A Method for Tensile Testing of Delicate Polymeric Specimens

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Abstract

New approaches for measuring the mechanical properties of small polymeric samples made by micro-stereo-lithography are described and investigated. Characterization of a test rig shows that sharing load between sample and a fairly stiff flexure mechanism provides robust protection with only a readily tolerable reduction in sensitivity. A specimen design having large clamping regions and support bars released by cutting successfully protects the sub-millimetre samples during manufacture and handling.

1 Introduction: the technical challenge

Techniques such as micro-stereo-lithography (MSL) are opening up practical potential for (small-batch) direct digital manufacture of specialized polymer-based micro-mechanical systems (MEMS). However, there is as yet rarely sufficient knowledge for design purposes of the mechanical properties of relevant materials. Because of surface:volume-ratio effects, the bulk properties characterized from large specimens in conventional machines (even if known) cannot be fully trusted [1].

Here, therefore, we investigate special forms of instrument and compatible sample designs for small scale tensile measurement. Tensile testing is preferred to non-axial approaches, e.g., bending, for its straightforward principle and, more significantly, the simplicity of data conversion [2]. The strategy is to use stiffly constrained mounting and loading surfaces and a flexure guideway in combination with high-sensitivity capacitive micrometry, so protecting against parasitic motions during the test.

2 System design

As illustrated in figure 1(a), the experimental test-rig is machined monolithically from an aluminium plate to provide a reference base and a notch-hinge flexure that acts as both the active mount and a linear guide for the samples. The flexure displacement, taken as a measure of sample extension, is monitored by a capacitive gauge comprising a pair of thin gold electrodes (8×5 mm^2) deposited on glass pads and glued between the stage and base. Data is recorded to a PC *via* a Queensgate Instruments NS2000S conditioner and National Instruments BNC-2010 interface. The stage is force-actuated, either electromagnetically or by dead-weights.

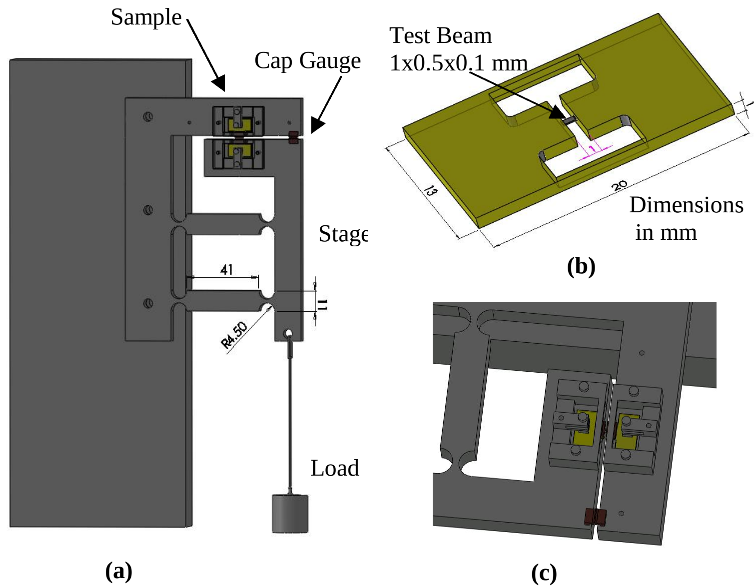

Figure 1: Schematics of (a) test-rig layout, (b) specimen and (c) specimen grip.

In operation, the flexure and specimen act as springs in parallel. This increases stability and protects the sample from transient load changes at the cost of slightly increased uncertainty in the force actually applied to the sample. A typically sized polymer sample having an elastic modulus of a few GPa will have an axial stiffness in the order of 100 kN m^{-1}, so the notches are designed to give the flexure a stiffness of around 200 kN m^{-1}. A typical maximum sample load of 1 N then requires a drive actuation of ~3 N. Sample extensions will rarely exceed 10-20 μm, so having flexure 'legs' about 40 mm long ensures that lateral parasitic motions are never more than a few nm. The parallel-motion stage allows a ~30 mm Abbe offset to be tolerated, so keeping the extension gauge conveniently clear of the sample mounting area.

The trial MSL specimens, Fig. 1(b), are fabricated using a multi-component acrylate. The test-section (typically 1×0.5×0.1 mm^3), is too delicate to handle easily. It is therefore made integrally within a larger carrier. The bulk of the specimen provides bases for hard, frictional, clamping. To prevent the delicate sample being pre-stressed or damaged during mounting and alignment, it is fabricated integrally with protection structures on both sides: they are gently cut through once it is properly positioned.

Sample mounting is critical to measuring small extensions because direct gauging is not possible on such small active specimens. The flanged specimen design is intended to facilitate pulling against pins on the test-rig in a near-kinematic arrangement. However, initial tests led to a preference for friction gripping by hard-clamping to the flats of the test rig using screws on slightly flexible brackets, Fig. 1(c). The slight disadvantage of this over-constrained approach is that sample surfaces need to be well prepared to align cleanly to the test-rig mounting flats.

3 Characterization, verification and performance

The flexure mechanism (without a specimen) and its main capacitive gauge were calibrated with a Keyence optical confocal sensor LT9010 and a high resolution Renishaw optical interferometer. The flexure stiffness was 230 kN m^{-1}, assessed using dead-weight loads. The gauge sensitivity is 10.8 mV μm^{-1}, with non-linearity less than 0.3% over 35 μm. No undesirable dynamic effects were detected. Gauge noise was about 10 mV at 50 Hz bandwidth, corresponding to a useful dynamic resolution of about 1 μm. The instrument is normally used quasi-statically, where additional filtering (averaging) will readily allow resolution to <0.1 μm

As a crucial factor in micro-tensile tests, the hard screw clamping condition was investigated in detail. A pair of small, extra-light gold capacitor electrodes (5×1 mm^2) were made and glued between the low-stressed inner surfaces of a specimen. This gauge detects actual motion of the sample beyond the clamps, albeit with sensitivity less than the main gauge at ~1.3 mV/μm. Figure 2 shows this gauge output plotted against actual stage motion. Although the small gauge suffers some thermal drift, repeat cycles show smooth and consistent slopes, confirming no sudden slipping, and no pattern consistent with steady creep at the clamps, even for relatively heavy loads over 30 μm movements. Repeated clamping is also consistent: even with possible variation in tightness of the screws, the divergence across all tests is within 93% of the mean. A 10 N drive force caused 27 μm extension; so for the calibrated stage stiffness, there is a 3.8 N load across the acrylic sample, indicating a Young's modulus of ~2.8 GPa based on the nominal specimen dimensions ($1 \times 0.5 \times 0.1\ mm^3$). These tests confirm that clamping the sample and then cutting its supports leaves the active section properly positioned for testing within the normal instrument settings.

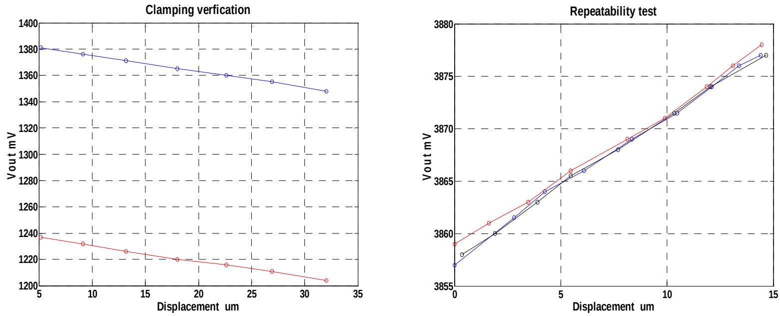

Figure 2: Clamping quality in two set-ups (left) and three repeat scans (right)

4 Conclusions

The new test-rig offers a practical solution to the unusual challenges of the current measurements. Dividing the applied load between the delicate sample and a guide flexure provides robustness to protect the sample from shocks. The flexure allows an operationally useful Abbe offset in the extension measurement: attaching small capacitors, as used here for calibration, is impractically slow and tedious for routine use. The specimen design works well with friction clamping followed by cutting of the support structures. There is no evidence of slippage at the clamps sufficient to significantly degrade extension measurements. Nevertheless, over-constraint of the sample is not ideal and further refinements will be explored in parallel with using the instrument to investigate new MSL materials at the sub-millimetre scale.

References:

[1] Chen, F-K. and Tsai, J-W. (2006) A study of size effect in micro-forming with micro-hardness tests. *J. Materials Processing Technology* **177**, 146-149.

[2] Johnson, G.C., Jones, P.T., and Howe, R.T. (1999) Materials Characterization for MEMS: A Comparison of Uniaxial and Bending Tests, *Proc. SPIE* **3874**, 94–101