LABORATORY CLASSES

1. TEST MACHINE (MONDAY)

To understand the load-carrying ability of a material and to determine the amount of deformation it can withstand before failure, the first step is to determine the properties of the material. To obtain these, a sample of material (i.e. a *test specimen* or *coupon*) is tested by loading in tension, i.e. stretching the material until failure occurs. To conduct the tensile test and apply the load in a controlled manner a specialist machine is used. A schematic of a typical tensile test machine is shown in Figure 1.

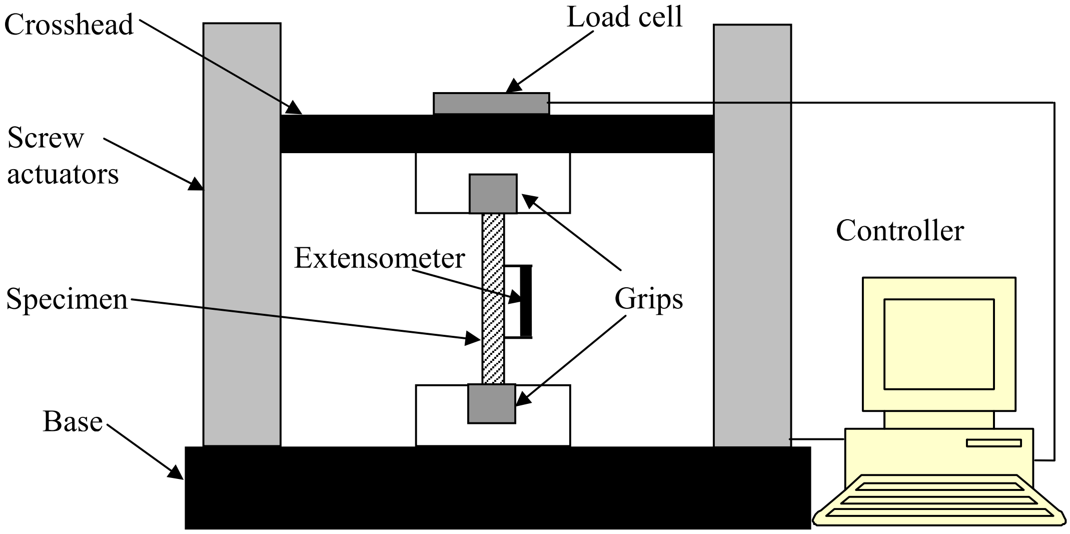

Figure 1 Schematic representation of a typical test machine

The tensile testing machine's main components are the *frame*, *load cell*, *grips* and an *actuator*. The frame is equipped with two metal columns, a base and a moving *crosshead*. The crosshead is a rigid metal block located on the columns that connect to a piston and slides up and down. It can be positioned according to length of the specimen and can move to any position within the available range of the column length. Two grips, one mounted on the base the other on the crosshead, are equipped with jaws that are used to mount the specimen and designed to retain the it even after fracture. While the lower grip is fixed, the moveable upper grip is controlled by an actuator providing a constant rate of motion hence loading the specimen. A load cell is mounted to the crosshead and it measures the magnitude of the applied load (*i.e. force*) building up as the specimen is stretched. Finally, all control operations are carried out via a separate control panel installed in the environs of the testing machine.

The most commonly used specimen geometries for engineering materials are the *dog bone* with wide ends and a narrow middle and *straight-sided specimen* with end tabs (BSI, 1977; BSI, 1990; ASTM D 3039/D 3039). The purpose of the end tabs is to protect the material from the gripping force and hence prevent premature failure at the jaws. A specimen is mounted by its ends into the gripping jaws of the tensile test machine and simply pulled in tension. Proper alignment of the grips and the specimen when clamped in the jaws is very important as offsets in alignment will create bending in the specimen and therefore change the loading and lead to inaccurate measurements. In this test an aluminium alloy dog bone type specimen will be used.

During a test, simultaneous measurements are made of the applied load from the load cell, displacement of the crosshead and increasing length of a selected portion at the middle of the specimen, called the *gauge length*. The change in the gauge length is measured by external sensors attached to the specimen known as *extensometers*; these can either be mechanical, laser or optical systems. In this laboratory class a simple mechanical extensometer is used.

The tensile test provides load-deformation characteristics of the specimens via the computer-based recording system. The magnitude of the deformation for a constant load depends on the geometry of the material tested. Equally, the magnitude of the load required to cause a given deformation also depends on the geometry of the specimen. This begs the question how can structure of different shapes and size but made from identical materials be compared. In order to compare different materials and eliminate the effect of sample dimensions, the quantities, *stress* and *strain* are much more frequently used than load and deformation. Stress is defined as the load on a specimen per unit cross-sectional area, is independent of test specimen geometry and has SI units of N/m^2 (*i.e.* Pa). Expressing the load that a material can withstand in this manner allows a direct comparison of the *strength* of all materials and hence appropriate material choices can be made. On the other hand, strain is deformation per unit length and is therefore a non-dimensional deformation. (The term *percentage elongation* is often used and also denotes *tensile strain*.) Strain is measured using a set length or *gauge length* on a specimen. If the gauge length changes then the amount of deformation changes but the percentage deformation remains constant. For example, if a specimen with a gauge length of 0.1 m stretches 0.01 m under load then the elongation is 10%. Similarly, for the same material under same load but measured over a gauge length of 0.05 m a 0.005 m deformation would occur, *i.e.* 10% elongation. To visualise the behaviour of a material under tensile load a graph of stress versus strain, *i.e.* a stress-strain curve, is used. Figure 2 shows a typical stress-strain curve for a ductile material.

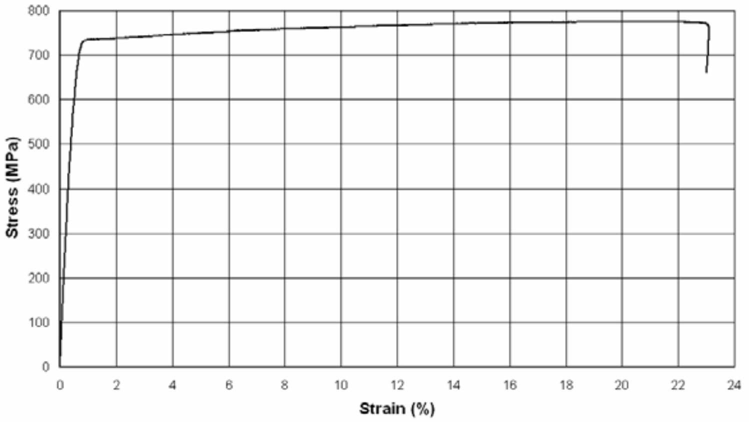

Figure 2 Stress strain curve for stainless steel

In general the stress-strain curve can be divided into two main regions, namely elastic and plastic regions. When the deformation (or strain) is approximately proportional to the load (or stress) and if the strain disappears when the load is removed then the deformation is non-permanent and therefore it is called *elastic*. While the relationship between the load and deformation depends on the geometry of the material, the relationship between the stress and strain is geometry independent and hence this relationship represents a material constant within the elastic region. This constant of proportionality is called the *elastic modulus* (*Young's modulus* or *modulus of elasticity*) and it can be defined as the rate of change of stress with respect to strain for the condition of pure uniaxial tension. When the material is deformed beyond a point where the stress is no longer proportional to strain, non-recoverable *plastic* deformation occurs, which remains even after the load causing it is removed. The stress level at which the plastic deformation is initiated is referred to *yield stress* (or *yield strength*) of the material and it is very important for design purposes as it provides a limit to the amount of stress a material can sustain without becoming permanently stretched. Many composite materials do not have a plastic region; this type of material is termed *brittle or quasi-brittle*. The maximum stress that a material can withstand before failure in tension is termed *ultimate tensile strength* and is where fracture occurs. The amount of strain up to failure is considered as the total elongation of the material.

Test procedure

1. Dog bone specimens 15 mm in width and 6 mm in thickness have been manufactured from the aluminium alloy; a strain gauge has been installed on the specimen and connected to the Vishay Strain Smart conditioning unit.
2. Mount the specimen in the grips of the Instron 5500 servo-mechanical test machine.
3. Mount a 10 mm long gauge extensometer on the specimen on the opposite side to the strain gauge.
4. Apply a constant displacement rate of 2 mm/min and collect data.
5. Load the specimen to below the elastic limit.
6. Record the stress, strain and displacement data from the Instron system. Record the strain from the strain smart system.

2. WHITE LIGHT (TUESDAY)

White Light Camera set up and performance

Specimen: Speckle pattern target
Equipment: Manta G125B-ASG with an 8 bit, 2452 x 2056 pixel CCD array and 50 mm lens
Purpose: Focusing and setting up of cameras, assessment of camera performance.
Activity: Assess effect of camera settings and lenses on images
Data: Bitmap images.

1. Magnification
    a. Find the smallest focus distance of the lens
    b. Calculate the magnification from theory and compare with measured estimation
    c. Look at effect of magnification on speckle pattern
2. Lighting
    a. Demonstrate effect of aperture and lighting, explore saturation issue
    b. Set-up lighting and aperture to provide good histogram
3. Noise
    a. Live observation of noise
    b. Subtract two images and report camera noise
4. Quantitative evaluation of set-up
    a. Capture two still images and perform DIC: map of noise
    b. Calculate mean and standard deviation
    c. How does the noise evolve with lighting?
    d. How does the noise evolve with correlation subset
    e. Always report subset size, shift and noise level when presenting data
5. Effect of out-of-plane movement
    a. Take one still image and move the target forward by 0.1 mm and take another image
    b. Run correlation and look at strain maps
    c. Hydrostatic strain maps, magnitude roughly dz/z where z is camera to target distance and dz is out-of-plane movement.
6. Aliasing
    a. Increase imaging distance to maximum and capture two images with a 0.5 mm out of plane movement between the two.
    b. Perform correlation and look at aliasing effects

Disc DIC and strain gauge

Specimen: Aluminium alloy disc 80 mm diameter x 6 mm thick

Equipment: Instron 8802/8032 servo hydraulic test machine, LA Vision Imager Pro LX camera with a 12 bit 4870 x 3246 pixel CCD (7.4 μm pitch), Sigma 105 lens, LA Vision DIC system, Vishay strain smart system

Purpose: Derive Young’s modulus for the aluminium alloy using the data sets compare the strain at the centre of the disc derived from both techniques – assess the error sources. Compare the derived strains and stresses along vertical disk diameters to theory.

Activity: Attach strain gauge to strain smart system – zero and shunt calibrate. Mount specimen in the test machine using an initial load (-0.5 kN) and start recording strain data and

obtain DIC reference image. Load to -5 kN take DIC image and then to -9.5 kN and take another DIC image (load increment 4.5 kN).
Data: Strain (DIC – full field data and strain smart) in shared folder.

DIC Stress strain behaviour evaluation
Specimen: Aluminium alloy dog bone 140 mm long (gauge length 50 mm) x 15 mm wide x 6 mm thick.
Equipment: Instron 5569 servo mechanical test machine, LA Vision DIC system, Imager E-lite (5 MPixel CCD, 12 bit), sigma 105 mm lens.
Purpose: Derive Young's modulus and Poisson's ratio for the aluminium alloy using data from the DIC.
Activity: Mount specimen in the test machine, apply initial load of 0.5 kN, then ramp to failure at 6 mm/min, collect DIC data to failure.
Data: DIC data in shared folder.

Grid Technique (No laboratory demonstration)
Specimen: Aluminium alloy disc 80 mm diameter x 5.8 mm thick
Equipment: Instron 8802 servo hydraulic test machine, MANTA G504B (gigabit Ethernet) camera with a 2452 x 2056 pixel CCD array (3.45 x 3.45 μm^2 pixel size). Grid pitch: 0.3 mm
Purpose: Derive Young's modulus and Poisson's ratio for the aluminium alloy using data– assess the error sources. Compare the derived strains and stresses along vertical disk diameter to theory.
Activity: Mount specimen in the test machine using an initial load (-0.4 kN) obtain reference image. Load to -7 kN take image and then to -9.5 kN and take another image.
Data: Image data in shared folder.

3. THERMOELASTIC STRESS ANALYSIS (THURSDAY)

Thermoelastic constant

Specimen: Aluminium alloy dog bone 240 mm long (150 mm gauge length) x 15 mm wide x 6 mm thick.
Equipment: Instron 8032 servo hydraulic test machine, Flir SC 5000 series infra-red system
Purpose: Derive thermoelastic constant.
Activity: Mount specimen in the test machine and increase load to 5.0 kN and cycle ± 1.5 and 3.0 kN at 10 Hz. Record data.
Data: ΔT, T and phase in shared folder.

Thermoelastic stress analysis on Brazilian disc

Specimen: Aluminium alloy disc 80 mm diameter x 6 mm thick
Equipment: Instron 8080 servo hydraulic test machine, Flir Silver 480M infra-red system
Purpose: Derive stress sum along vertical and horizontal diameter.
Activity: Mount specimen in the test machine using an initial load (-0.5 kN) increase load to -5 kN and cycle ± 2.25 kN and 4.5 kN at 10 Hz. Record data.
Data: ΔT, T and phase data in shared folder.