EP06 Young’s modulus

A solid material has a certain elastic deformation when subjected to a force. Young's modulus is a parameter describing this elastic deformation of a solid, and it is one of the most important parameters for selecting materials in engineering. Accurate measurement of the Young's modulus of a material is a prerequisite for material application. Young's modulus can be measured by the dynamic method and static method. In this experiment, one of the static measurement methods, the elongation method is used to measure the Young's modulus of a steel wire. The core of the experiment is the measurement of small deformations with a microscope.

OBJECTIVE

1. To familiarize the student with the use of micrometer and reading microscope
2. To familiarize the student with the successive difference method, and to measure the Young’s modulus of steel using it.
3. Could you imagine the micro-origin of Young’ modulus?

Prelab Question:

1. What are stress and strain?
2. To calculate the Young’s modulus, what parameters should we known?
3. Could you imaging the micro-origin of Young’s modulus?

THEORY

The terms ‘stress’ and ‘stain’ are introduced when referring to the deforming force and the deformation it produces.

Stress is the force (1 N) acting on unit cross-section area ($1m^2$). For a force F and area A we can write: stress=force/area. The unit of stress is the pascal (Pa) which equals one newton per square metre (that is, 1 Pa=1 Nm^{-2}).

Stain is the extension of unit length (1 m). We can write: stain=extension/original length. Stain is a ration without unit.

The stress required to produce a given strain depends on the nature of the material under stress. The ratio of stress to strain, or *the stress per unit strain,* is called an elastic modulus of the material. The larger the elastic modulus, the greater the stress needed for a given strain.

In the case in which the force causes elongation, stress is measured as the force per unit cross sectional area and strain is the increase in length of unit length. The modulus is then known as Young's modulus (E) and hence

$$E = \frac{tensile\ stress}{tensile\ strain} = \frac{F/S}{\Delta l/l} = \frac{F \cdot l}{S \cdot \Delta l} \qquad (1)$$

Where F is the force in N; S is the cross-sectional area in m^2; Δl is the increase in length (in M) caused by F; and l is the original length of the wire in m.

In the lab, F ,S ,l can be obtained easily, so how to measure Δl is the key.

As shown in Figure 1, hanger for weights is attached on one end of the wire for measurement. When adding weights (M), the force acting on the wire will increase by F

$$F = Mg \qquad (2)$$

and the wire elongate Δl, which means that the tensile strain is Δl. From the microscope, the Δl can be measured directly from the change of cross-hairs in the cross board. If the value of the diameter of the wire is d, the cross-sectional area equal to $\frac{1}{4}\pi d^2$, so the young's modulus

$$E = \frac{F \cdot l}{S \cdot \Delta l} = \frac{4Mgl}{\pi d^2 \Delta l} \qquad (3)$$

Where the acceleration of gravity g is 9.788 m/s^2 in Guangzhou. The l and M are given in the lab. If Δl is measured, E can be obtained.

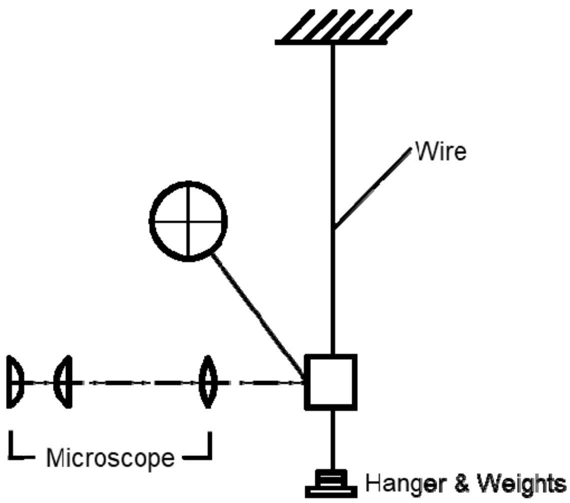
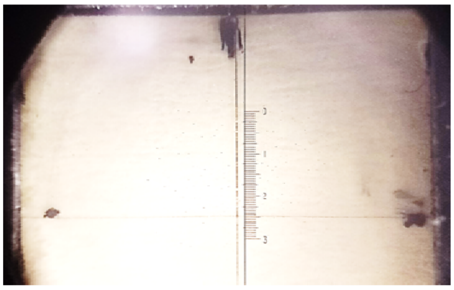


Figure 1 Schematic of measurement set-up

Experiment set-up



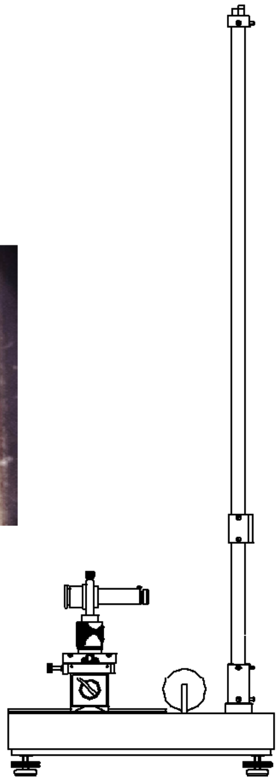


Figure 2 Measuring Set-up for Young's modulus

PROCEDURE

1. Calibration of the set-up

(1) Level the base by adjusting the four screws of the base.

(2) Adjust the screws at both sides of the cross board into the "V" slot. Ensure that the wire is freely suspended and will not rotate in the horizontal plane.

(3) Adjust the ocular of the microscope until the scale is clear. Move the microscope until the cross-hairs on the cross board is clear in the optical microscope, then lock the base. Use the fine adjustment to ascend or descend until some reticule in the scale coincides with "—"in the cross, read the readings on the scale, that is C_0.

2. Measurement of Young's modulus

(1) Load the weights one by one on the hanger nine times (every time the weight added is 0.200 Kg). Take the corresponding readings from the scale of the microscope after each addition, that is C_i (i=1, 2, ..., 8, 9)

(2) Unload the weights one by one, take the corresponding readings at each stage, that is C_i' (i=8,7,...,1,0),then

$$\overline{C_i} = \frac{C_i + C_i'}{2} \text{ (i=8,7,...,1,0).}$$

$$\Delta l_i = \overline{C_i} - \overline{C_0} (i = 0,1,2,\Lambda\ ,8).$$

(3) Measure the diameter (*d*) of the wire at five different points along its length and calculate a mean value. This measurement must be done carefully with a micrometer caliper. Before measurement, record the zero reading (d_0) of the micrometer caliper.

DATA RECORDING AND PROCESSING

micrometer caliper: zero reading $d_0(m)$ =________

$d(m)$	1	2	3	4	5	average

m_i(Kg)		$c_i(load)$ $(\times 10^{-3} m)$		$c'_i(unload)$ $(\times 10^{-3} m)$		$\bar{c} = (c_i + c'_i)/2$ $(\times 10^{-3} m)$		$\Delta l = \bar{c}_i - \bar{c}_0$	
m_0		c_0		c'_0		$\bar{c}_0$			
m_1		c_1		c'_1		$\bar{c}_1$		Δl_1	
m_2		c_2		c'_2		$\bar{c}_2$		Δl_2	
m_3		c_3		c'_3		$\bar{c}_3$		Δl_3	
m_4		c_4		c'_4		$\bar{c}_4$		Δl_4	
m_5		c_5		c'_5		$\bar{c}_5$		Δl_5	
m_6		c_6		c'_6		$\bar{c}_6$		Δl_6	
m_7		c_7		c'_7		$\bar{c}_7$		Δl_7	
m_8		c_8		c'_8		$\bar{c}_8$		Δl_8	
m_9		c_9							

Using successive difference method to calculate Δl, and then calculate E using equation (3).

Post lab question:

1. What is origin of the difference between C_i and C_i'?
2. List the Young's modulus of three commonly used materials.

Appendix:

Using Micrometer Caliper

1. The principle and structure of micrometer caliper

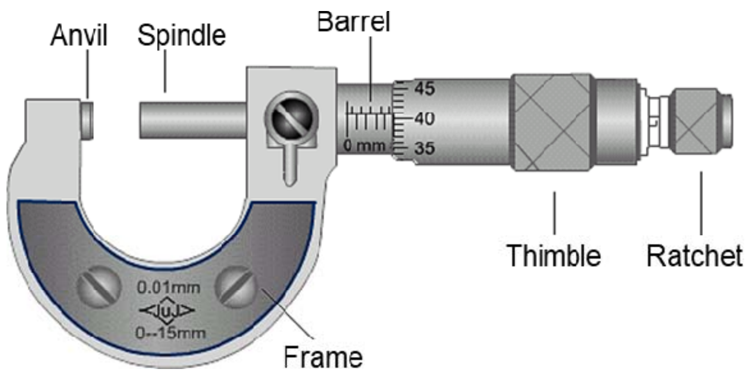


Figure 4 Structure of micrometer

The screw micrometer is a kind of length measuring instrument that measure the length of micro meter by changing the linear displacement into angular displacement of a micrometer screw. Schematic structure of a micrometer is shown in Figure 4. A movable thimble is sleeved on a fixed barrel, and the two are tightly engaged by high-precision threads. The movable thimble is connected with the measuring shaft, and rotating the movable sleeve can drive the measuring shaft to extend and retract. The movable thimble rotates 1 circle (360°), and the measuring shaft extends or retracts by 1 pitch. Therefore, the moving distance of the measuring shaft can be obtained according to the angle of rotation. This is the so-called "mechanical amplification". A ratchet wheel is installed at the tail end of the movable thimble. It can drive the movable thimble to rotate when it rotates. When the resistance is too large, the ratchet wheel will rotate idly, that is, it will not drive the thimble to rotate. This ensures that the object to be measured between the anvil and the spindle will not be clamped too tightly and deformed. The fixed barrel and the anvil are connected by a bow-shaped bracket called a "bow frame". When measuring, the bow frame is generally held in the left hand and the ratchet wheel is turned with the right hand. There is also a locking handle on the bow frame, move it to the left to lock the measuring spindle. As shown in Figure 4, the micrometer has a pitch of 0.5 mm, and the perimeter of the movable thimble is equally divided into 50 division. When the movable thimble rotates by 1 division, the measuring spindle moves 0.5/50=0.01 accordingly. With an estimated reading, the measurement can reach 0.001 mm.

2 reading method of micrometer

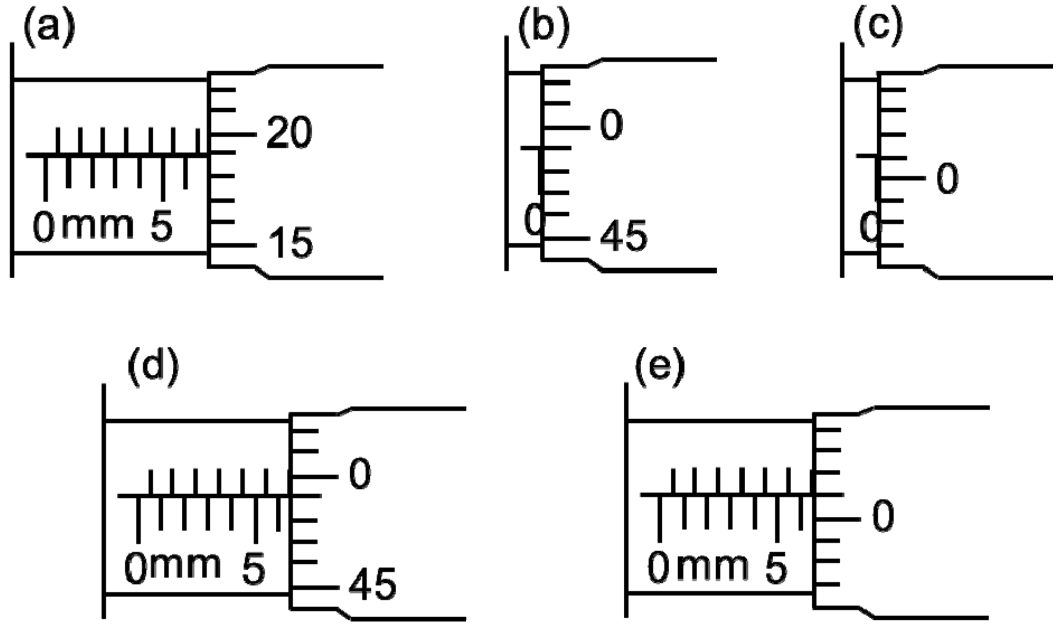


Figure * Schematic diagram of reading of micrometer

When reading, first read the full circle value on the fixed barrel (one turn is 0.5 mm), and then read the value aligned with the reference line from the movable thimble with one estimated digit, and multiply this value by 0.01 mm. Finally, add these two parts together to get the measured value. As shown in Figure 5(a). The reading is:

$$6.5+0.189=6.689 \text{ mm}$$

To clamp the object to be measured, the ratchet wheel must be used instead of turning the movable thimble directly. Hearing the sound of "creak" means that the object to be measured has been clamped, and the ratchet wheel is idling. Stop Rotate the ratchet and lock the handle, and then read the value. After reading, unlock the handle and turn the ratchet in reverse to release the clamped object. The clamped object to be measured should not be pulled out to avoid abrasion of the anvil and measuring shaft.

When reading, pay attention to the situation that the edge of the movable thimble is on the main scale line. It should be judged whether the movable thimble really exceeds the line scale. If the zero scale line on the movable thimble does not pass the reference line, it should not be read out. Otherwise, it should be read. For example, in Figure 5(d), the reading is:

$$6.0+0.489=6.489\ \text{mm}$$

While in Figure 5(e), the reading is:

$$6.5+0.010=6.510\ \text{mm}$$

When there is no object between the anvil and the measuring axis, rotate the ratchet until you hear a "creak". The reading at this time is the "zero reading". In Figure 6(b), the "zero reading" is -0.009 mm. In Figure 6(c), the "zero reading" is 0.011 mm. The "zero reading" should be subtracted from the subsequent reading of measurement get the real length measurement value.