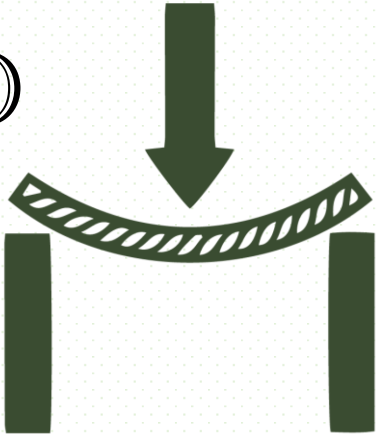
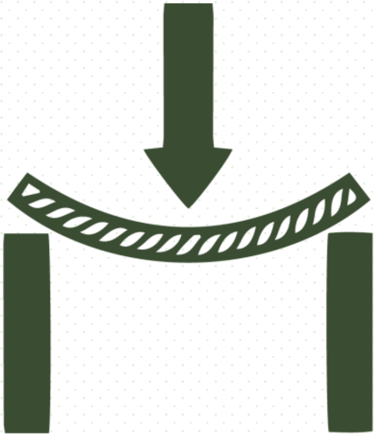
Department of Materials Science and Engineering

Mechanical Properties and Materials Forming Laboratory



Analytical and non-analytical instruments

ANALYTICAL INSTRUMENTS

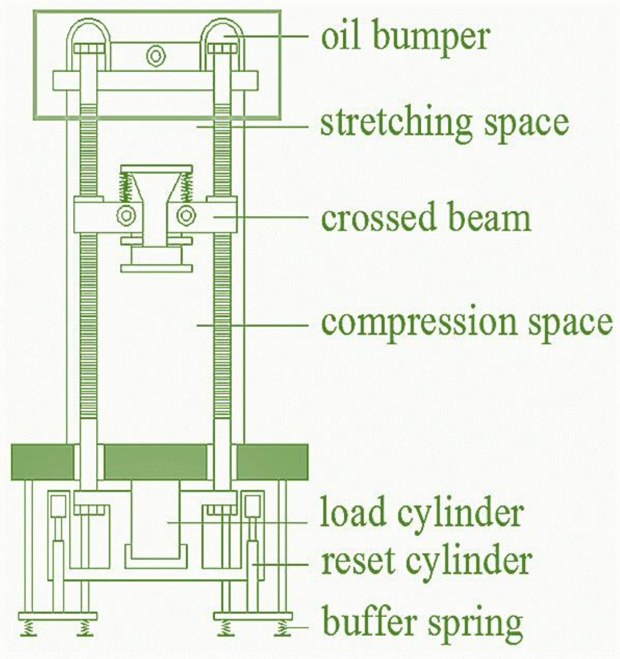


Device: Screw press

Introduction

A screw press is a type of machine press in which the ram is driven up and down by a screw. It works by using a coarse screw to convert the rotation of motor into a small downward movement of greater force. By this machine, it is possible to perform any procedure which requires high levels of compressive force with high accuracy of recording data, including but not limited to:

- Compression test
- Plain strain compression test
- Double compression test
- Powder compaction
- Extrusion, Forging, Blanking, …
- Hot compression molding



Schematic figure of a screw press

Device: Screw press

Manufacturer: *TOKYO TESTING MACHINE*

This lab is equipped with a screw press machine, with the following specifications.

Technical specifications

Max force	**20 tons**
Ram speed	**0.05-7 mm/s**

*** Computer controlled machine**

*** Controlling the load, ram speed, ram displacement, and strain rate**

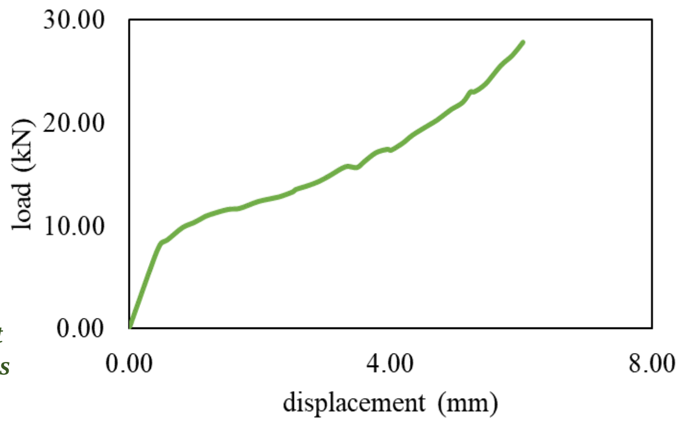
*** Load and displacement stopping criteria**

*** Real-time measurement and plotting of the force and displacement**

Device: Screw press

Manufacturer: *TOKYO TESTING MACHINE*

The recorded data could be saved as an MS EXCELL file in terms of load (kN) vs. displacement (mm).

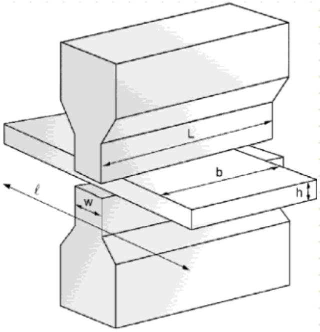


The resulting load-displacement curve recorded by the screw press

By using this device and the available die sets, it is possible to perform two other mechanical test: **plane strain compression test** and **double compression test**.

Introduction to plane strain compression test

Although the mechanical behavior of materials is assumed to be path-independent in many applications, that is, for example, the effective stress vs. effective strain curves obtained from tensile test and torsion test are expected to coincide, the fact is that it is not the case!



Schematic presentation of plane strain compression test

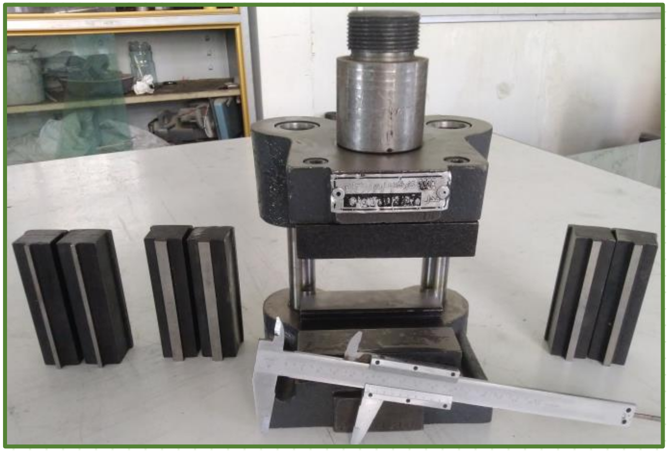
Introduction to plane strain compression test

Experiments and theories show that in certain circumstances the straining path may also have an affection. In this regard, it is highly of favor to characterize the mechanical behavior of a material by means of the tests which have almost the same strain path as the straining path of the material in its final application. Therefore, characterizing the mechanical behavior of material by plane strain compression test, may result in the valuable data to be further used to analyze industrial processes such as flat rolling, slab extrusion, and slab drawing.

Setup: plane strain compression test

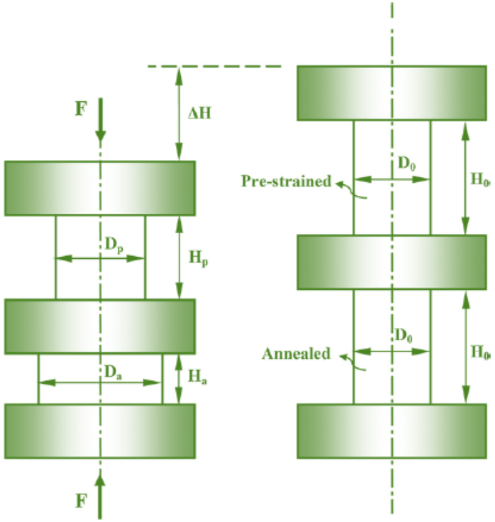
Manufacturer: *ARAS GHOOCHAN*

This lab is equipped with a plain strain compression test setup as shown here.



Introduction to double compression test

Double compression test is a newly developed technique which based on simultaneous compression of two specimens having the same composition and geometrical dimensions, one in the annealed condition, while the other undergone a predetermined amount of pre-strain. Taking the material obeys the Hollomon hardening law, the following relationship could be established:



$$n = \frac{\bar{\varepsilon}_a - \bar{\varepsilon}_p}{ln\left(\frac{\bar{\varepsilon}_a + \bar{\varepsilon}_p}{\bar{\varepsilon}_0}\right)}$$

Where n is the work-hardening exponent of material, $\bar{\varepsilon}_0$ is the amount of pre-strain, and $\bar{\varepsilon}_a$ and $\bar{\varepsilon}_p$ are the magnitude of effective strain in the annealed and pre-strained specimens which could be determined by geometrical measurements. This method could be employed in two valuable manners:

- If the magnitude of the pre-strain is known, by this method it is possible to calculate the work-hardening exponent without the requirement of the any load recording device.

Introduction to double compression test

- If the magnitude of the work-hardening exponent is known, by this method it is possible to measure the amount of pre-strain. That is of crucial importance in the situations where it is required to verify the amount of plastic strain imposed on the specimen during a special process, such as SPD processed materials.

Setup: Double compression test

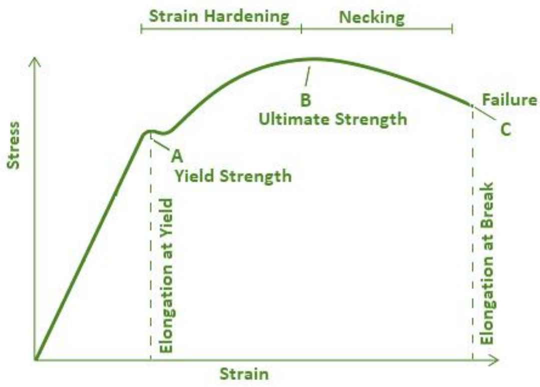
Manufacturer: *MANUFACTURED IN-HOUSE*

This lab is equipped with a die set to perform double compression test as shown.

Device: Universal testing machine

Introduction

It is not far from reality to state that tensile test is the most standardized mechanical behavior characterization test procedure which gives wide variety of information about the material being tested. This includes, yield strength, ultimate tensile strength, resilience, toughness, strain hardening exponent, coefficient of strength, and whether the material could be considered as ductile or brittle. This lab. is equipped with two universal tensile test machines which will be presented. Along with the tensile test, these instruments may be used to perform compression test, three-point bending test, and shear punch test.



Typical engineering stress-strain curve

A variety of tensile test specimens

Device: Universal testing machine

Manufacturer: *INSTRON / STM150*

This lab is equipped with a universal testing machine, with the following specifications.

Technical specifications

Max force	**15 tons**
Ram speed	**0.05-400 mm/s**
Available load cells	0.1, 1, 5, and 15 tons

*** Computer controlled machine**

*** Three zone furnace with the maximum temperature of 800 °C**

*** Real-time measurement and plotting of the force and displacement**

*** Calculation of the engineering stress-strain curve by the device's software**

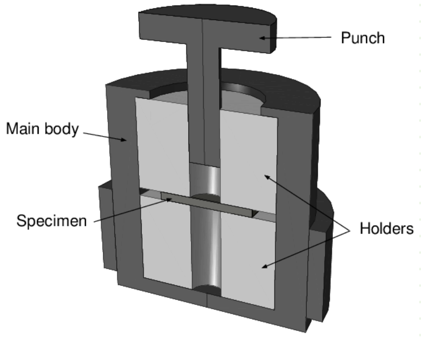
By using this device and the available die sets, it is possible to perform two other mechanical test: **three-point bending test** and **shear punch test**.

Introduction to shear punch test

This mechanical test is rather new compared to the other mechanical testing approaches where in this method, the ultimate shear strength of material would be examined. One of the key advantages of this test is that very limited amount of material is needed and the preparation of the specimen is rather simple compared to many mechanical tests.

This technique is most helpful when:

- It is not possible to prepare the samples with the required geometry for other mechanical tests
- Low amount of material is available
- The ultimate shear strength of material is of importance, for example the material is to be further subjected to blanking



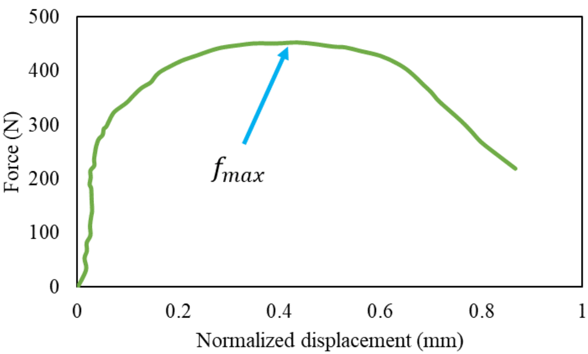
Schematic representation of shear punch test

Introduction to shear punch test

Typical load-displacement curve of shear punch test is shown below, denoting the maximum force as f_{max}, the ultimate shear strength (τ_u) could be obtained as follows:

$$\tau_u = \frac{f_{max}}{\pi D t}$$

Where D is the diameter of the punch and t is the thickness of the specimen.



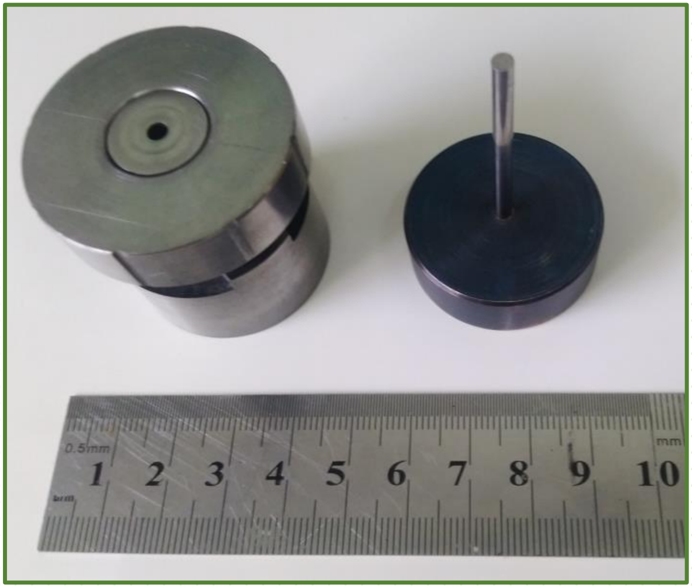
Typical shear punch test load-normalized displacement curve

Setup: Shear punch test

This lab is equipped with a die set to perform shear punch test as shown.

Technical specifications

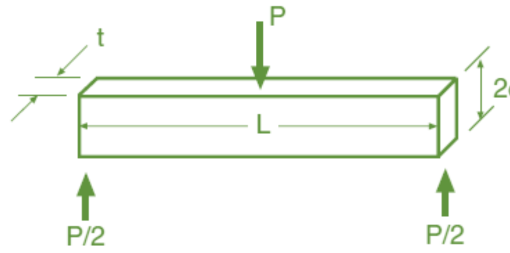
Punch diameter	**3 mm**
Max specimen thickness	**1 mm**



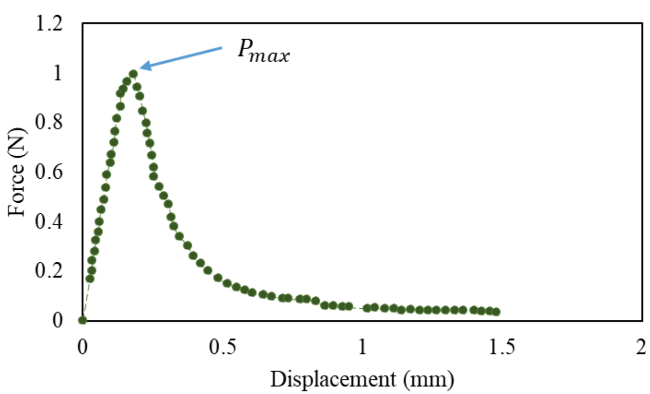
The available shear punch test die set

Introduction to three-point bending test

Bending test on bars of material are commonly used for flat metal spring material, and for concrete, natural stone, wood, plastics, glass, and ceramics. Bending tests, also called ***flexure tests***, are especially needed to evaluate tensile strengths of brittle materials, as such materials are difficult to test in simple uniaxial tension due to cracking in the grips. The specimens often have rectangular cross sections.



Schematic representation of three-point bending test



Typical force-displacement curve corresponding to three-point bending test

Typical load-displacement curve corresponding to three-point bending test is shown. Denoting maximum force as P_{max}, the fracture stress (σ_{fb}) of material could be obtained by the following relation:

$$\sigma_{fb} = \frac{3L}{8tc^2} P_{max}$$

Where L, t, and c are shown in the above schematic figure.

Setup: Three point bending test

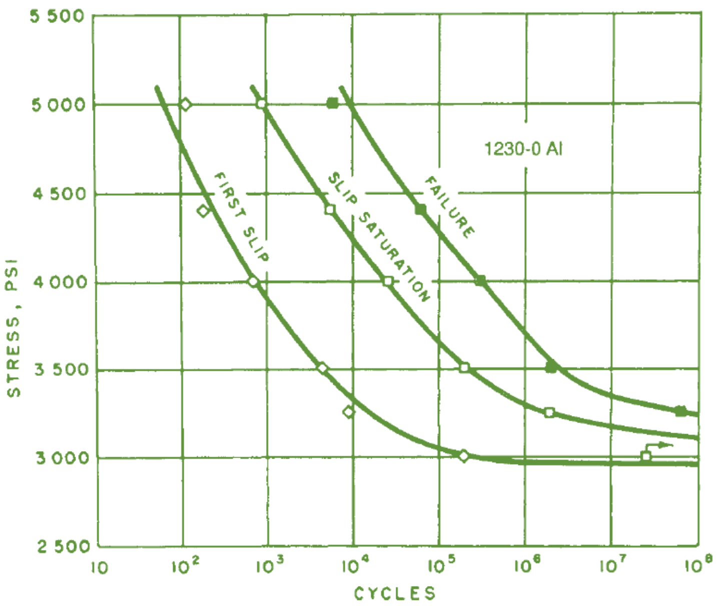
This lab is equipped with the following set up to perform three point bending test.

Available three-point bending test setup

Rotating – bending fatigue test

Introduction

Fatigue is the progressive damage of the material under cyclic loads which finally results in the failure of the component during service. Estimating the fatigue life of the material includes imposing cyclic loads on the specimen and counting the number of cycles the material can withstand before failure. By the rotating-bending method, a bending moment is imposed on the specimen, and rotation of the specimen results in the tensile-compressive stresses with zero mean stress to be imposed on each element of the specimen.



S-N curve achievable by fatigue test

After completing the test for several specimens tested under different loads, the curves shown above may be obtained for each material, known as S-N curves. These curves are of crucial importance for the design purposes of components subjected to cyclic loads.

Device: Rotating – bending fatigue test machine

Manufacturer: *MANUFACTURED IN HOUSE*

This lab is equipped with a rotating-bending fatigue test machine with the following specifications.

Technical specifications

Max rotation speed	3000 rpm
Automatic cycle counting limit	**9,999,999 cycles**

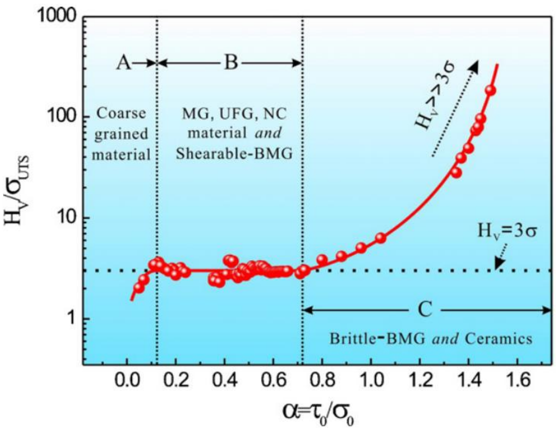
*** Setting stress level by hanging different weights**

*** Capable of assembling proper furnace to perform hot fatigue test**

Hardness test

Introduction

For engineering problems and design considerations, the yield strength and ultimate tensile strength of a material, determined by tensile test, are of much importance. On the other hand, hardness is defined as the material's resistance to the localized plastic deformation induced by an indenter. However, there is a good correlation between the hardness of a material and its yield strength and ultimate tensile strength as follows:



Correlation between hardness and UTS for different class of materials

$$\sigma_y \leq \frac{HN}{c} \leq \sigma_{UTS}$$

In this regard, it can be seen that by performing hardness test, a good estimation of the yield strength and ultimate tensile strength of material could be achieved. The benefit of performing the hardness test is that there is no need for specific specimen preparation as opposed to the tensile test or compression test, the short times required to complete the hardness test, and the fact that hardness test can be performed non-destructively on the final part in many situations.

Device: Hardness test machine

Manufacturer: *KOOPA*

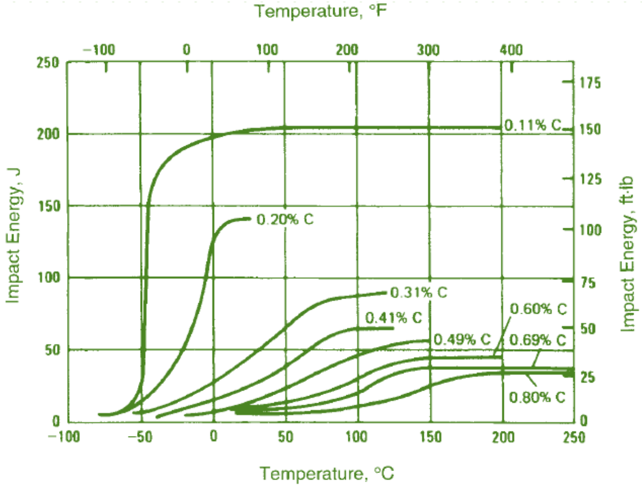
Technical specifications

Load range	**3 to 187.5 kgf**
Load accuracy	**0.01% of nominal force**
Indenter displacement	**4 mm**
Displacement accuracy	**± 0.1 micrometers**
Dwell time range	**1 – 99 sec**

Impact test

Introduction

The fracture behavior of a component has a vital role in safety considerations. Little absorbed energy, along with limited plastic deformation, is known as a brittle fracture, and considerable energy absorption, along with well-developed plastic deformation, is known as a ductile fracture. The amount of the absorbed impact energy can be a good measure to determine the nature of the fracture. This test consists of striking a notched specimen with a hammer on a pendulum arm



Effect of temperature on the absorbed impact energy of different steels

while the specimen is held securely at each end. The hammer strikes opposite the notch. The energy absorbed by the specimen is determined precisely by measuring the decrease in motion of the pendulum arm. The important factors that affect the toughness of a material include low temperatures, high strain rates (by impact or pressurization), and stress concentrators such as notches, cracks, and voids. Usually, the absorbed impact energy would be measured at several temperatures and the trend in the variation of the absorbed impact energy with the temperature is observed.

Device: Impact test machine

Manufacturer: *ZWICK*

This lab is equipped with an impact test machine with the following specifications.

Technical specifications

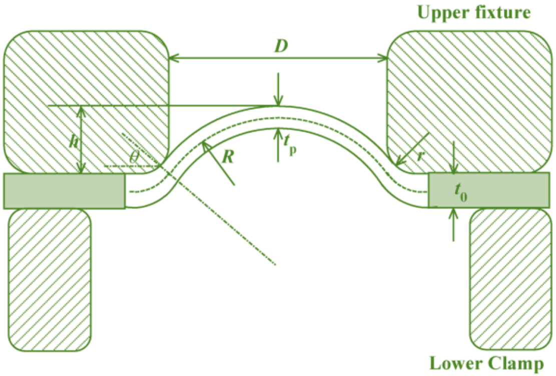
Hammer weight	18.75 kg
pendulum arm length	**815 mm**
Radial position of the hammer	**160° with respect to specimen**

Standard Charpy impact test specimen

Bulge test

Introduction

It is well-known that the formability of the sheet materials depends strongly on the state of straining. That is the limiting strains may vary as the material stretches in biaxial manner compared to the situation where material stretches under uniaxial state of stress. In this regard, it is desirable to perform bulge test during which a sheet specimen is placed over a circular hole, clamped, and bulged outward by oil pressure acting on one side. During the formal application of this test, a grid of circles would be printed on the surface of the specimen which transform into ellipses due to straining. After the test, the burst specimen is taken off and the major and minor diameters of these ellipses are measured by means of a camera or other proper devices.



Schematic representation of the bulge test

Bulge test

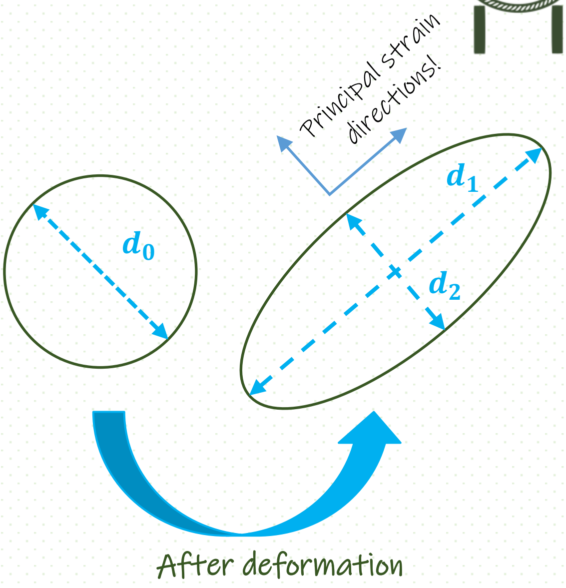
Introduction

The principal stresses at the onset of instability may be calculated by:

$$\varepsilon_1 = \ln(d_1/d_0)$$

$$\varepsilon_2 = \ln(d_2/d_0)$$

$$\varepsilon_3 = -\varepsilon_1 - \varepsilon_2$$



Where d_1 and d_2 are major and minor diameters of the corresponding ellipses, and d_0 is the diameter of the original circles. On the other hand, if the device allows the continues measurement and recording of the fluid pressure and height of the dome, the stress-strain behavior of the sheet material could be obtained by the following relations:

$$\bar{\sigma} = \frac{(a^2 + h^2)^3}{4ht_0a^4}P \qquad \bar{\varepsilon} = 2ln\left(1 + \frac{h^2}{a^2}\right)$$

Where a is the base radius of the die, h is the height of the dome, and t_0 is the initial thickness of the sheet. The equi-biaxial state of stress in this test increases the workability of the material, therefore, the stress-strain curve may be obtained up to higher strains compared to what is achievable in the tensile test.

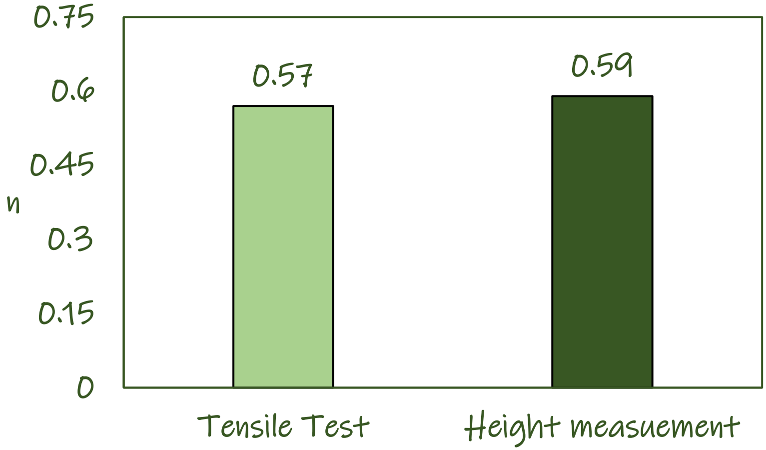
Bulge test

Introduction

Additionally, the final height of the dome (h^*) can be used to determine the work-hardening exponent of the specimen by the following relationship:

$$n = \left(\frac{5}{2} - \frac{a^2}{2h^{*2}}\right) ln\left(1 + \frac{h^{*2}}{a^2}\right)$$

Figure below shows the value of n calculated by the above equation after bulge test and the one that is obtained from tensile test on the same sheet. The good conformity between these results suggests that it may not be a bad idea to use bulge test to obtain work hardening exponent of the sheet materials since no special sample preparation will be required for the bulge test. Note that no special recording system is necessary, just the final height of the dome is enough.



Comparison of the work-hardening exponent obtained from tensile test and measurement of the final height of the dome after bulge test

Device: Bulge test machine

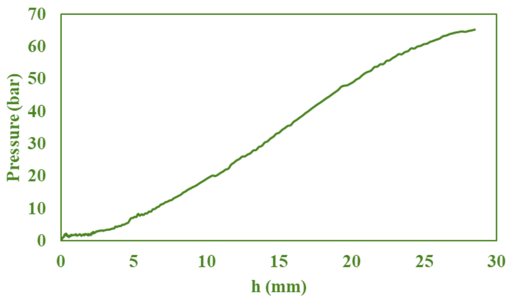
Manufacturer: *TOKYO TESTING MACHINE*

This lab is equipped with a bulge test machine with the following specifications.

Technical specifications

Maximum clamping force	**80 tons**
Maximum bulge pressure	**500 kg/cm^2**

*** Computerized recording of the oil pressure and height of the dome**

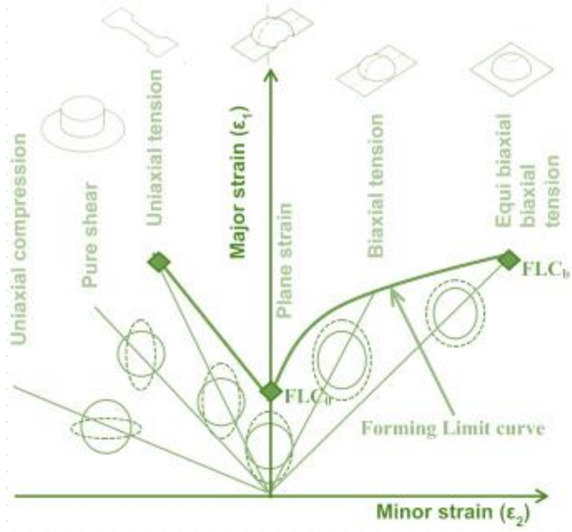


The resulting P-h curve recorded by the bulge test machine

Deep drawing test

Introduction

Forming Limit Diagram is an essential tool to determine the formability of the sheet materials and design the sheet forming process so that no deficiencies such as necking, fracture, or wrinkling to occur. Determination of the formability of a sheet specimens include the measurement of the principal strains at the onset of instability. Since the formability of the sheets is strain path-dependent, it is required to investigate the limiting strains for as many strain paths as possible. This is usually done by standard procedures such as Nakajima or Erichsen tests, which include stretching a sheet specimen over a punch with a specific geometry. After specimen rupture or necking, like what is described for the bulge test, the grid of circles previously printed on the specimen would be examined by a proper camera, and the values of the principal strains at the onset of instability could be determined to draw the corresponding FLD of the material.



Schematic representation of FLD and different strain paths

Device: Deep drawing test machine

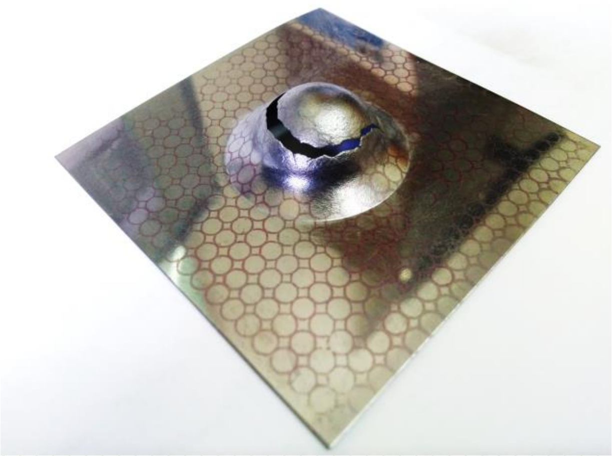
Manufacturer: *TOKYO TESTING MACHINE*

This lab is equipped with a deep drawing test machine with the following specifications.

Technical specifications

Maximum force	**4 tons**

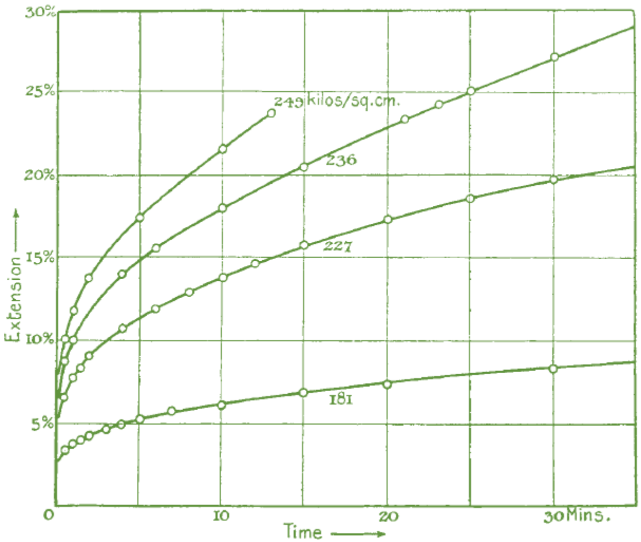
*** Capable of using punches with different dimensions**



Creep test

Introduction

Creep is the time-dependent permanent deformation of a material at high temperatures and under loads that no plastic deformation is expected. The most common creep testing method is applying a constant axial force, either in tension or compression, to a bar or cylinder of the material of interest. The creep strain is measured with time, and the time at rupture is recorded if this occurs during the test. Tests on a given material are generally done at various stresses and temperatures, and test durations can range from less than one minute to several years. After performing creep test under several combinations of stresses and temperatures, above set of curves may be achieved.



Extension-time behavior of a martial under several loads

Device: Creep test machine

Manufacturer: *ZWICK/ROELL*

This lab is equipped with a creep test machine with the following specifications.

Technical specifications

Maximum temperature	**800 °C**
Load cells	**1, 2.5, and 5 tons**

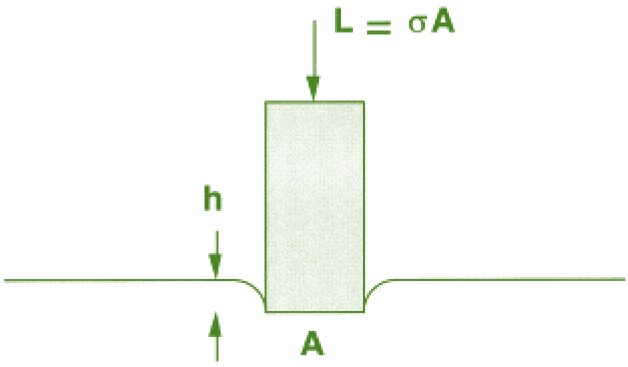
*** Controlling of the applied load and temperature**

*** Computerized recording of time and extension**

Impression creep test

Introduction

The impression creep technique is a modified indentation creep test wherein a cylindrical indenter with a flat end is impressed in a specimen to apply a steady state load through a small area, and the resulting penetration velocity is recorded. At a constant load and elevated temperatures, the indenter penetration velocity reaches a steady rate after a transient period, which is due to the time-dependent plastic flow of a relatively small volume of materials underneath the indenter. Due to the inherent localized plastic deformation in this test, one may use the following relations to convert the mean pressure under the indenter, p, to the corresponding uni-axial stress, σ, and to convert the creep displacement, Δ^c, to the corresponding uniaxial creep strain ε^c:



Schematic of impression creep geometry

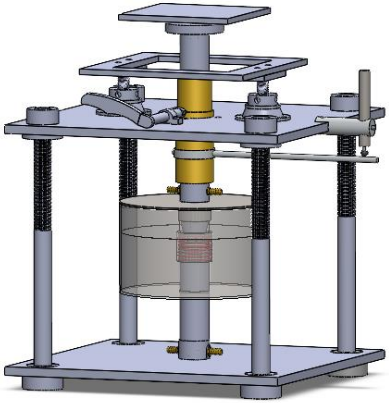
$$\boldsymbol{\sigma = \eta p \;\&\; \varepsilon^c = \Delta^c/\beta d}$$

Where d is the indenter diameter. The η and β values have been shown to be 0.296 and 0.755, respectively, for a cylindrical indenter

Impression creep test

Introduction

By using the previous relations, it is possible to obtain the data needed from uni-axial creep from impression creep test. In fact, it has been shown that the stress and temperature dependencies obtained from the impression creep test, display a good agreement with the results of the conventional creep test on the metals. Compared to uni-axial creep test, this method particularly reduces the testing time from days, weeks, and months to hours. Additionally, the sample preparation for this technique is much simpler and only a small disk of material with flat faces is enough. Therefore, both from the point of view of sample preparation and testing time, this test is incomparably economical.



Schematic of impression creep test machine

Other advantages of this method include: performing many tests on a single samples to avoid the sample-to-sample variations, probing very small material volume particularly attractive for testing of modern micro-components or HAZ in weldments, requirement of the minimum amount of tools in the laboratory, capability of measuring the effect of temperature and stress on the creep of a single crystal.

Device: **Impression creep test machine**

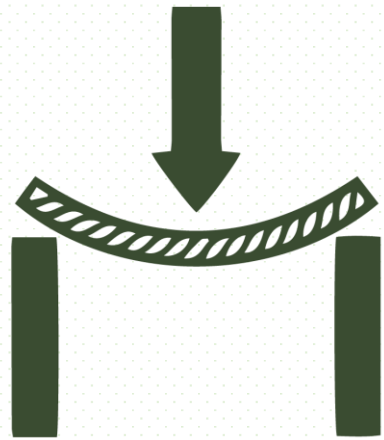
Manufacturer: *MANUFACTURED IN-HOUSE*

This lab is equipped with an impression creep test machine with the following specifications.

Technical specifications

Operating Temperature	**RT - 600 °C**
Load range	**9.7 – 64 kg**
Displacement range	**0 - 4000 µm**
Displacement accuracy	**10-30 mm**
Minimum specimen thickness	**5 mm (adjustable for higher thicknesses)**
Indenter diameter	**2 mm WC indenter**

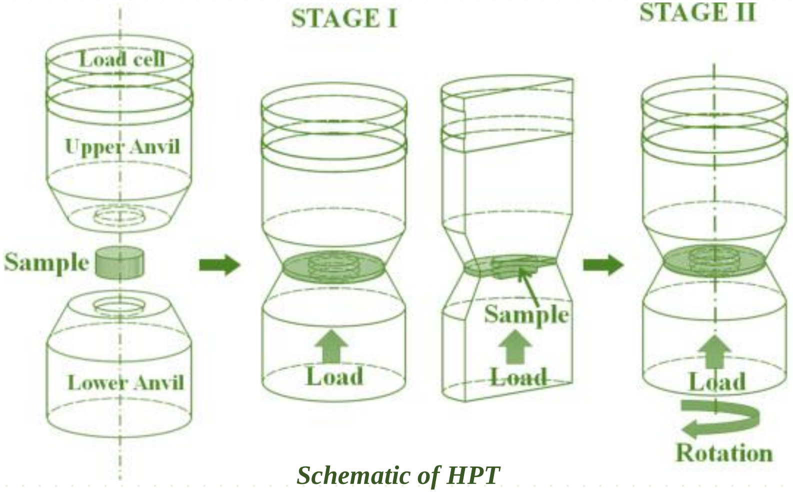
Non-Analytical Instruments



High-pressure torsion (HPT)

Introduction

High-pressure torsion is one of the most well-known severe plastic deformation (SPD) techniques. SPD processes result in the modification of the microstructure of the material, as a result of which mechanical and physical properties of the starting material would alter drastically. Such high levels of straining in these processes could not be imposed on the material unless appropriate levels of hydrostatic pressure prevail during the process. The range of aforementioned microstructural evolutions is vast and includes, production of ultrafine-grained structures, powder consolidation, and production of high-entropy alloys. HPT itself consist of two stages: 1) application of a compressive force and 2) shear straining by relative rotation of the two anvils with respect to each other.



Schematic of HPT

Device: **High-pressure torsion (HPT)**

Manufacturer: *MANUFACTURED IN-HOUSE*

This lab is equipped with a HPT machine with the following specifications.

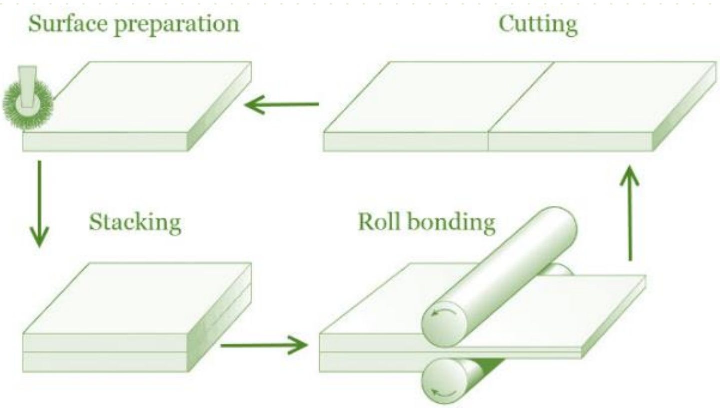
Technical specifications

Maximum compressive force	**50 tons**
Maximum rotation speed	**0.25 rpm**

Rolling & accumulative roll bonding

Introduction

Now a days, the rolling process has become well-studied, and very limited investigations are directed toward this process. On the other hand, accumulative roll bonding (ARB) is a new material processing routine during which very high strains could be imposed on the sheet materials. ARB involves sectioning a sheet into two halves, wire brushing, degreasing the surface of the pieces, stacking, and rolling two pieces by a rolling setup. This process may be continued to several passes resulting in very high strains imposed on the sheet. These high strains result in the development of an ultrafine-grained structure with superior mechanical properties. On the other hand, rolling setup may also be used for cladding, production of the composite sheets, and mechanical alloying.



Schematic of ARB

Device: Rolling setup

Manufacturer: *MANUFACTURED IN-HOUSE*

This lab is equipped with a rolling setup with the following specifications.

Technical specifications

Maximum sheet thickness	**10 mm**
Maximum sheet width	**100 mm**
Roll diameter	**110 mm**

*** Proper guiding bars may be attached to the setup**

Device: Refrigerator

Manufacturer: *

Technical specifications

Minimum temperature	**-40 °C**

Device: Electrical furnace

Manufacturer: *AZAR*

Technical specifications

Maximum temperature	**1000 °C**