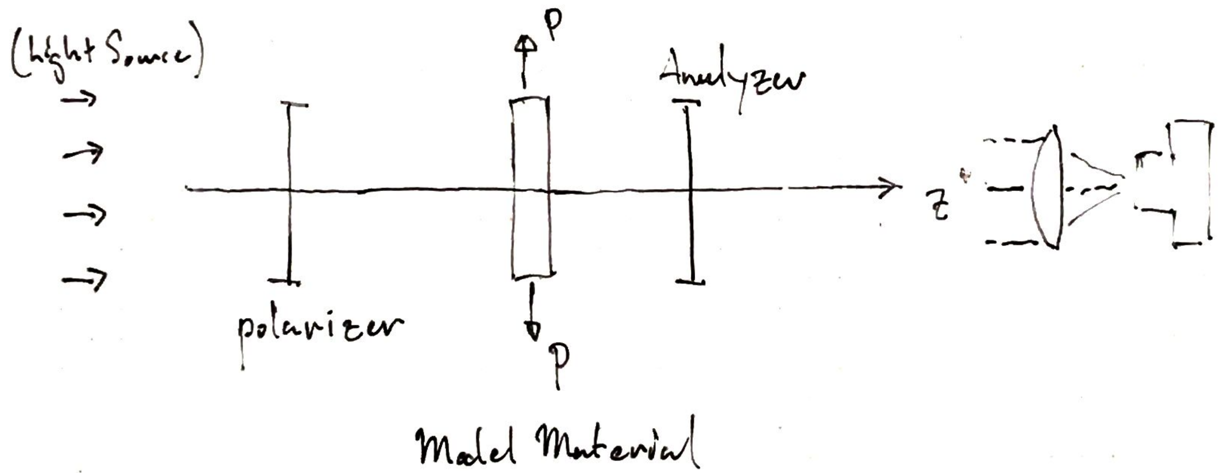
12/5/18
DEC 05 2018

Experimental Mechanics Final Presentation

- Slide Outline First
- Break outline into dendritic growth has no good analogue in the physical process of Laser Metal Project. Modulii of the steel very hard. — Problem
  + Need Supporting Equations from some site
  + A couple of slides?
  + Compare scale of dendritic growth to minimum length scale of the AFM
- Set Up with: FEM Research process on pg ②
  + Processes of Dendritic Growth linked to solidification of both unary and multicomponent liquid, examples like ice, ...
    i) Pure Liquid
    ii) Solid Nucleus of Spherical Shape grows into the liquid
      - Begin in the free vacuum or (free growth)
    iii) Liquid Solid Interface grows where regions befor the boundary becomes super-cooled
      - There is a great visualization video in 3D → gif
      - Note how the boundary is not a clean line but rather
      - Relate to "ϕ" or state parameter and phase field approach
      - Graph of the State as a product of the environment
    iv) Its distictive shape comes from how the crystal anisotropy allows for solidification in energy favorable direction
      - State → Propogates in shape preserving manner → "dot ~~of~~ flux?"
      - Energy favorable directions
      - As the dendrite growth goes on, heat energy goes into the dendrite

Experimental Mechanics: 9 October 2018

- Lecture #11: Photoelasticity & Fringes (Isoclinic vs. Isochromatic)
  - Photoelastic Materials
  - Analysis of Fringe Patterns
- Linear Polariscope



$$I = K \underbrace{\sin^2\left(\frac{\Delta}{2}\right)}_{0} \underbrace{\sin^2(2\alpha)}_{0} = 0$$

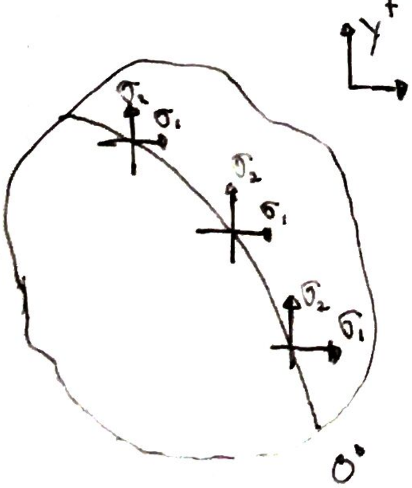
or

- if $\sin^2 2\alpha$: Isoclinic ; or principal stress inline w/pol.
- " $\sin^2 \frac{\Delta}{2}$: Isochromatic ; $\frac{\Delta}{2}$

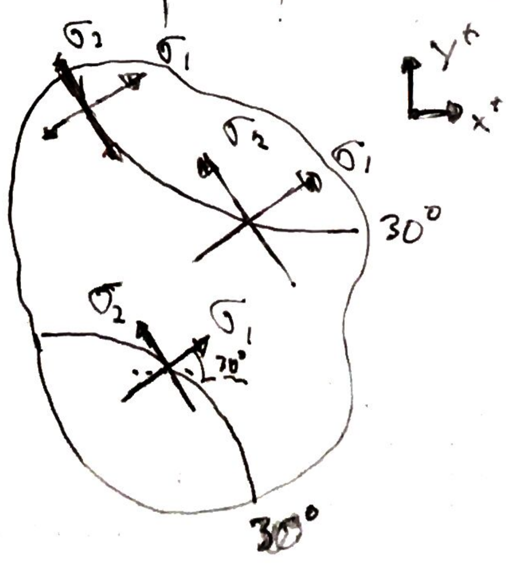
- Isoclinic : $I = 0$ because $\sin^2 2\alpha = 0$

$$2\alpha = n\pi , \quad n = 1, 2, 3 \ldots$$

- Principal stress in axis of polarizer
- Isoclinic parameter: rotate polarizer to varied orientation to create a full field map of stress
- Overlay of outline of isoclinic fringe create 2D stress direction
- Isoclines must pass through isotropic or singular point; $\sigma_1 = \sigma_2$
- Isoclinic of atleast one parameter will have coincided with axis of symmetry.
- Stress/loaded as singular :. isoclinic of all parameters



a) Polarizer set to $0°$



b) Polarizer set to $30°$

- Isochromatic : I = 0 because $\sin^2 \frac{\Delta}{2} = 1$

$$\Delta/_2 = n\pi \; ; \; n = 1, 2, 3 \ldots$$

$$n = \frac{\Delta}{2\pi} = \frac{hc}{\lambda}(\sigma_1 - \sigma_2)$$

- n = fringe order
- Δ = relative retardation $(\propto [\sigma_1 - \sigma_2])$ & is an integer multiple of λ of light
- Give lines of principal stress difference $\sigma_1 - \sigma_2$, we know $\tau_{max} = \frac{\sigma_1 - \sigma_2}{2}$ by Mohr's Circle

Quarter Wave Plates before & after model material @ $\pm 45°$ isoclinics will be removed

- Ultimately, want to know n^{th} order of fringe order
  - Might be done by tracking loading lines
  - Through movement of line under loading.
  - With white light, 0^{th} order is black and successive are λ
  - Isotropic $(\sigma_1 = \sigma_2)$ will always be black

- Sample Pieces has been "model material", so few materials are isotropic and stress induced birefringence
- Still, can be loaded to see a full field stress distribution by applying stressed geometries.
- Generally a polycarbonate:
  + Homolite 100
  + Polycarbonate

  } For Creep

  + Epoxy Resin
  + Urethane Rubber

  } Older Materials

Experimental Mechanics : 17 Sept 2018

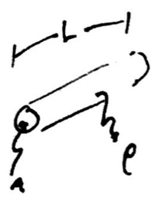
Notes on

- Electrical Resistance Strain Gauge : (ER)

  → $R(\epsilon, \text{material})$: resistance is a function of strain and material

  → Wheatstone bridges used for $\Delta R \rightarrow \Delta V$

- Strain Sensitivity



- L: length
- ρ : resistivity [$\Omega \cdot m$]
- A : area

→ with increased ε, increased R

→ "$R = \rho\, L/A$", but is it from "ρ" or from "L/A"

$$R = \rho\, L/A \quad \rightarrow \quad dR = \frac{1}{A}\left(L\, d\rho + \rho\, dL - L \frac{dA}{A}\right)$$

$$\frac{dR}{R} = \frac{d\rho}{\rho} + \underbrace{\frac{dL}{L}}_{\varepsilon} - \frac{dA}{A} \qquad A = \frac{1}{4}\pi d^2$$

Poisson's Ratio or change in transverse cross section : $\nu = -\frac{\varepsilon_T}{\varepsilon_A}$

$$d_f = d_0 \left(1 - \nu \frac{dL}{L}\right)$$

$$\frac{dA}{A} = -2\nu \frac{dL}{L} + \nu^2 \cancel{\left(\frac{dL}{L}\right)^2}^{\,\varnothing} \cong -2\nu \frac{dL}{L}$$

$$\frac{dR}{R} = \frac{d\rho}{\rho} + \varepsilon + 2\nu\varepsilon$$

$$S_A = \frac{dR/R}{\varepsilon} = \underbrace{1 + 2\nu}_{\substack{\text{change in}\\ \text{dimension}\\ \in[1.4,\,1.7]}} + \underbrace{\frac{d\rho/\rho}{\varepsilon}}_{\substack{\text{change in}\\ \text{specific resistance}\\ \in^{?}[1,\,3]}} \quad : \text{Strain Sensitivity}$$

{ dependent of the free electrons of material }

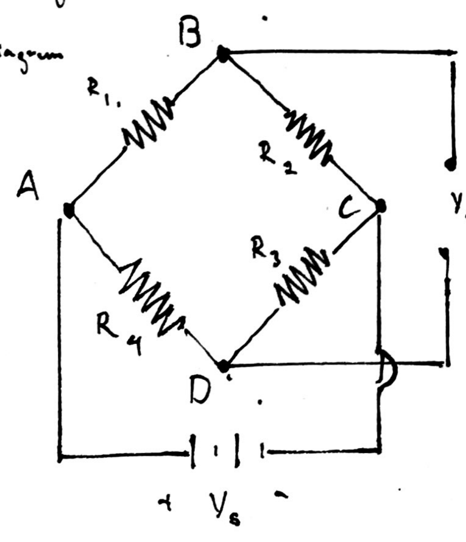
Experimental Mechanics : 20 Sept 2018

Notes on

- Midterm Presentation and Report
  - → Use Dr. KZ's research as more familiar
  - → 5 pages use Terrall format

{ Guest Speaker 18 Oct }

- Electrical Resistance Strain Gage Analysis
  - → $\frac{\Delta R}{R} = S_g \varepsilon_a$ ← Unknown strain, to be found
    - ← Gage property (see 17 Sept)
  - → Convert $\Delta R / R$ into ΔV, read by instrument called Wheatstone Bridge
- Wheatstone Bridge Equations
  - → Equations for circuit sensitivity & effective range
  - → Can go down to low resistance $\in [3, 5]\ \mu\varepsilon$
  - → Diagram



- $V_{AB} = \frac{R_1}{R_1 + R_2} V_s$
- $V_{AD} = \frac{R_4}{R_3 + R_4} V_s$

$\Big\} \; V_0 = V_{BD} = V_{AB} - V_{AD}$

- $V_0 = \frac{R_1(R_3 + R_4) - R_4(R_1 + R_2)}{(R_1 + R_2)(R_3 + R_4)} V_s$

- for $V_0 = 0$: $R_1 R_3 + \cancel{R_1 R_4} - \cancel{R_1 R_4} - R_2 R_4 = 0$

$$\underline{R_1 R_3 = R_2 R_4}$$

- → Place Strain Gage on any resistor, we convert $\varepsilon \to \Delta V$

$$V_0 (R_i) \to \Delta V_0 = f(R_i + \Delta R_i) \to \Delta V_0 = \frac{R_1 R_2}{(R_1 + R_2)^2} \left(\frac{\Delta R_1}{R_1} - \frac{\Delta R_2}{R_2} - \frac{\Delta R_3}{R_3} \frac{\Delta R_4}{R_4} \right) V_s$$

Neglect H.O.T.

→ Generally only one "R" is replaced so is "active"

→ Linear function of ΔR because we neglect Higher order terms

- Bridge Sensitivity

→ "S_c" or sensitivity of bridge one by constant V_s & single active arm

→ $S_c = \dfrac{\Delta V_o}{\Delta R_1 / R_1} = \dfrac{r}{(1+r)^2} V_s$

+ ΔV_o for only ΔR_1

+ $r = \cancel{R_1 R_2}\ R_2 / R_1$

$$V_s = I_T (R_1 + R_2) = I_T R_T (1+r)$$

$$V_s = \underbrace{(1+r)}_{\text{circuit } \cancel{\text{efficency}}} \underbrace{\sqrt{P_T R_T}}_{\text{physical characteristics}}$$

→ $S_c = \underbrace{\dfrac{r}{1+r}}_{\text{circuit efficency}} \sqrt{P_T R_T}$

circuit efficency generally less than 70%

P_T : power dissapated as heat

R_T : total resistance

$$P_T R_T : \in [1, 1000]\ W \cdot \Omega, \text{ commercially}$$

- Strain Analysis

→ What is known affects gage placement

→ Stress State

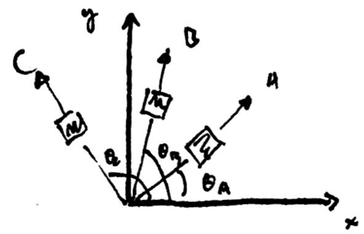
(i) Uniaxial Stress : 1 gage in stress axis

if E is known : $\sigma_{xx} = \sigma_1 = E \epsilon_{xx}$

(ii) Principal direction known but unknown magnitude : rectangular rosette in principal direction

(iii) Stress field unknown : 3 element rosettes needed

→ 3 Element Rosettes in general



· measuring ε_A, ε_B, ε_C

$\downarrow$

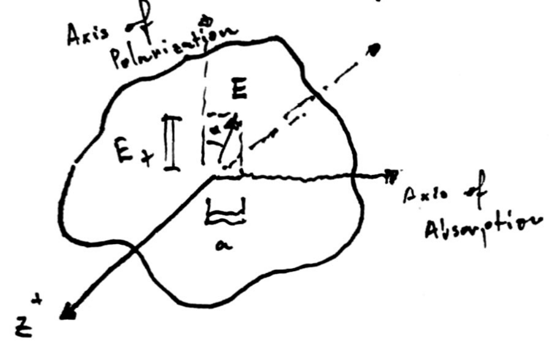
ε_{xx} + ε_{yy} ! by Mohr's Circle

Experimental Mechanics: 1 Oct 2017

Notes on Birefringence

- Polariscope: use linear polarizers through a transparent model material
- Plane polarizer for plane wave; circularly with wave plane
- Linear or Plane Polarizer

→ Thin material between light source and continues



$\vec{E}$: light vector

E_t : transmitted light

E_a : absorbed light

α : angle b/w $\vec{E}$ & axis of polarization

→ Equation for Light Vector: $\bar{E} : a \cos \frac{2\pi}{\lambda}(z_0 - ct) \rightarrow a \cos(\omega t)$

+ initial phase (δ) of light can be neglected

+ $f = c/\lambda$; $\omega = 2\pi f$

→ Break into E_t and E_a

+ $E_a = a \cos(\omega t) \sin \alpha$

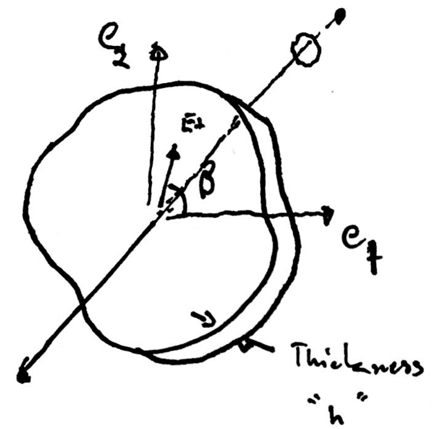
+ $E_t = a \cos(\omega t) \cos \alpha$

- Polaroid Filters

Iodoquinine crystals in nitrocellulose } J sheet: older & replaced w/ H Sheets

- Wave Plate: transmits 2 orthogonal light vectors with different velocities

→ Wave plate after linear polarizer



- β : angle
- e_1 : index of refraction axis (#1) / fast axis
  - → n_1 : index of refraction
  - → c_f : velocity of propagation
- Labeled so that $e_1 > e_2$

+ $E_{t_1} = E_1 \cos\beta = a\cos(\omega t)\cos\alpha\cos\beta = k\cos\omega t\cos\beta \ \} \ k = a\cos\alpha$
+ $E_{t_2} = E_2 \sin\beta = k\cos\omega t \sin\beta$
+ δ : phase shift due to $c_1 \neq c_2$; n w.r.t. air

$$\left.\begin{array}{l}\delta_1 = hn_1 - hn \\ \delta_2 = hn_2 - hn\end{array}\right\} \delta = h(n_2 - n_1);$$ relative linear phase difference

$$\Delta = \frac{2\pi}{\lambda}\delta = \frac{2\pi}{\lambda}h(n_2 - n_1)$$: Angular phase shift

→ Classification

+ Quarter wave : $\Delta = \pi/2$
+ Half wave : $\Delta = \pi, 2\pi, \ldots$

→ Results in

$$\left.\begin{array}{l}E'_{t,1} : k\cos\beta\cos\omega t \\ E'_{t,2} : k\sin\beta\cos(\omega t - \Delta)\end{array}\right\} E'_t = \sqrt{E_{t_1}^2 + E_{t_2}^2} \Rightarrow \cancel{|E_T| = k\cos}$$

→ Angle Relative to e_1 : $\tan\gamma = \frac{E'_{t_2}}{E'_{t_1}} = \frac{\cos(\omega t - \Delta)}{\cos(\omega t)}\tan\beta$

- Conditioned Light using wave plates and linear polarizers
  - → 3 defined cases
  - → Plane Polarized Light : $\beta = 0$; Δ has no restriction

$$E_t' = k\cos(\omega t)$$

$$\gamma = 0$$

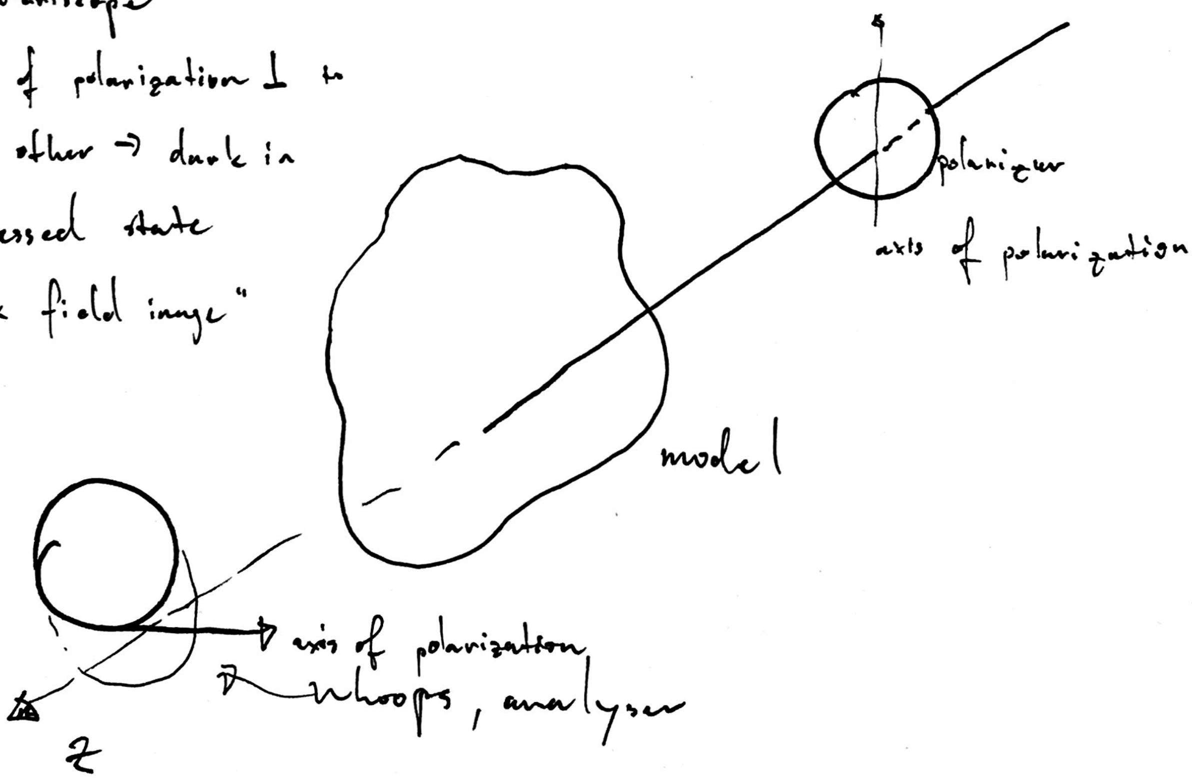
  - → Circularly Polarized Light : $\Delta = \pi/2$; $\beta = \pi/4$ for left ; $\beta = 3\pi/4$ for right

$$\left.\begin{aligned} E_t' &= \frac{\sqrt{2}}{2}k \\ \gamma &= \omega t \end{aligned}\right\} \text{Constant Magnitude, helical shape}$$

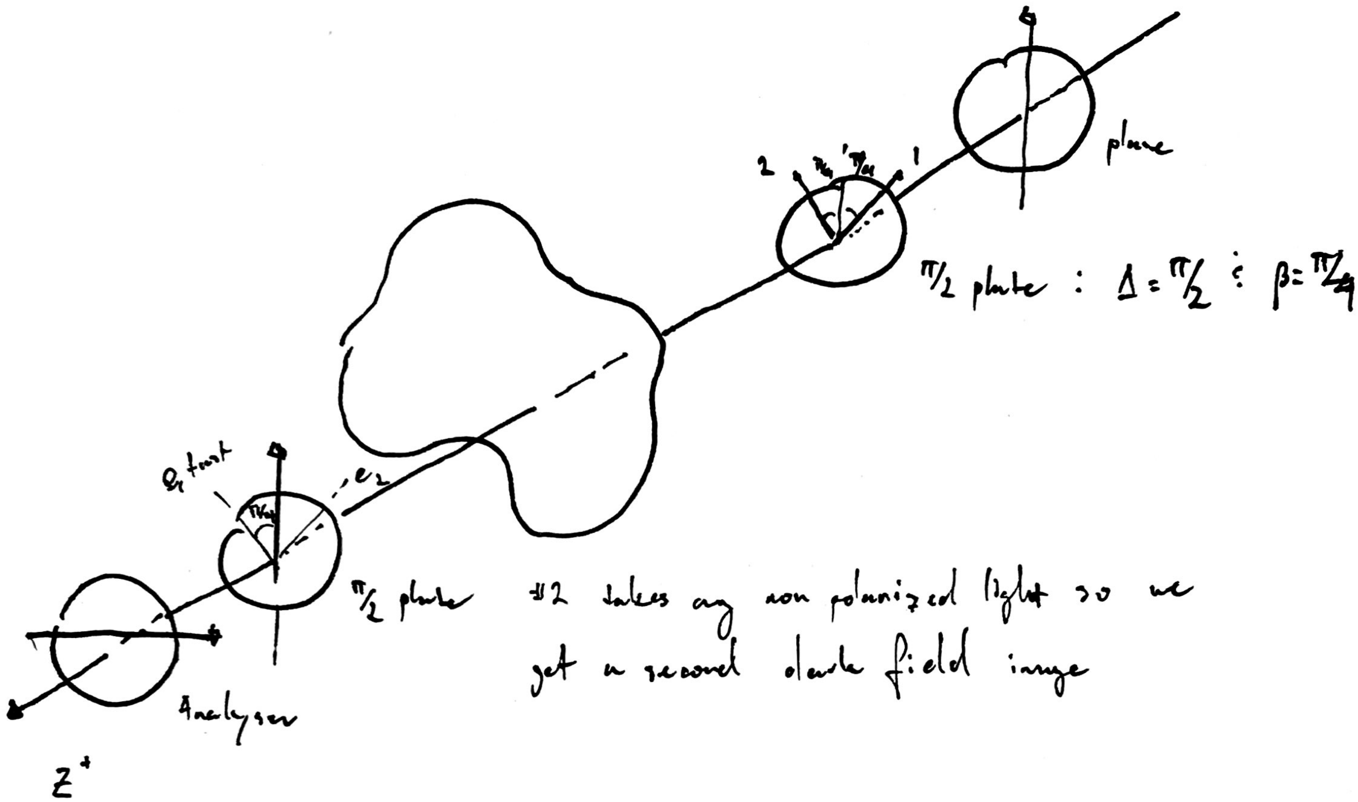
  - → Elliptically Polarized : quarter wave plate ($\Delta = \pi/2$)

$$\left\{ \beta \neq \frac{n\pi}{2} \; , \; n \in \mathbb{I} \right\}$$

- Plane Polariscope
  - → Axis of polarization ⊥ to each other → dark in unstressed state "dark field image"

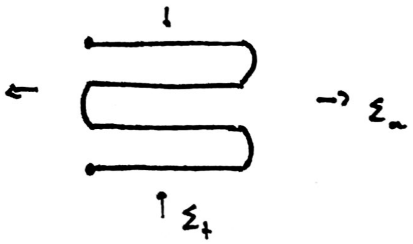


· Circular Polarizer



#2 takes any non polarized light so we get a second dark field image

- Most commonly used is advance or constantan w/ $S_A \sim 2.1$
  - → 45% Ni, 55% Cu is nice because of linear for elastic ε and even into plastic
  - → High "ρ" and insensitive to ΔT
- Gage Construction
  - → needs to be relatively long (~ 0.1 m) but we want ε at a specific location
  - → Put onto grid pattern



- 1930's Ruge / Simmons : wire on paper
- 1950's Sanders & Roe : photo etched on metallic foil normally bonded to plastic for durability & insulation

  - → need special appreciation for bonding to ~~specimine~~ specimin
  - → $L_{gage} \in [200\,\mu m, 100\,mm]$
- Arrays
  - → Linear Array :  for capturing a line of ε
  - → Rosettes
    - + 90° Rosette :  if we know principal strain
    - + 45° Rosette :  & 60° 
- Gage Sensitivity and Gage Factor
  - → using a grid adds transverse component "ε_t" which we don't want to measure
  - → $S_A = \frac{dR/R}{\varepsilon} \doteq \frac{\Delta R/R}{\varepsilon}$ must be transformed for biaxial strain
  - → $$\Delta R/R = \underbrace{S_a\varepsilon_a}_{\text{Axial Sensitivity}} + \underbrace{S_t\varepsilon_t}_{\text{Transverse Sensitivity}} + \underbrace{\overbrace{\cancel{S_s\gamma_{at}}}^{0}}_{\text{Shear sensitivity}} = S_a(\varepsilon_a + K_t\varepsilon_t)\ ;\ \varepsilon_t = -\nu\varepsilon_a$$
    "$K_t = S_t/S_a$" or transverse sensitivity factor
  - → S_g = Gage factor
    $$\Delta R/R = S_g\varepsilon_a = S_a\varepsilon_a(1-\nu K_t)\ ;\ S_g = S_a(1-\nu K_t) \text{ w/ } [S_g, S_a, K_t] \in \begin{bmatrix} 1.96 \to 2.13, \\ 1.93 \to 2.14 \\ -4.2 \to 1.8 \end{bmatrix}$$

• Error comes from only considering axial strain, knowing there is some transverse strain

$$\Delta R / R = \frac{S_g \varepsilon_a}{1 - \nu K_t} \left(1 + K_t \frac{\varepsilon_t}{\varepsilon_a} \right) \rightarrow \varepsilon_a = \frac{\Delta R / R}{S_g} \frac{1 - \nu K_t}{1 + K_t (\varepsilon_t / \varepsilon_a)}$$

is true axial strain

$$\text{apparent} \quad \varepsilon_a' = \frac{\Delta R / R}{S_g} \rightarrow \varepsilon_a = \varepsilon_a' \frac{1 - \nu K_t}{1 + K_t (\varepsilon_t / \varepsilon_a)}$$

so that % error from neglecting transverse component

$$\varepsilon = \frac{\varepsilon_a - \varepsilon_a'}{\varepsilon_a} (100) = \cancel{\varepsilon} \; \frac{K_t (\varepsilon_t / \varepsilon_a + \nu)}{1 - \nu K_t} \; ?$$

$\varepsilon_t / \varepsilon_a$ is a prescribed value from problem; independent of ν