AE314 and AE 727
Aircraft Structures Lab
Department of Aerospace Engineering, IIT Bombay
Lab Manual – Autumn 2009

EXPERIMENT 5(B): STRAIN MEASUREMENT

Title:

Measurement of strain using the strain gauges

Objectives:

The objectives of this experiment are:

1. Measure the strain using strain gauges and calculate the young's modulus of the material.
2. Understand the principle of operation of the strain gauge, bridge circuits & effects of temperature on the performance of a strain gauge.
3. To get familiar with commercially available strain gauges and associated instrumentation.

Equipments used:

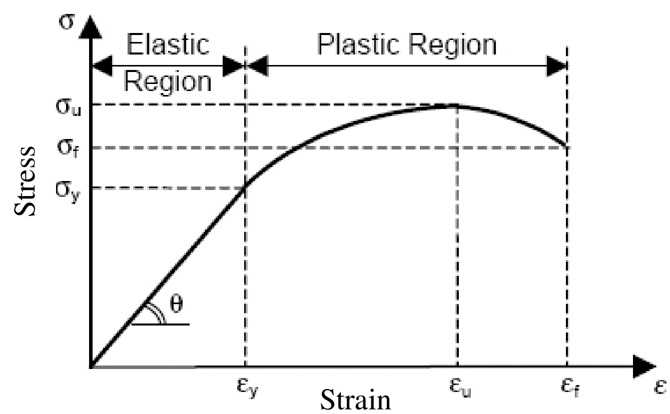
1. Strain Gauges
2. Aluminium specimen
3. Woven fabric composite specimen of known fibre volume fraction.
4. Steel Rule
5. Clamp
6. Vernier calipers
7. Weights
8. Pan

Brief Introduction:

Stresses & Strains:

When a force is applied to an elastic body, it deforms. The (normal) strain is defined as deformation per unit length. Strain may be either tensile (positive) or compressive (negative). A bar with axial force F applied along the x-axis experiences the stress on the plane of the cross-section, and is defined as force per unit area. This stress is perpendicular to the cross-sectional plane and is called the (normal) stress. It has the unit of pressure. Young's modulus is defined by Hooke's law as the ratio of stress to strain, within the elastic limit. The unit of Young's Modulus is same as that of pressure.

A relationship between stress and strain can be found experimentally and often has a characteristic as shown in the Fig. 1 below:



σ_u = Ultimate Stress

σ_f = Failure Stress

σ_y = Yield Stress

ε_u = Ultimate Strain

ε_f = Failure Strain

ε_y = Yield Strain

Fig. 1: Typical Stress-Strain diagram of Aluminium specimen

<u>Strain Gauges:</u>

The most common form of strain gauge is an electrical resistance type strain gauge. Strain Gauges are metallic or semiconductor elements whose electrical resistance is made particularly sensitive to strain. They are very versatile and usually bonded on a surface of an elastic body, which deforms in response to force, pressure, temperature, etc. The gauges are formed by arranging a long wire in axial grid pattern, or etching a thin metal foil on desired shape. In both the cases the conductor is bonded to a backing material.

In general, Wire gauges are used for high temperature applications, foil gauges are used for routine applications. Advantages of foil gauges are high stability & high accuracy.

Installation of strain gauge on the specimen is a very important and critical task. If the bond between the gauge and specimen is not good, wrong readings can result. Surface of the specimen has to be cleaned and then gauges are bonded on it with correct alignment. Correct bonding agent should be selected depending on the surface and type of strain gauge. **REFER TO THE LINK GIVEN IN REFERENCES BELOW FOR MORE INFORMATION.**

<u>Relation between change in resistance and strain:</u>

The resistance of a conductor is given by

$$R = \frac{\rho L}{A} \qquad \text{……………....................... (1)}$$

where R = Resistance of conductor in Ω

ρ = Resistivity in Ωm

L = Length in m

A = Area in m^2

From Equation (1), if there is a change in conductor length, ΔL, then

$$\Delta R = \frac{\rho \Delta L}{A}$$

Hence,

$$\frac{\Delta R}{R} = \frac{\Delta L}{L} = \varepsilon$$

If resistance varies through other parameters, then

$$\frac{\Delta R}{R} = \frac{\Delta \rho}{\rho} - \frac{\Delta A}{A} + \frac{\Delta L}{L}$$

$$\Rightarrow \frac{\Delta R}{R} = \frac{\Delta \rho}{\rho} - 2\frac{\Delta D}{D} + \frac{\Delta L}{L} \qquad \left(\because A = \frac{\pi D^2}{4}\right)$$

$$\Rightarrow \frac{\Delta R}{R} = \frac{\Delta \rho}{\rho} + 2\nu\frac{\Delta L}{L} + \frac{\Delta L}{L} \qquad \left[\because \nu = -\left(\frac{\Delta D}{D} \Big/ \frac{\Delta L}{L}\right)\right]$$

$$\Rightarrow \frac{\Delta R}{R} = \left\{1 + 2\nu + \left(\frac{\frac{\Delta \rho}{\rho}}{\frac{\Delta L}{L}}\right)\right\}\frac{\Delta L}{L}$$

The term in the brackets is called as Gauge Factor (GF) and can be defined as the fractional change in resistance to unit strain.

$$\boxed{\Rightarrow \frac{\Delta R}{R} = GF\frac{\Delta L}{L} = GF.\varepsilon_a}$$

Where ε_a is the measured strain.

Generally, value of Gauge Factor is around 2 and is specified in the manufacturer's catalogue. The measured value of strain is usually expressed in micro-strain as the value of strain is of the order of 10^{-3}. So, the signal that is sensed using strain gauge is conditioned using a large voltage with a large gauge factor. Wheat stone's bridge circuit is used to measure the change in resistance.

Wheatstone Bridge Circuit:

A Wheatstone bridge circuit converts a change in resistance to a voltage signal, which can be measured with higher accuracy than change in resistance, and we can make a provision for the temperature compensation.

When the bridge is in balanced state (i.e., $R_1.R_3 = R_2.R_4$ in Fig.2) then there will be no output voltage. If we connect the strain gauge at R_1 (say $R_1 = R + \Delta R$) then circuit is called as quarter bridge as the strain sensor appears only in one of the four resistors as shown in Fig. 3. Similarly we can replace two or four resistors with strain gages and the bridge is called half bridge or a full bridge respectively.

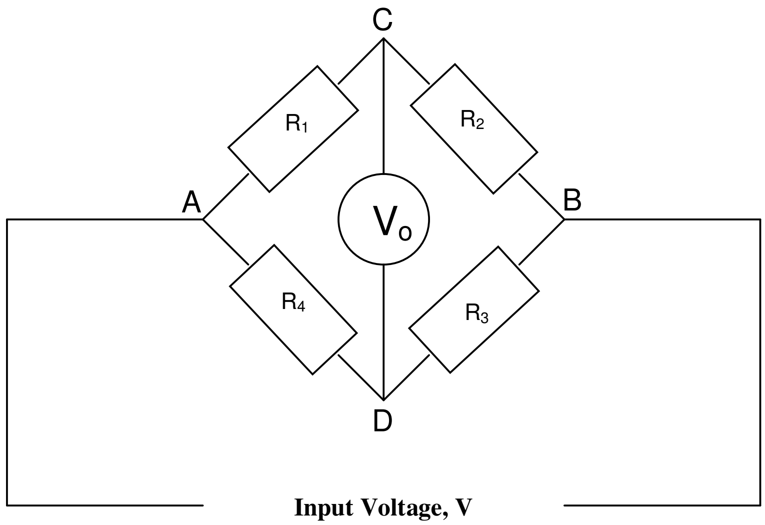


Fig. 2: Wheatstone Bridge Circuit

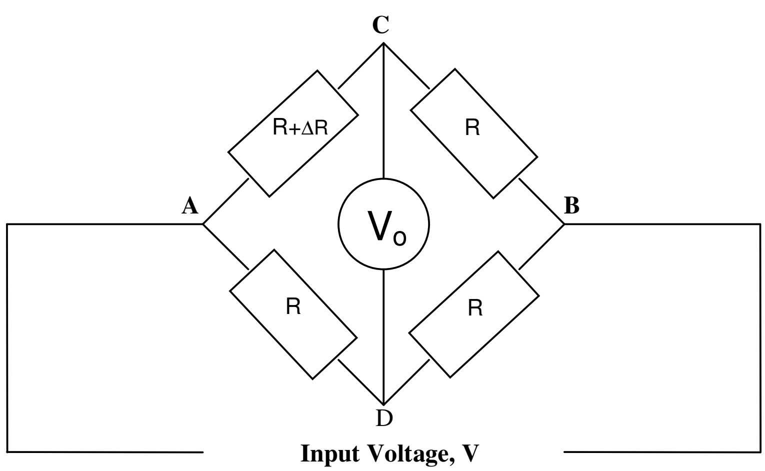


Fig. 3: Quarter Bridge Circuit

For a quarter bridges, if the voltage given is V and output is V_o, then the strain is given by

$$\varepsilon_a = \frac{4V_o}{V} \times \frac{1}{GF} \qquad \left(\because \frac{\Delta R}{R} = \frac{4V_o}{V} \right)$$

The major disadvantage in quarter bridge circuit is that the change in resistance due to temperature cannot be differentiated from resistance changes due to strain. To compensate this, we use half bridge circuit or a full bridge. Half bridge offers sensitivity twice that of Quarter Bridge.

The half bridge circuit is shown in Fig. 4 below:

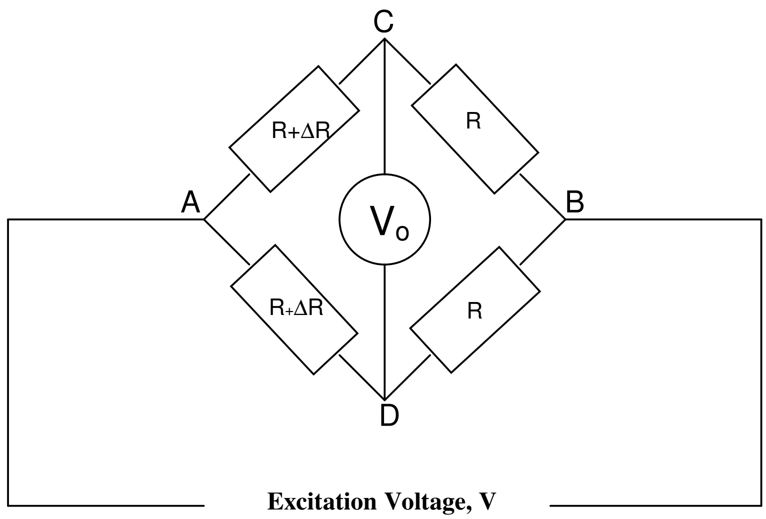


Fig. 4: Half Bridge Circuit

<u>Strain Indicator:</u>

We use strain indicator for getting the value of strain from the strain gauges. The strain gauges are connected to this instrument and the strain reading is indicated on the LCD screen. This instrument acts as the Wheatstone Bridge. Strain gauges can be connected in either quarter bridge, half bridge or full bridge circuit. Wiring for the required circuit should be done as explained on the strain indicator front panel. There is also a facility to get an analog reading from the strain indicator which is proportional to the value of strain.

Procedure:

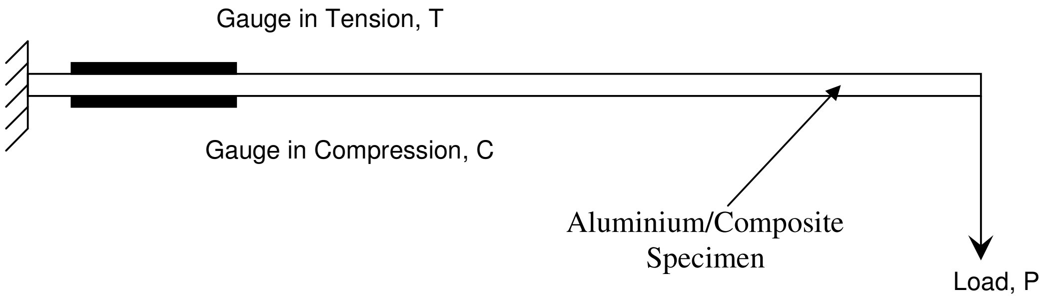


Fig. 5: Experimental setup of the specimen

The bending strain in the cantilever beam specimen can be measured by modeling it as shown in the diagram The strain gauges are kept on both sides of the specimen to measure the strain in tension and compression layers of the beam. However, they are at the same distance from the root of the cantilever beam. This arrangement is known as a half bridge circuit.

The strain value that is effectively read on the strain indicator is as follows:

$$\varepsilon_{effective} = \varepsilon_1(tension) - \varepsilon_2(compression)$$

$$But,\ \ \varepsilon_2(compression) = -\varepsilon_1(tension) = \varepsilon$$

$$\varepsilon_{effective} = 2 \times \varepsilon$$

From the applied load the stresses can be calculated using

$$\sigma_a = \frac{M.y}{I_a} = \frac{6P.l}{bt^2}$$

The stresses and strain at various loads are calculated and tabulated. A graph is plotted using the measured stress and strain values obtained from the experiment. From the stress - strain graph, we can obtain the Young's modulus.

Observations:

The following data are obtained from test specimens:

Dead weight of the pan =

Gauge factor of the Strain Gauge =

	Aluminium	Composite Specimen
Length, l(in cm)		
Width, b(in mm)		
Thickness, t(in mm)		

Observations for Aluminium:

Weight (P in gm)	Strain (ε_a in μ)

Observations for E- glass epoxy woven laminate of fibre volume fraction V_f = :

Weight (P in gm)	Strain (ε_a in μ)

Calculations and graph:

Calculate the stress values for each step of loading, plot the stress-strain graph and thus get the Young's modulus for the two materials you have tested.

How does it compare with the values in literature? (give references)

Exercise:

1. Explain the significance of Gauge Factor
2. What circuit is used in our experiment? Why?
3. What are different forms of electrical strain gauges available commercially?
4. What is the strain gauge configurations used for calculating bending stress, torsional stress?
5. How are the strain gauges connected for compensating the effect of temperature?

References:

[1] "The Strain Gauge"

http://www.omega.com/literature/transactions/volume3/strain.html

[2] "Strain gauge installation techniques"

http://www.vishay.com/strain-gages/knowledge-base-list/appnotes-list/

http://www.efunda.com/DesignStandards/sensors/strain_gages/strain_gage_install_bond.cfm