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Title: Measurement of Compressive Stress–Strain Response at Small-Strains

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Author Questionnaire

1. Microscopy: Does your protocol require the use of a dissecting or stereomicroscope for performing a complex dissection, microinjection technique, or something similar? **Yes, all done**

2. Software: Does the part of your protocol being filmed include step-by-step descriptions of software usage? **No**

3. Filming location: Will the filming need to take place in multiple locations? **No**

4. Testimonials (optional): Would you be open to filming two short testimonial statements **live during your JoVE shoot**? These will **not appear in your JoVE video** but may be used in JoVE's promotional materials. **No**

Current Protocol Length
Number of Steps: 03
Number of Shots: 06

Introduction

Videographer: Obtain headshots for all authors available at the filming location.

Videographer's Note: Some shots were slated incorrectly. Use the following files:
FX6_0486.MXF is 1.3
FX6_0487.MXF is 1.4
FX6_0489.MXF is 1.3
FX6_0490.MXF - is 1.4

INTRODUCTION:

~~What technologies are currently used to advance research in your field?~~

1.1. **Jaehyeong Kim:** Technologies currently used to advance research include MEMS-based testers, nanoindentation, and custom micro-scale compression systems for precise small-strain material characterization.

1.1.1. INTERVIEW: Named Talent says the statement above in an interview-style shot, looking slightly off-camera.

~~What are the current experimental challenges?~~

1.2. **Hyerin Ahn:** Current experimental challenges include achieving accurate force–displacement measurements, reliable calibration, and minimizing noise in small-strain, low-force micro-scale experiments.

1.2.1. INTERVIEW: Named Talent says the statement above in an interview-style shot, looking slightly off-camera.

CONCLUSION:

~~What research gap are you addressing with your protocol?~~

1.3. **Jaehyeong Kim:** Our protocol addresses the lack of low-cost, repeatable compression testing methods in the small-strain, low-force region.

1.3.1. INTERVIEW: Named Talent says the statement above in an interview-style shot, looking slightly off-camera.

~~How will your findings advance research in your field?~~

1.4. **Jaehyeong Kim:** Our findings provide a validated, accessible platform for small-strain testing, accelerating material evaluation and device optimization in MEMS and microneedles.

1.4.1. INTERVIEW: Named Talent says the statement above in an interview-style shot, looking slightly off-camera.

~~What questions will future research focus on?~~

1.5. **Sangjun Pyo:** Future research will focus on extending force ranges, testing diverse polymers, and quantifying how tension–compression asymmetry affects modulus estimates.

1.5.1. INTERVIEW: Named Talent says the statement above in an interview-style shot, looking slightly off-camera.

Videographer: Obtain headshots for all authors available at the filming location.

Protocol

2. Compression Testing of a PDMS Sample Using a Motorized Z-Stage and Force Sensor

Demonstrator: Jaehyeong Kim

2.1. To begin, place the PDMS *(P-D-M-S)* sample on the force sensor within the compression test setup **[1]**. Align the moving part perpendicular to the force sensor and center it over the sample to ensure a normal compressive load is applied **[2]**.

2.1.1. WIDE: Talent placing the PDMS sample onto the force sensor in the compression setup.

2.1.2. Talent adjusting the position of the moving part so that it is vertically aligned and centered over the PDMS sample.

2.2. Set the drive speed to the previously validated value using the controller interface **[1]**. Drive the moving part axially downward along the z-axis using the motor controller to apply a compressive load to the sample **[2]**.

2.2.1. Talent setting the drive speed.

2.2.2. Talent operating the motor controller to move the stage downward toward the sample.

2.3. Measure the compressive force transmitted to the sample in real time using the force sensor mounted underneath **[1]**. Observe and record the deformation of the sample during compression using a digital microscope **[2]**.

2.3.1. Close-up of the force sensor as it measures the applied load.

2.3.2. SCOPE: Scope.mp4 00:00-end
NOTE: I suggest speeding up the video because the compression is happening at a very slow rate. It might look like nothing is happening to the block if video is played in real-time.

Results

3. Results

3.1. The error rate between the MS *(M-S)* and MTS*(M-T-S)* force measurements was within 2%, confirming the accuracy and reliability of the MS **[1]**.

3.1.1. LAB MEDIA: Figure 5. *Video editor: Highlight the overlapping red line labeled "Load cell"*

3.2. The displacement errors of the linear actuator at drive speeds of 0.5 micrometer per second was minus 0.1%, **[1]**, 1 micrometer per second was plus 0.1% **[2]**, and 10 micrometers per second was plus 0.04% **[3]**.

3.2.1. LAB MEDIA: Figure 6. *Video editor: Highlight the purple circle and the blue line corresponding to 0.5 [µm/s]*

3.2.2. LAB MEDIA: Figure 6. *Video editor: Highlight the orange circle and the green line corresponding to 1.0 [µm/s]*

3.2.3. LAB MEDIA: Figure 6. *Video editor: Highlight the black circle and the red line corresponding to 10.0 [µm/s]*

3.3. The stress–strain responses of the scaled-down samples measured using the MS and MTS differed by less than 2%, supporting the reliability of the MS **[1]**.

3.3.1. LAB MEDIA: Figure 7. *Video editor: Highlight the red line labeled "MTS"*

Pronunciation Guide:

- **Compressive**
Pronunciation link: https://www.merriam-webster.com/dictionary/compressive
IPA: /kəmˈprɛsɪv/
Phonetic Spelling: kuhm·preh·siv
- **Stress–Strain**
Pronunciation link: https://www.merriam-webster.com/dictionary/stress-strain
IPA: /ˈstrɛs ˈstreɪn/
Phonetic Spelling: stres·strayn
- **MEMS**
Pronunciation link: https://www.merriam-webster.com/dictionary/MEMS
IPA: /mɛmz/
Phonetic Spelling: memz
- **Nanoindentation**
Pronunciation link: https://www.merriam-webster.com/dictionary/nanoindentation
IPA: /ˌnænoʊˌɪndɛnˈteɪʃən/
Phonetic Spelling: na·noh·in·den·tay·shuhn
- **Micro-scale**
Pronunciation link: https://www.merriam-webster.com/dictionary/microscale
IPA: /ˈmaɪkroʊˌskeɪl/
Phonetic Spelling: my·kroh·skayl
- **Calibration**
Pronunciation link: https://www.merriam-webster.com/dictionary/calibration
IPA: /ˌkælɪˈbreɪʃən/
Phonetic Spelling: ka·luh·bray·shuhn
- **Microscopy**
Pronunciation link: https://www.merriam-webster.com/dictionary/microscopy
IPA: /maɪˈkrɑːskəpi/
Phonetic Spelling: my·krah·skuh·pee
- **Stereomicroscope**
Pronunciation link: https://www.merriam-webster.com/dictionary/stereomicroscope
IPA: /ˌstɛrioʊˈmaɪkrəˌskoʊp/
Phonetic Spelling: stair·ee·oh·my·kruh·skohp
- **Microinjection**
Pronunciation link: https://www.merriam-webster.com/dictionary/microinjection
IPA: /ˌmaɪkroʊɪnˈdʒɛkʃən/
Phonetic Spelling: my·kroh·in·jek·shuhn
- **Biomedical**
Pronunciation link: https://www.merriam-webster.com/dictionary/biomedical
IPA: /ˌbaɪoʊˈmɛdɪkəl/
Phonetic Spelling: by·oh·meh·di·kuhl

- **PDMS**
Pronunciation link: https://www.merriam-webster.com/dictionary/PDMS
IPA: /ˌpiː diː ɛm ˈɛs/
Phonetic Spelling: pee·dee·em·ess
- **Motorized**
Pronunciation link: https://www.merriam-webster.com/dictionary/motorized
IPA: /ˈmoʊtərˌaɪzd/
Phonetic Spelling: moh·ter·yzd
- **Axially**
Pronunciation link: https://www.merriam-webster.com/dictionary/axially
IPA: /ˈækʃəli/
Phonetic Spelling: ak·shuh·lee
- **Z-axis**
Pronunciation link: https://www.merriam-webster.com/dictionary/z-axis
IPA: /ˈziː ˈæksɪs/
Phonetic Spelling: zee·ak·suhs
- **Micrometer**
Pronunciation link: https://www.merriam-webster.com/dictionary/micrometer
IPA: /maɪˈkrɑːmɪtər/
Phonetic Spelling: my·krah·muh·ter
- **Actuator**
Pronunciation link: https://www.merriam-webster.com/dictionary/actuator
IPA: /ˈæktʃuˌeɪtər/
Phonetic Spelling: ak·choo·ay·ter
- **Asymmetry**
Pronunciation link: https://www.merriam-webster.com/dictionary/asymmetry
IPA: /ˌeɪˈsɪmətri/
Phonetic Spelling: ay·si·muh·tree
- **Modulus**
Pronunciation link: https://www.merriam-webster.com/dictionary/modulus
IPA: /ˈmɑːdʒələs/
Phonetic Spelling: mah·juh·luhs
- **Polymers**
Pronunciation link: https://www.merriam-webster.com/dictionary/polymer
IPA: /ˈpɑːlɪmər/
Phonetic Spelling: pah·luh·mer
- **Microneedles**
Pronunciation link: https://www.merriam-webster.com/dictionary/microneedle
IPA: /ˈmaɪkroʊˌniːdəl/
Phonetic Spelling: my·kroh·nee·duhl