Operation of the Instron Model 3382 Universal Testing Machine

1 Introduction

The mechanical properties of metallic materials stem from their elemental composition, the manufacturing processes employed in forming them and post-production exposure to load and environment. Mechanical property measurement can aid in the determination of a material's alloy class, heat treatment, degradation (during service or post-service exposure) and conformance to material specifications.

The Instron Model 3382 UniversalTesting Machine can impose tensile, compressive, shear or bending stresses depending on the test fixture configuration and samples used. These types of mechanical tests can be performed under various atmospheric and temperature conditions.

2 Scope

This document applies to personnel using the associated instrument(s)/equipment in the following disciplines/categories of testing: general physical analysis in support of metallurgy examinations. Mechanical testing and the response of metals to such tests are the subjects of several college-level courses within typical materials science/engineering curricula. Performance and interpretation of meaningful mechanical testing requires a well-trained, experienced operator. It is essential that an operator has attended such course(s) or has equivalent experience prior to attempting to operate the uniaxial load frame. The following procedure outlines only the basic process for performing uniaxial load (tension, compression, bending or shear) tests using the Instron Universal Testing Machine. Published ASTM standards provide guidelines for a variety of test configurations.

3 Principle

The mechanical test system is designed to apply, read and record a calibrated load along a central load axis. The type of stress imparted to a specimen depends upon the configuration of components (load cell, test fixtures, and specimen) along this load axis, called the load train. The validity and usefulness of the data generated will be determined by the alignment of this load train, so effective design is critical. An electrically powered screw mechanism drives the crosshead during testing. Test speeds are controlled to isolate the effect of strain rate, which can be substantial for some materials. Deformation of the test specimen during and/or after the test can be monitored and recorded.

a. Tension: The load train is configured to apply a tensile force, usually directly pulling on the ends of a test specimen with a reduced cross-sectional area referred to as a gage section. Force-extension data is monitored using an extensometer, allowing generation of a stress-strain curve and determination of the modulus of elasticity (E), Poisson’s ratio（ν）, yield strength (YS), tensile strength (TS), elongation, reduction in area (RA) and the strain hardening characteristics.[1]

b. Compression: The load train is configured to apply a compressive force, usually by directly pushing on the ends of a right circular cylindrical test specimen with a length-to-diameter (l/d) ratio of less than 2.0. Force-extension data is monitored using an extensometer, allowing generation of a stress-strain curve and determination of the bulk elastic modulus, yield strength, and strain hardening characteristics.[1]

c. Bending: The load train is configured to apply a bending force, usually to a flat, rectangular test specimen or beam. Bend ductility tests determine the smallest radius around which a specimen can be bent without cracks being observed on the tensile surface. Bending strength tests determine the modulus of elasticity in bending and the bending strength. For both of these types of testing, a wide variety of test fixtures are available.

d. Shear: The load train is configured to apply a shear force to a test specimen. For example, tests are often performed on fasteners, oriented to the load as they would be in service, to measure their shear strength. Translational shear tests are performed on sheet materials to characterize shear anisotropy. Torsional (rotational) shear tests are not covered by this procedure. For all types of shear tests, a wide variety of test fixtures are available.

e. A variety of other mechanical properties, such as stress relaxation and spring constant, can also be determined using the universal testing machine. Guidelines for performing such tests are available from standards-producing organizations like ASTM International.

4 Specimens

Specimens must be designed to mount into the test frame such that the appropriate stress mode is conveyed to the desired portion of the specimen. Entire components may be tested if the load train configuration can accommodate the component alignment. ASTM provides test specimen size and shape specifications for many mechanical tests (see section 16 References).

The orientation and location of specimens taken from parent materials must be recorded, particularly for anisotropic materials. Proper orientation of the stresses with respect to the principal axes of microstructural orientation is an important test consideration.

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[1] In situations where breaking stress (or load) is the only desired output, the crosshead displacement can be substituted for the strain signal.

5 Equipment/Materials/Reagents

a. Instron Model 3382 Universal Testing Machine

b. Computer with Instron Bluehill 2 software (version 2.0 or later)

c. Externally calibrated load cell

d. Extensometer (optional)

e. Test fixtures (grips) appropriate for the test specimen(s)

f. Standard weights with calibration certificates from supplier: 1, 2, 5, 10, 20 and 50 lbs and 2, 5, 10 and 20 kg .

g. Dimensional measuring device(s) such as a micrometer, caliper, traveling microscope, etc.

h. Environmental chamber (oven, cooling jacket, etc.) (optional)

6 Standards and Controls

Prior to use in casework, the individual load cell to be used will be verified using supplier-certified calibration weights, and the strain gage or crosshead displacement will be verified using a calibrated linear measurement device such as a micrometer, caliper or traveling microscope according to the procedures outlined in section 9 Procedure.

7 Calibration and Verification

The instrument components (load cells and strain gages along with crosshead displacement and speed) are calibrated annually by a certified and licensed service provider that meets the FBI Laboratory Operations Manual (LOM) requirements. The user will verify the performance of the load cell and strain or displacement measuring device each day that the configuration is used to perform tests. The performance check procedures can be found in section 9 Procedure.

8 Sampling

Whole components, or sections from a component, can be affixed into the load train for mechanical testing. These sections are accepted to represent the mechanical properties of that component. The orientation and location of specimens taken from the parent component must be recorded, particularly for anisotropic materials. Proper orientation of the stresses with respect to the principal axes of microstructural orientation is an important test consideration. Depending on the test specimen size and configuration, one or more test specimens may be machined from a single component.

Typically, all submitted components, or sections from each component, are tested. However, if large numbers of physically indistinguishable samples are received for mechanical property measurement, a sampling plan may be employed for testing. If the sampling plan will be used to make an inference about the population, then the plan will be based on a statistically valid approach. Any sampling plan and corresponding procedure used will be recorded in the case notes.

9 Procedure

9.1 Load Cell Performance Check

a. Select, install and connect the appropriate load cell for the type of test and material being tested. The maximum capacity of the cell must exceed the breaking strength of the test specimen. Attach a fixture to accommodate hanging weights.

b. Apply power to both the load frame and computer. Allow the system to warm up for 15 minutes to stabilize the load cell before verifying it.

c. In the software, zero the load channel. (Press key 2 “Balance Load” or, under “Load Cell Setup Dialog”, “Load” tab, click “Balance”.)

d. Verify the load cell by hanging standard weights from it, it, using at least 1% of the load cell capacity. When applying the weights, never exceed the maximum capacity of the load cell.

e. Assure that the value displayed by the load channel matches the applied load within the accuracy limit required for the test. If it does not, the load cell and output channel must be serviced and recalibrated by a certified and licensed service provider that meets the LOM requirements.

f. Record the results of the performance check in the instrument log. Retain the data in the examiner’s case notes.

9.2 Strain Extensometer Performance Check (optional)

a. Select the appropriate extensometer for the specimen geometry and expected elongation range to be tested. Connect it to the test frame and ensure the correct scale is chosen in the software.

b. Mount the extensometer on the verification device (e.g., calibrated micrometer) in the same manner as it is normally attached to the test specimen. Position the extensometer at approximately the neutral position (not compressed or extended). View and zero the strain channel in the software.

c. Dial the full range of the extensometer extension on the micrometer. Adjust the scale factor in the software to assure the electronic output on the strain channel matches this extension.

d. Verify the extensometer’s linearity by returning it to zero in appropriate increments. Use at least ten increments which span the entire extensometer range. Record the micrometer spacing versus extensometer output.

e. Repeat for compression, if the extensometer is so rated.

f. Perform a linear regression of the data. The linearity required will depend on the test to be conducted. If the linearity over the entire extensometer range is insufficient, verify similarly over a smaller range and limit subsequent tests to this limited range. Various classes of extensometers are required to meet different levels of accuracy so consult the appropriate ASTM test method. For yield strength determination, a Class II extensometer should be chosen so the fixed error does not exceed 0.0002 in/in, and the variable error does not exceed 0.5% of strain, over the entire range used for subsequent testing.

g. If the extensometer cannot be adjusted to achieve linearity over the required test interval, the extensometer and output channel must be serviced and recalibrated by a certified and licensed service provider that meets the LOM requirements.

h. Record the performance check results in the instrument log. Retain the data and regression equation in the case notes.

9.3 Crosshead Displacement Performance Check (optional)

a. Mount a traveling microscope onto the load frame base and mark a point on the crosshead for observation.

b. Open the Setup Dialog box and zero the displacement channel.

c. Move the crosshead to the extreme range expected to be encountered during the test and measure the interval with the traveling microscope.

d. Assure that the value displayed by the displacement channel matches the interval measured by the traveling microscope within the accuracy limit required for the test.

e. Verify linearity by returning to zero in appropriate increments (at least ten increments over the entire interval). Record the distance traveled by the microscope versus the displacement transducer output.

f. Plot distance vs. output. Calculate the best linear fit to the data using a regression analysis. The degree of linearity required will depend upon the test to be conducted. If the data linearity is insufficient, the transducer must be serviced and recalibrated by a certified and licensed service provider that meets the LOM requirements.

g. Record the performance check results the examiner’s case notes.

9.4 Sample Testing

The guidelines below apply for methods that have been pre-programmed in the software to perform an appropriate test sequence, calculate desired values and output data in a specific format. Newly created methods must be validated in accordance with the LOM.

a. Select and install the appropriate components and fixtures for the type of test and material being tested, including an environmental chamber if required, and assure the measuring components are verified, as in 9.1 through 9.3 in section 9 Procedure.

b. Adjust the crosshead position to achieve appropriate grip separation for the test being performed using the crosshead controller.

c. Adjust crosshead stop and opposite limit stops to the positions required by the test by sliding them up or down.

d. Select the appropriate display units.

e. Open (or create) the appropriate method for the test to be performed. Typically a prompted test method will be used.

f. Measure the required dimensions of the specimen and enter them into the appropriate software data fields.

g. Mount the specimen in the grips.

h. (Optional) Attach and align the extensometer on the specimen.

i. Zero the transducers using the software. Click on the appropriate instrument set-up dialog box and select “Balance”, “Zero” or “Reset”. Alternatively, click on key 1 “Reset Gauge Length” and key 2 “Balance Load” to zero the values prior to starting each new test run (each new specimen).

j. From the “Test” tab, click on "Start". The machine will now prompt the user for information, perform the test and display the test progress.

k. Observe the progression of the test. If using an extensometer, pause the test and remove the extensometer before displacement threatens to surpass its rated extension or compression range. Otherwise press stop when the specimen fractures or when the desired data has been acquired.

l. Remove the specimen from the grips; then return the crosshead to the starting position and repeat the test for the desired number of specimens.

m. Save the test data. Print a report of the test results and retain the report in the case notes.

10 Instrumental Conditions

a. The instrumental operating conditions are determined by the examiner in accordance with the desired test parameters.

b. Load cells and extensometers are to be used only within their rated capacities. Capacities are listed on certification sheets stored near the instrument.

c. Grips and fixtures must be rated for any environmental exposure conditions encountered during testing. (e.g., do not use a room temperature-rated strain gage extensometer for elevated temperature tests.)

11 Decision Criteria

Load cells, extensometers, and displacement transducers will be considered within calibrated limits if the performance check results meet the requirements of the applicable ASTM specification(s) or the manufacturer-specified instrument accuracy.

The conclusions derived from this procedure are based on careful interpretation of all of the data gathered during testing. The applicability of the test results depends on the uniformity of the material response during testing, the material homogeneity, and how well the test specimens represent the component, among other factors.

In general, problems with a given test, such as the specimen slipping in the test fixtures, will be reflected in the stress-strain curves generated during data collection. The factors responsible for unexpected curve non-linearities or erratic curves will be investigated and the tests rerun if problems are found.

12 Calculations

a. For the evaluation of component design strength, mechanics-based design equations can often be used to predict the approximate behavior of materials under complex stresses from the measurements of mechanical behavior under uniaxial tension or compression. See section 16 References for a list of references that are appropriate for this purpose.

b. The mean value of a property, such as tensile strength, is calculated as: $\bar{x} = \frac{\sum_{i=1}^{n} x_i}{n}$, where $\sum_{i=1}^{n} x_i$ is the sum of the individual tensile strength measurements, n is the number of measurements and $\bar{x}$ is the mean tensile strength of the test specimens.

12.1 Quantitative Analysis

a. A variety of mechanical properties (such as E, YS, TS, and elongation) can be automatically calculated by the instrument software from the load and displacement data. These readings, and their associated measurement uncertainty, may be used to report a range or series of measurements.

b. To report averaged measurements, collect at least five values. Calculate and report the mean and expanded measurement uncertainty.

The mean value of a property, such as tensile strength, is calculated as: $\bar{x} = \frac{\sum_{i=1}^{n} x_i}{n}$, where $\sum_{i=1}^{n} x_i$ is the sum of the measurements, n is the number of measurements and $\bar{x}$ is the mean value of the property.

c. For the evaluation of component design strength, mechanics-based design equations can often be used to predict the approximate behavior of materials under complex stresses from the measurements of mechanical behavior under uniaxial tension or compression. See section 16 References for a list of references that are appropriate for this purpose.

12.2 Comparative Analysis

a. Where quantitative data from two specimens are being compared, a pooled, two-tailed Student-t test statistic of the sample means is typically used for the comparison. Two samples are deemed to be “indistinguishable” in the property under consideration if the two samples differ by less than the preselected critical t value ($t_{critical}$). The critical t value is typically chosen so that a value of $\alpha = 0.05$ can be achieved for the analysis and is determined by the degrees of freedom associated with the measurements. An $\alpha = 0.05$ means that there is a 5.0% chance of incorrectly rejecting a match between two samples when one actually exists.

To perform this test, the sample means and variances are determined as follows:

The mean value: $\bar{x}_a = \frac{\sum_{i=1}^{n_a} x_i}{n_a}$ where $\bar{x}_a$ is the average value of the measurement on sample "a", $\sum x_i$ is the sum of the individual measurements and n_a is the number of measurements made on that sample. The variance of the individual measurement values from sample "a" is given by:

$$s_a^2 = \frac{\sum_{i=1}^{n_a} (x_i - \bar{x})^2}{n_a - 1}$$

The mean and variance of the sample "b" data are calculated in an analogous manner.

The pooled sample variance is then calculated as: $s_p^2 = \frac{(n_a - 1)s_a^2 + (n_b - 1)s_b^2}{(n_a + n_b - 2)}$

A standard two-tailed statistical test of the two sample means is performed.

If $\left| \frac{(\bar{x}_a - \bar{x}_b)}{\left(\sqrt{s_p^2(\frac{1}{n_a} + \frac{1}{n_b})}\right)} \right| > t_{critical}$, the samples have a statistically significant difference. If not, the samples are deemed to be indistinguishable in the property being compared.

b. When multiple mechanical properties are being evaluated to compare two items, the critical t values for the Student-t test are typically chosen so that an overall (Bonferroni corrected) value of $\alpha = 0.05$ can be achieved for the combined analysis.

13 Measurement Uncertainty

The quantitative data from this procedure is sometimes used for comparative purposes. Expanded uncertainty should not be used for these inter-comparisons because it increases the probability two samples will appear to be analytically indistinguishable and therefore increases the likelihood of type II errors (false inclusion). In the event that it is necessary to calculate the expanded uncertainty of a measurement, it will be done in accordance with the *Chemistry Unit Procedures for Estimating Measurement Uncertainty*.

14 Limitations

Mechanical testing is, by its nature, destructive testing. Destructive tests on evidence should only be considered if absolutely necessary and must be pre-approved by the contributor. Application of this procedure is limited by the material availability, component geometry and numerous other factors specific to the situation under consideration.

15 Safety

Standard safety precautions, such as wearing protective gloves, should be observed when handling evidentiary materials. Electrical or mechanical hazards may require special precautions.

This instrument SOP has the following specific safety requirements:

- Safety glasses must be worn during load application to prevent possible eye injury.
- High loads on test pieces with large cross-sections may generate projectiles when they fracture. If such loading conditions are anticipated, install a shield between the test piece and the operator.
- Ties and other loose clothing should not be worn when operating this instrument, and long hair should be tied back. If entanglement occurs, a red “EMERGENCY STOP” button can be used to interrupt the instrument power and halt the screw drive motion.
- When testing at elevated temperatures, wear appropriate heat resistant protective gloves and clothing.

16 References

Bluehill 2 – Extended System and Software Introduction and Test Method Development Manual, Application Guide, Manual M18-14443-EN Revision A, Instron Corporation 2004

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Rev. #	Issue Date:	History:
2	07/29/2016	Reinstated with editorial revisions in accordance with new formatting guidelines. Added Section 3e covering component property testing. Removed reference to specific calculation tools in Sections 5i and 7.2e. Clarified extensometer calibration in Sections 7.2 and 7.2a. Corrected and simplified equation in Section 12b. Changed Section 13 to reflect updated measurement uncertainty requirements.
3	12/21/2018	Corrected software title in section 1. Renumbered Metallurgy SOP Manual documents. This document was formerly Metal 16 and is now designated Metal 703. Added personnel to section 2. Made minor editorial corrections throughout document. Added common acronyms and ASTM references in section 3. Clarified where to find sample size specifications in section 4. Generalized section 7 and moved specific verification (performance check) procedures to section 9. Added Sampling section 8.. Moved ASTM test recommendation from section 9 to section 2. Reworded sections 11 and 15. Added additional references to section 16.

Redacted - Signatures on File

Approval

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