Development of a Methodology for Measurement of Mechanics Properties of Materials Used on the Microscale

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A methodology has been developed for measuring the mechanical properties of materials used in micro-devices. A direct tension test consisting of a dog-bone-type specimen fabricated from single crystal silicon (SC-Si) has been employed for determination of Young's modulus E and the fracture strength σ_f , while the strain field has been obtained using Digital Image Correlation (DIC) combined with optical microscopy. SC-Si is expected to have the same value of Young's modulus on both the micro and macro-scales and has been chosen as a convenient benchmark for examination of the accuracy of the methodology. Our results indicate that the developed relatively simple yet universal experimental protocol combining accuracy of DIC with availability of optical microscopy can be efficiently used in academic and industrial environments for the evaluation of mechanical properties of materials employed on the micro-scale.

It has been shown [1] that for certain materials, mechanical properties are scale and process dependent and may differ from their bulk values. Although a variety of micro-scale testing methods have been suggested including indentation, an ultrasonic test, a bulge test, beam bending, a resonant method or an indirect tension test [1,2], much scatter is found in results and further development of experimental procedures is required. A direct tension test is considered as the most reliable method in which an entire stress-strain curve may be obtained. In the direct tension tests found in the literature [3, 4], specimen gripping has been achieved directly by mechanical grips, or by means of adhesion or an electrostatic force; whereas, displacement control was carried out using an external loading machine or microfabricated actuators integrated with the tested specimen. Detection of the displacement field within the gage which has a crucial influence on accuracy has been performed by means of a CMOS camera, laser interferometry, scanning electron microscopy (SEM) or atomic force microscopy (AFM) [5]. Sample handling and installation, as well as methods of load application are among the main challenges of direct tension testing.

In this investigation, a methodology developed for measuring the mechanical properties of micro-specimens is presented. The direct tension test method has been employed. A dog-bone-type specimen (Fig. 1) with a gage length, width and thickness of 500 μm, 50 μm and 20 μm, respectively, was designed based upon the ASTM E8M-04 standard [6], as well as similar adaptations found in the literature [3]. Specimens were fabricated from SC-Si using an SOI (silicon on insulator) wafer and a DRIE (deep reactive ion etching) based process. The test set-up includes a small loading machine with a load cell of maximum capacity 5 N, with direct gripping using loading holes, displacement control, an optical microscope with a CCD camera and a data acquisition system (Fig. 2). Direct gripping using loading holes provides satisfactory alignment between the load train and the specimen gage and allows testing of any material. In order to measure displacements within the gage, a speckle pattern was created on the surface of the specimen and images of the gage were sequentially acquired during loading up to failure (Fig. 3). The two-dimensional displacement field (Fig. 4) has been obtained by means of DIC leading to calculation of the axial strain. In addition, the homogeneous field provides an indication of the quality of the experiment. Geometric parameters measured by means of an SEM together with the measured load were used to determine the stress. The average value of Young's modulus E obtained in the micro-tests (Fig. 5 and Table 1) is consistent with values obtained on the macro-scale (E = 169 GPa). Obtained results reflect the reliability of the methodology which is suitable for characterization of a large variety of materials exploited in micro-devices.

References

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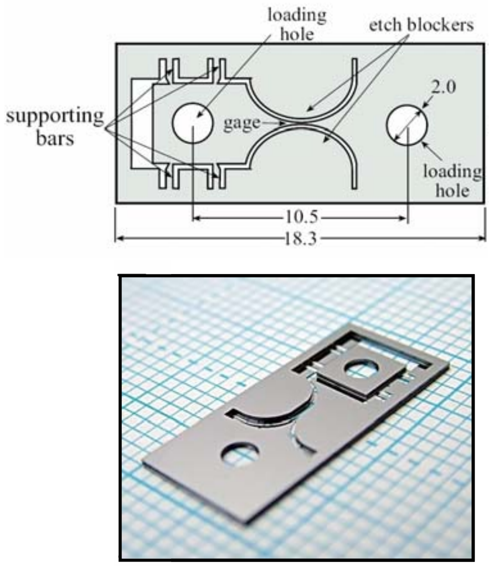

Fig. 1: Micro specimen used in experiments. Supporting bars are cut prior to measurement. All dimensions are given in mm.

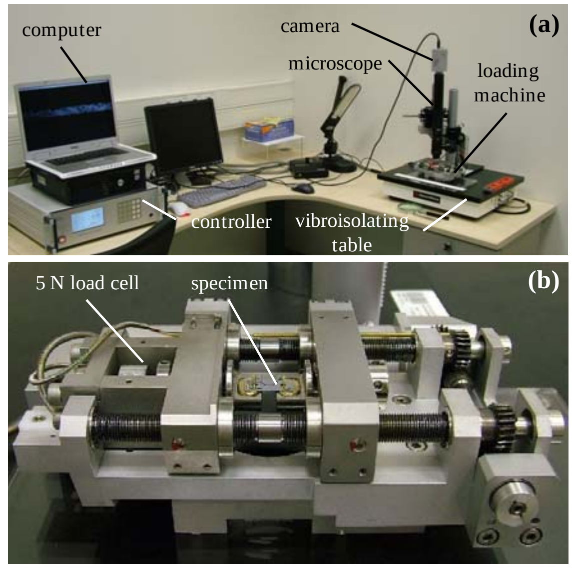

Fig. 2: (a) Experimental set-up and (b) miniature loading machine.

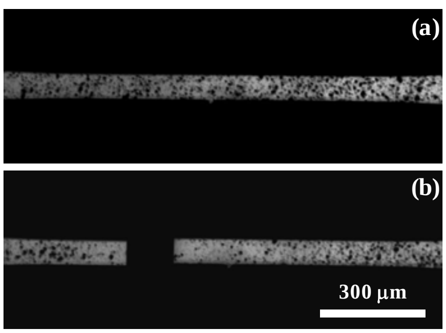

Fig. 3: Micrograph of the specimen during testing (a) before and (b) after failure. The black dots are speckles intentionally provided as a pattern for DIC.

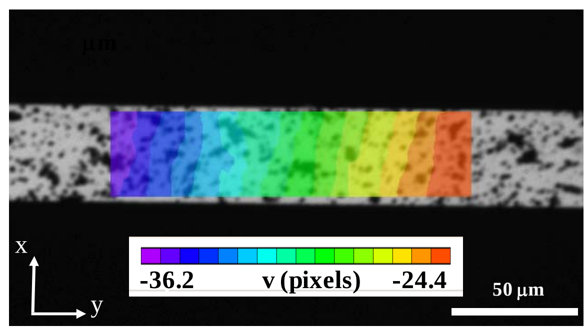

Fig. 4: Measured two-dimensional displacement in the *y*-direction obtained using DIC.

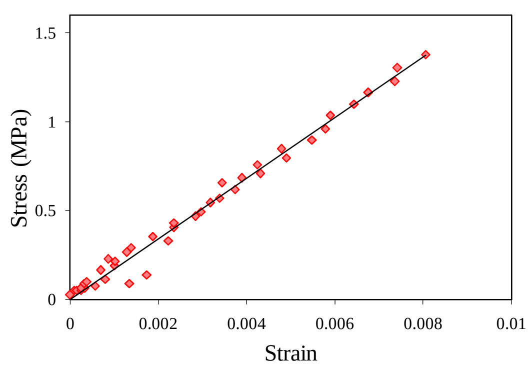

Fig. 5: Example of the experimental stress-strain curve. The extracted Young's modulus is E = 170.6 GPa.

Table 1: Measured values of E and σ_f.

Specimen	E (GPa)	σ_f (GPa)
1	176.2	---
2	170.6	1.38
3	166.3	0.85
4	185.3	2.41
5	161.0	0.95
Average	171.9	1.40