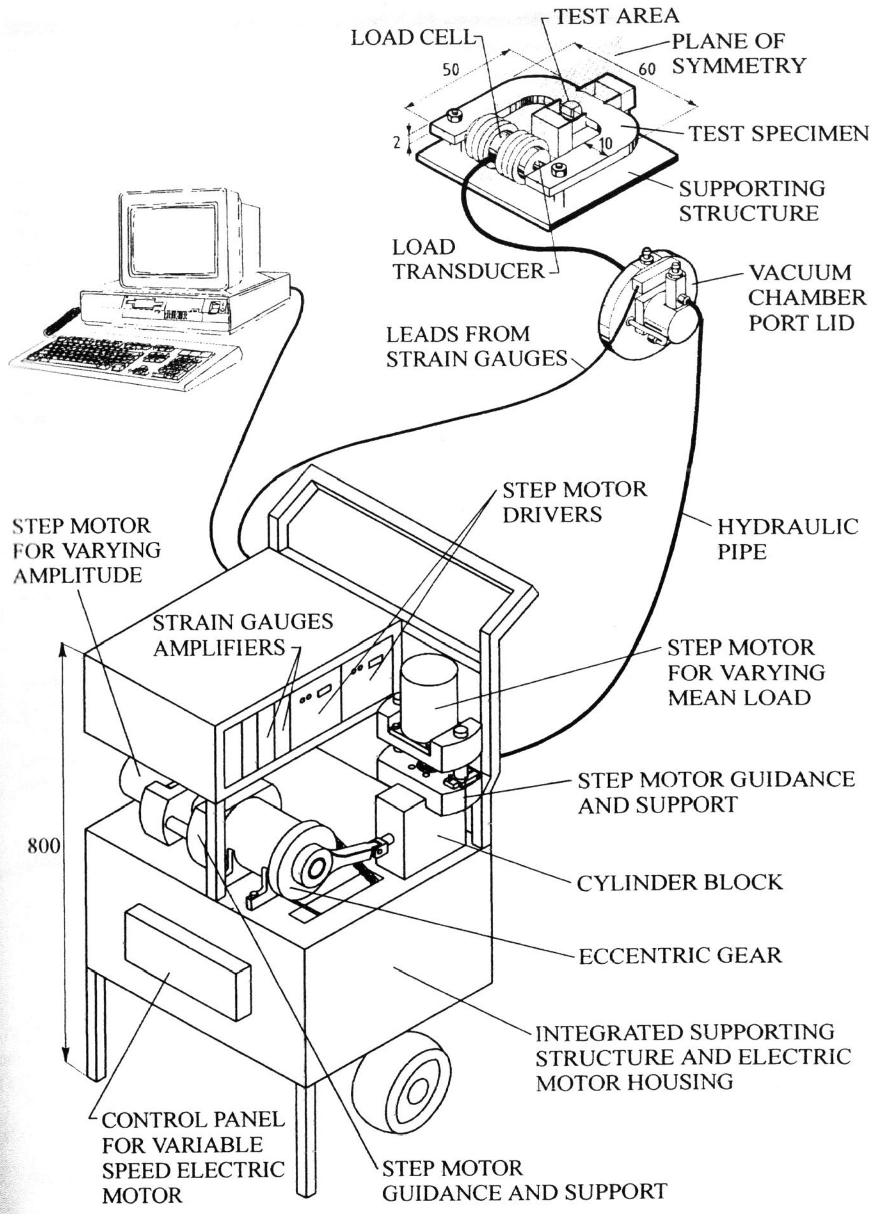

Fig. 1 The principal components of the computer-controlled fatigue device

A brief description of the principal components of the fatigue device follows. Fuller details can be found in Christensen *et al.* (1989), Mouritsen (1990), and Mouritsen and Karihaloo (1991).

Test Specimen

The test specimen for metallic materials has been designed in the shape of a horseshoe. A V-notch is machined on the inward side in the plane of symmetry of this test specimen. The high stress gradients and consequently the high stress concentration factor at the root of a sharp V-notch ensure that crack initiation will take place in this region. Test specimens suitable for ceramics were designed by Møller and Karihaloo (1990).

Supporting Structure

The test specimen is elastically suspended on a fixed base plate by springs. The springs are designed so as to provide the maximum stiffness in the desired directions and negligible stiffness in the directions in which they must act as bearings.

Load Cell

The load cell is designed as a closed symmetric bellows system. The cell is fixed on the base plate of the supporting structure in the plane of symmetry.

The pressurized hydraulic system inside the vacuum chamber is completely enclosed in a safety compartment vented to the atmosphere outside the SEM. This compartment is formed by enclosing the load bellows in a set of safety bellows and the flexible part of the hydraulic piping system in a safety tube. For additional safety, a special inorganic silicone oil is used in the hydraulic loading system inside the vacuum chamber. This oil has a very low vapour pressure, well below the working pressure in the vacuum chamber.

The load cell is designed to deliver a maximum cyclic load range of 150 N to each moment arm, and a maximum overload level of 400 N. The maximum stroke of the load cell is 1 mm.

Load Transducers

The load transducers form an integral part of the load cell. There are two identical strain gauge based transducers in the cell allowing double check of the load levels. The sensitivity is about 2.2 μstrain/N, corresponding to an accuracy better than 0.2% at the maximum load level (400 N). To minimize electric noise pick up, the leads from the strain gauges are plaited.

Vacuum Chamber Port Lid

A blind flange on the vacuum chamber is removed. The above four components of the test set-up are introduced through this port and attached to the tilt-table in the vacuum chamber. The blind flange is replaced by the port lid which is a part of the test device.

The leads from the strain gauges are retrieved through this lid and connected to amplifiers outside the SEM. To minimize the possibility of oil leakage in the vacuum chamber, an oil separator is mounted in the lid. This also enables the use of an ordinary hydraulic oil in the system outside the vacuum chamber. The safety compartment surrounding the pressurized parts inside the vacuum chamber is also vented through this lid.

Hydraulic Pressure Supply

The hydraulic pressure supply is composed of a cylinder block with an adjustable piston and a plunger operated by an eccentric gear. The eccentric gear is driven by a variable speed electric motor.

The mean load and the single overloads are controlled by the adjustable piston. The cyclic load range results from the adjustable eccentricity of the gear. With this design both mean load and load range can be independently adjusted during operation.

Computer- Controlled Feedback Systems

The adjustable mean load piston and the adjustable eccentricity of the gear are operated by electric step motors.
A personal computer (type 486 or pentium) form the central part of the feedback control systems. The analog signals from the strain gauge based load transducers are fed into the computer through I/O cards (PC-LabCard PCL-812). These load transducer signals and reference input (desired values of minimum and maximum loads) are compared in the computer. On the basis of the resulting error, corrective signals are fed to the appropriate step motor drivers.
The computer and I/O-cards result in a very flexible control system and also offer the opportunity of monitoring a set of safety switches. The test runs for the specified number of cycles or until another stop condition is detected.

EVALUATION

The fatigue test device has performed very satisfactorily during test runs. Cyclic tension loading can be applied to the test area of the specimen with a maximum frequency of up to 15 Hz. The computer-controlled feedback systems control both the amplitude and mean value of cyclic loading on the test specimen to an accuracy better than 1 % of maximum values.
A videotape from tests will be played during the presentation.

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