광탄성 강의노트
Lecture note for photoelasticity

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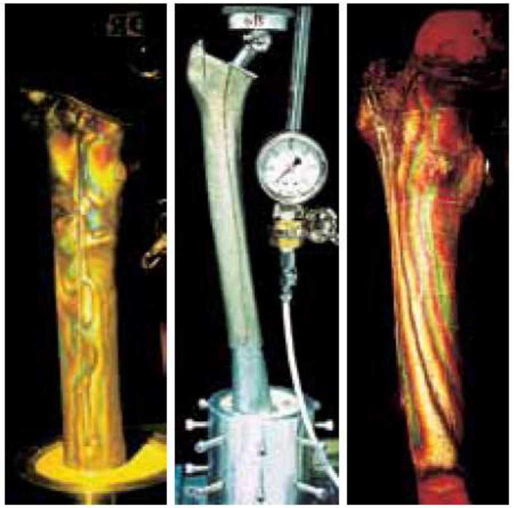
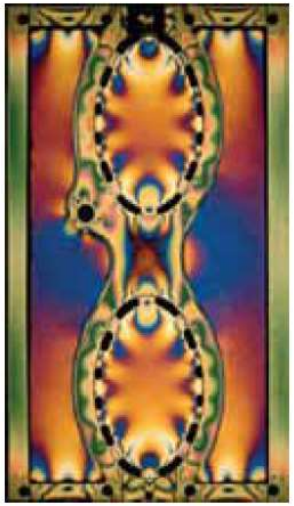
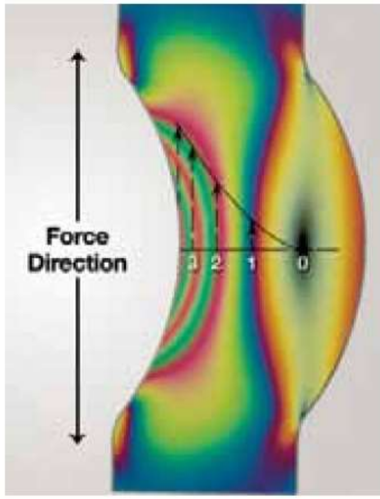
광탄성이란?

- 작용되는 하중에 의해 물체 내부에 응력이 발생함
- 투과성이 있는 물체에는 응력에 의해 분자의 배열이 변하여 굴절율 차이가 발생하여 복굴절이 유발되고 이로 인해 광탄성 (Photoelasticity) 현상이 발생함


Human bones—PhotoStress stress distribution analysis

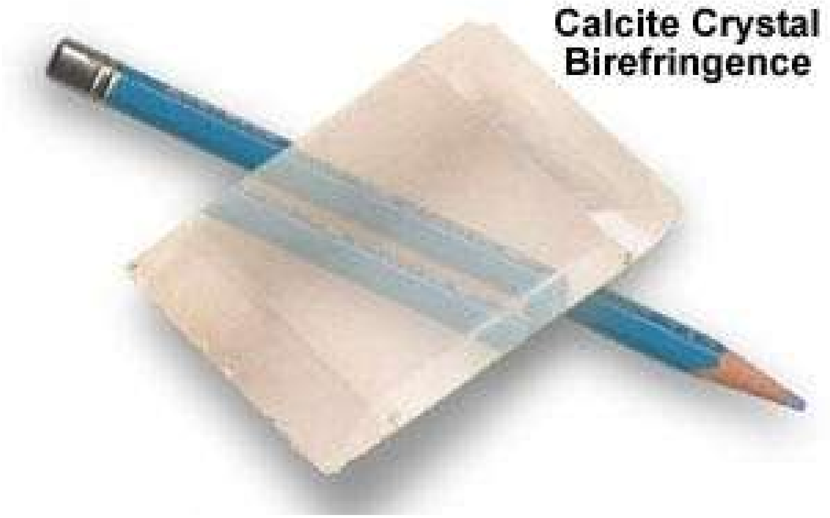

PhotoStress stress patterns of an aircraft fuel door panel under load



Stress distribution in a C-shaped beam

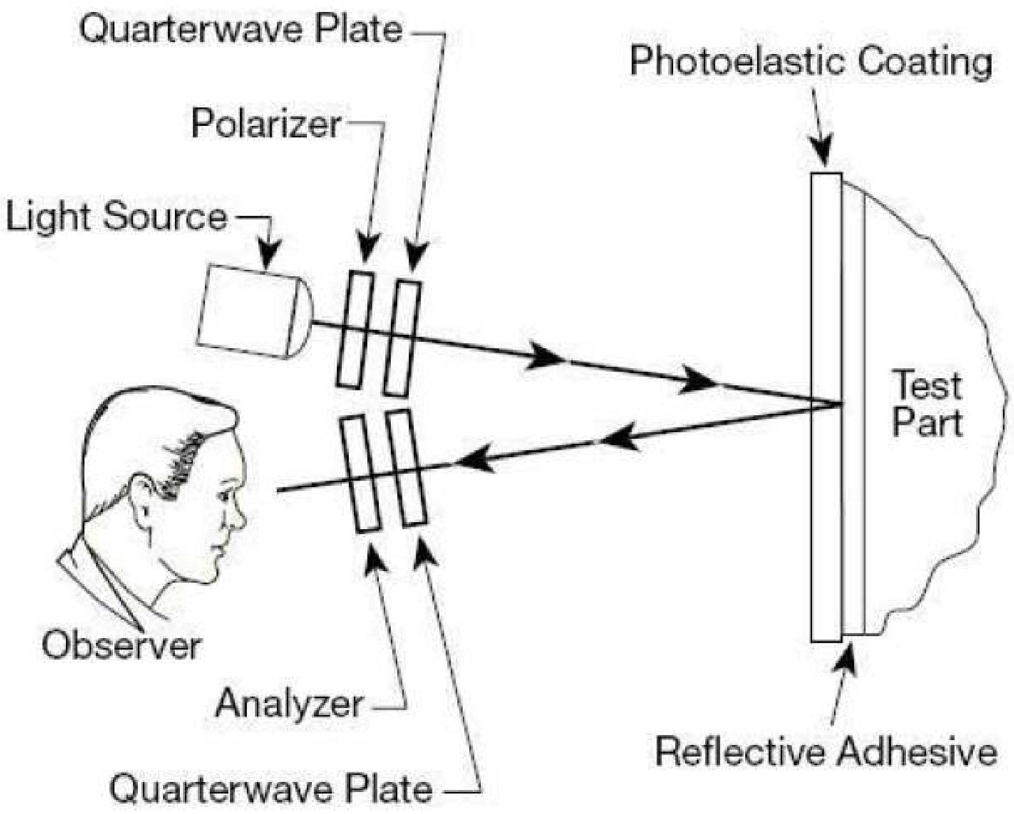
복굴절 현상

Example of birefringence



- One of the images appears as would be expected when viewing an object through clear glass or an isotropic crystal
- The other pencil image appears displaced due to the nature of doubly refracted light

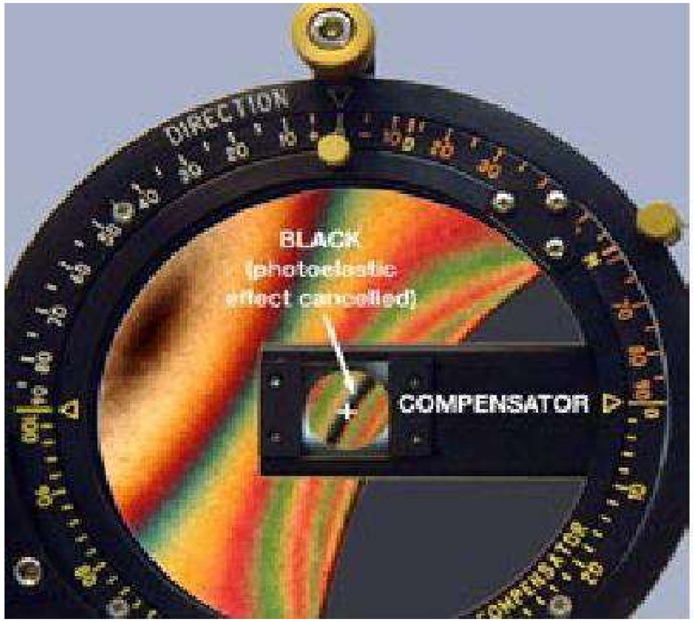
반사형 광탄성 장비



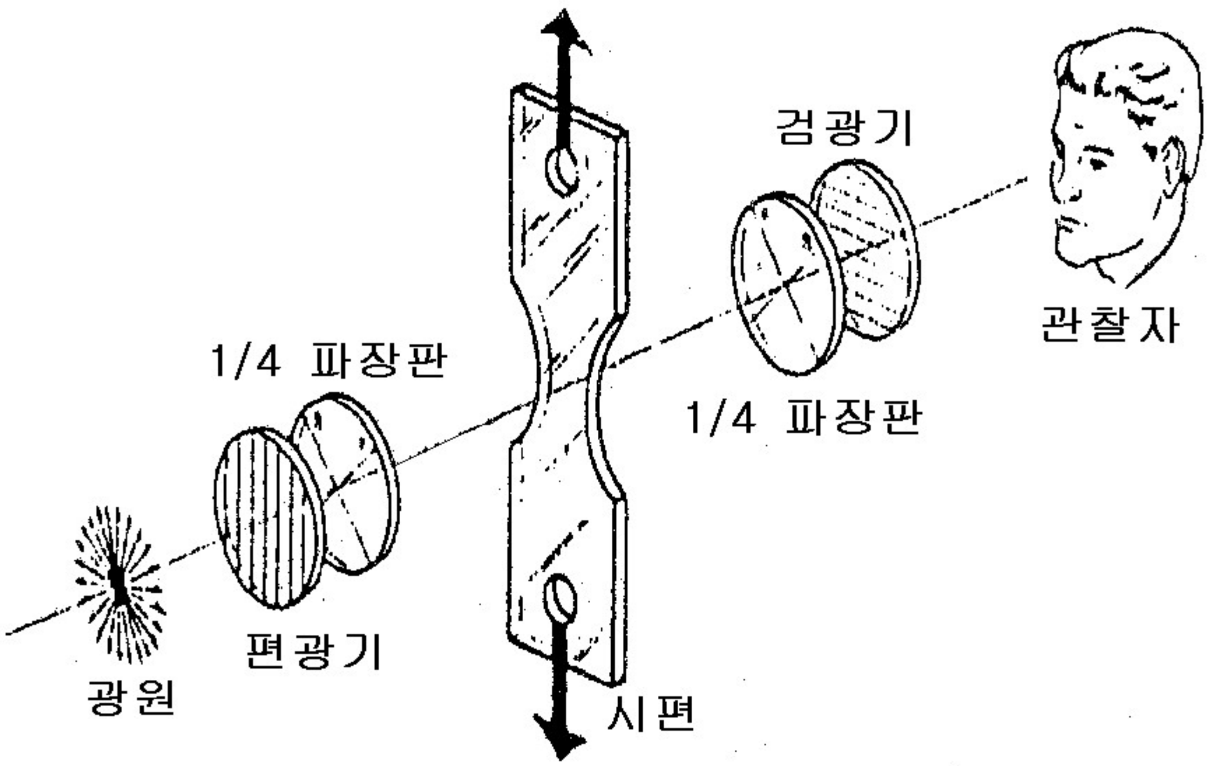
Schematic representation of reflection polariscope

반사형 광탄성 장비

반사형 광탄성 장비

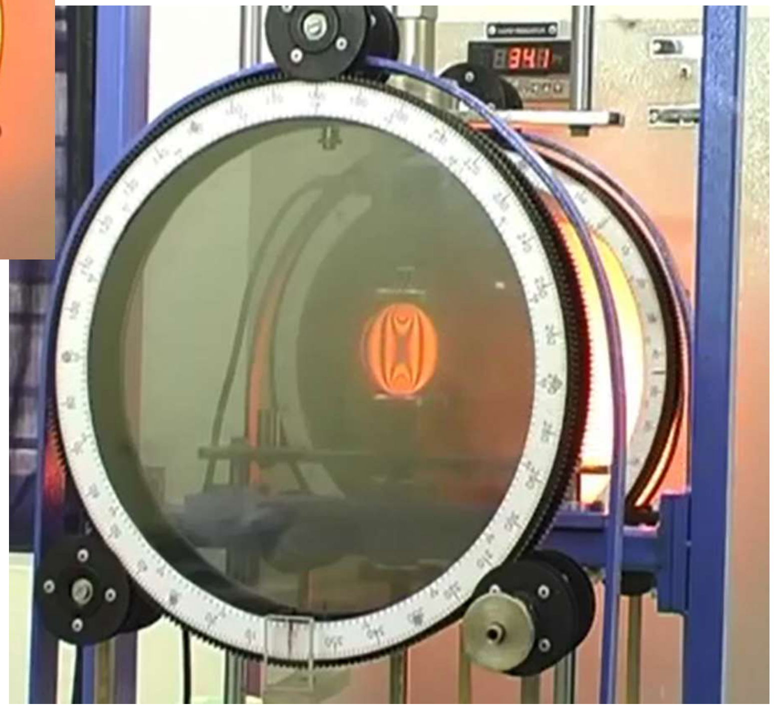

DIRECTION
BLACK
(photoelastic
effect cancelled)
COMPENSATOR

투과형 광탄성 장비

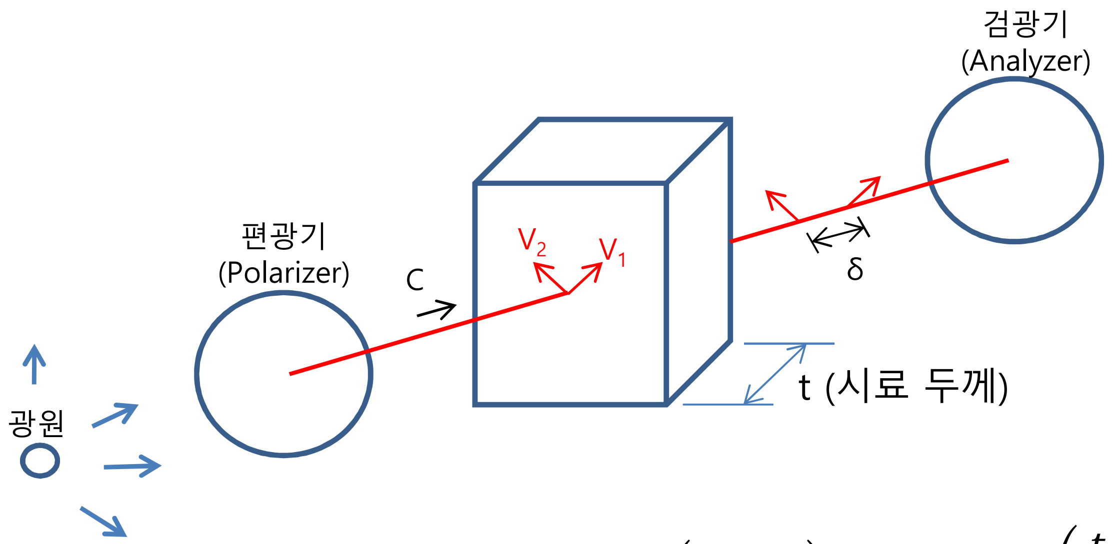


Schematic representation of transmission polariscope

투과형 광탄성 장비



광탄성 측정원리



$$n = \frac{C}{V}$$

n : 굴절율
C : 공기 속의 속도
V : 재료 속의 속도

투명체 속을 빠져 나오는데 걸리는 시간 차 : $\left(\frac{t}{V_1} - \frac{t}{V_2}\right)$

$$\delta = C\left(\frac{t}{V_1} - \frac{t}{V_2}\right) = t\left(\frac{C}{V_1} - \frac{C}{V_2}\right)$$
$$= t(n_1 - n_2)$$

Brewster의 법칙 : 굴절계수 상대차는 주변형률의 차에 비례한다. $n_1 - n_2 = K(\varepsilon_1 - \varepsilon_2)$

$$\delta = tK(\varepsilon_1 - \varepsilon_2) \qquad (\varepsilon_1 - \varepsilon_2) = \frac{\delta}{tK} \qquad N = \frac{\delta}{\lambda}$$

$$(\varepsilon_1 - \varepsilon_2) = \delta/tK = N\frac{\lambda}{tK} = Nf$$

n = index of refraction

f = fringe value of coating

N = fringe order

K = strain-optic coefficient

λ = wave length

광탄성 측정원리

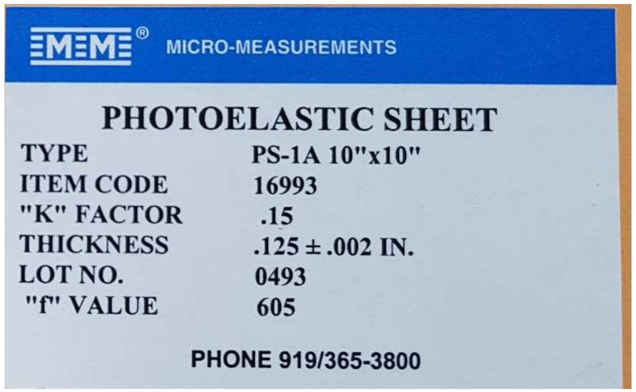
$$(\varepsilon_1 - \varepsilon_2) = \delta / tK = N \frac{\lambda}{tK} = Nf$$

using $$\varepsilon_1 = \frac{1}{E}(\sigma_1 - \nu\sigma_2)$$

$$\varepsilon_2 = \frac{1}{E}(\sigma_2 - \nu\sigma_1)$$

$$\Rightarrow \quad \varepsilon_1 - \varepsilon_2 = \frac{1}{E}(1+\nu)(\sigma_1 - \sigma_2)$$

$$\sigma_1 - \sigma_2 = \frac{E}{1+\nu}(\varepsilon_1 - \varepsilon_2) = \frac{E}{1+\nu} fN$$



반사형 광탄성 측정원리

$$\varepsilon_1 - \varepsilon_2 = Nf$$

$$f = \frac{\lambda}{2t_c K}$$

λ (파장길이) = 575 nm

t_c (코팅두께) = 3.05 mm

N = 무늬차수 (fringe order)

$$\sigma_1 - \sigma_2 = \frac{E}{1+\nu}(\varepsilon_1 - \varepsilon_2) = \frac{E}{1+\nu} fN$$

$$\sigma_1 - \sigma_2 = \frac{E}{1+\nu} fN$$

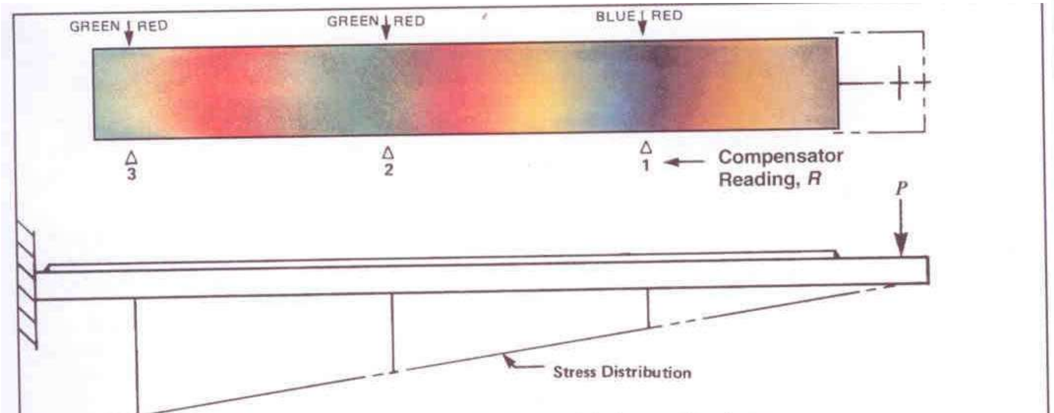
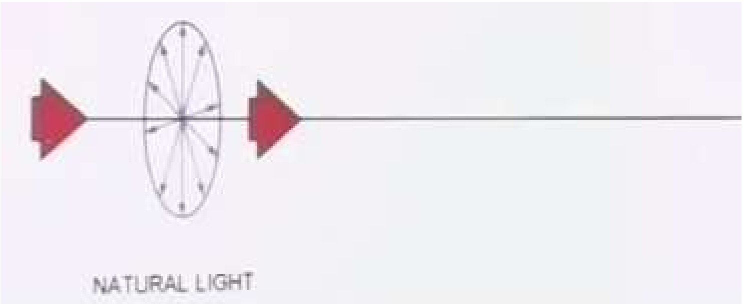


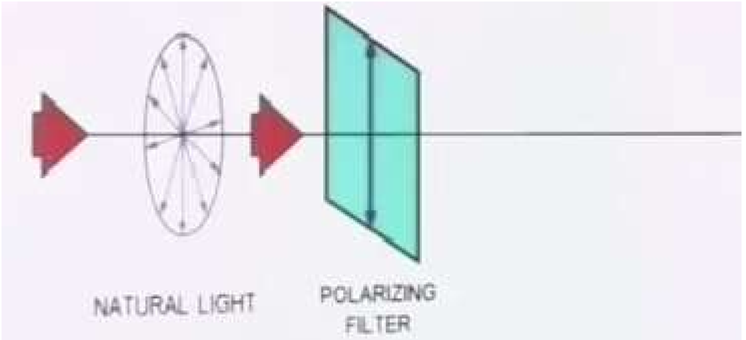
Fig. 12—Color band sequence on a coated aluminum cantilever beam.

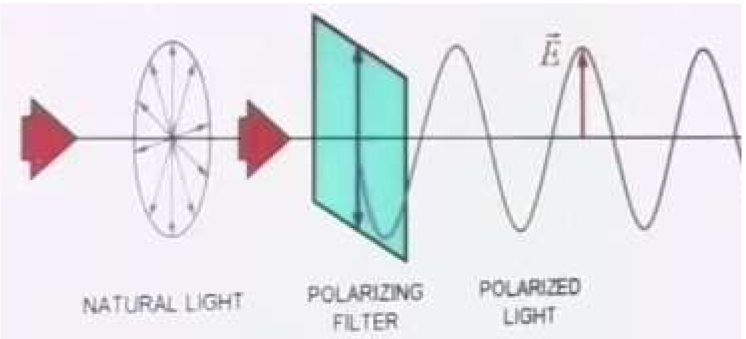
TABLE 1
Approximate Relationship Between Color Bands, Compensator Reading (R), and Stress

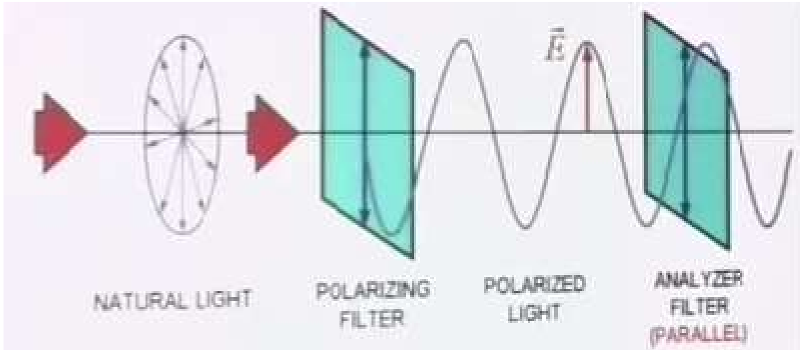
Color	Compensator Reading and Equivalent Stress (σ) when using PhotoStress Coating Type PS-1A on Aluminium	
BLACK	0	
YELLOW	0.6	
RED	0.9	
RED/BLUE TRANSITION	1.0	(4,736 PSI)
BLUE-GREEN	1.2	
YELLOW	1.5	
RED	1.75	
RED/GREEN TRANSITION	2.00	(9,472 PSI)
GREEN	2.2	
YELLOW	2.5	
RED	2.8	
RED/GREEN TRANSITION	3.0	(14,208 PSI)
GREEN	3.2	

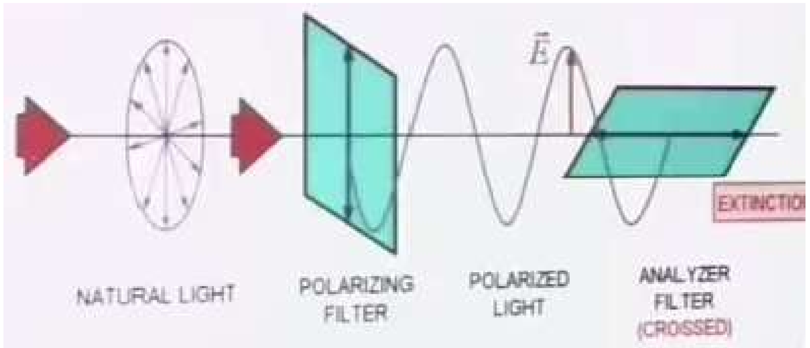
편광 원리


NATURAL LIGHT

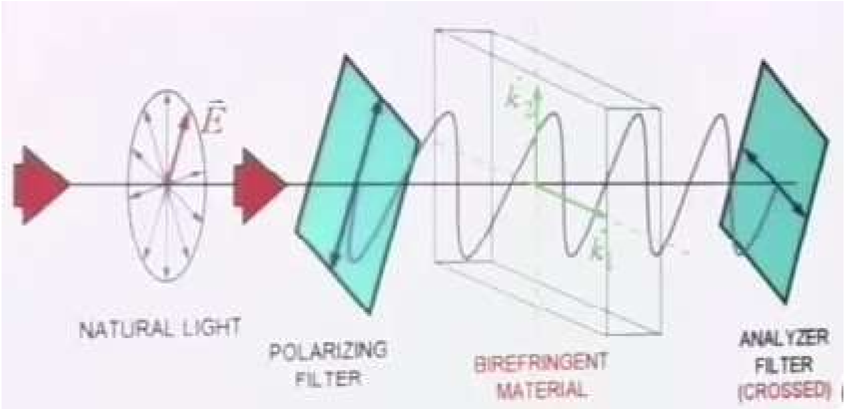

NATURAL LIGHT
POLARIZING FILTER

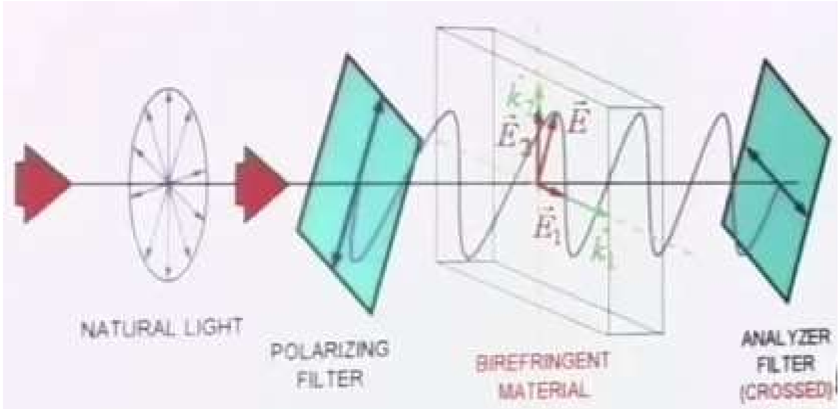

$\vec{E}$
NATURAL LIGHT
POLARIZING FILTER
POLARIZED LIGHT

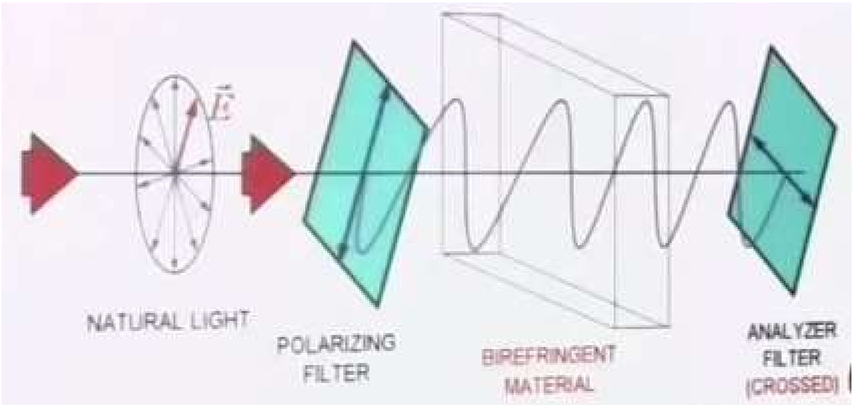

$\vec{E}$
NATURAL LIGHT
POLARIZING FILTER
POLARIZED LIGHT
ANALYZER FILTER (PARALLEL)

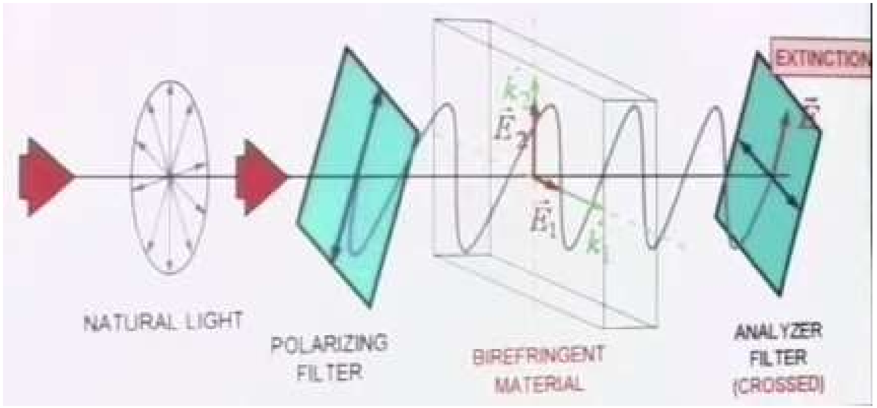

$\vec{E}$
NATURAL LIGHT
POLARIZING FILTER
POLARIZED LIGHT
ANALYZER FILTER (CROSSED)

광탄성 측정원리


NATURAL LIGHT
POLARIZING FILTER
BIREFRINGENT MATERIAL
ANALYZER FILTER (CROSSED)


NATURAL LIGHT
POLARIZING FILTER
BIREFRINGENT MATERIAL
ANALYZER FILTER (CROSSED)

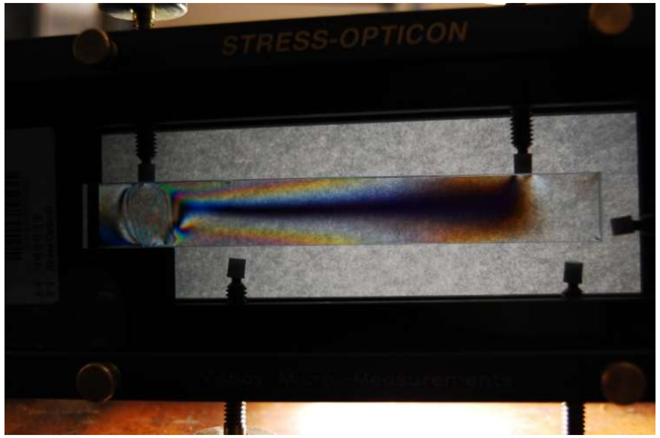

NATURAL LIGHT
POLARIZING FILTER
BIREFRINGENT MATERIAL
ANALYZER FILTER (CROSSED)


EXTINCTION
NATURAL LIGHT
POLARIZING FILTER
BIREFRINGENT MATERIAL
ANALYZER FILTER (CROSSED)

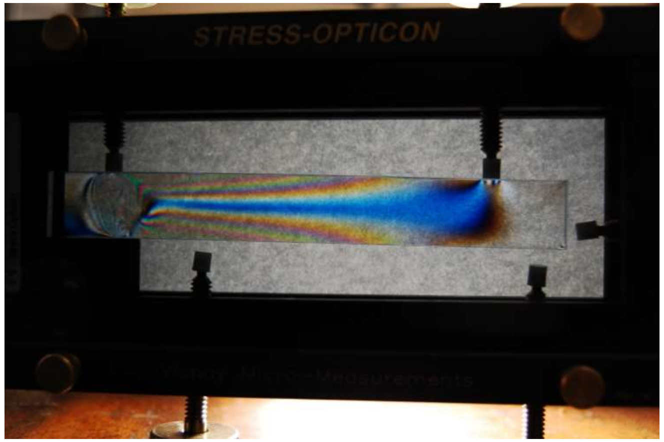
투과형 광탄성 실험

Deformation : 0mm

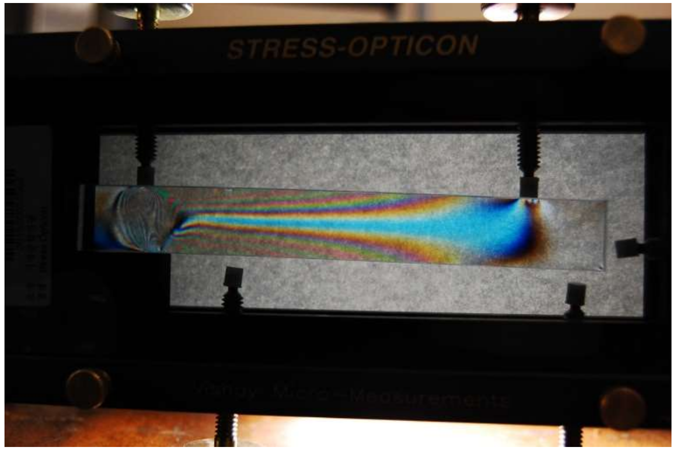
Deformation : 0.75 mm



Deformation : 1.50 mm



Deformation : 2.25 mm



투과형 광탄성 실험

$$\varepsilon_1 - \varepsilon_2 = \frac{\delta}{tK} = \frac{\lambda}{tK} N = fN$$

$$\varepsilon_1 - \varepsilon_2 = fN$$

$$\sigma_1 - \sigma_2 = \frac{E}{1+\nu} fN$$

$$\sigma_1 - \sigma_2 = KN$$

$$K = \frac{k}{t} = \frac{7}{5.57} = 1.26 MPa / fringe$$

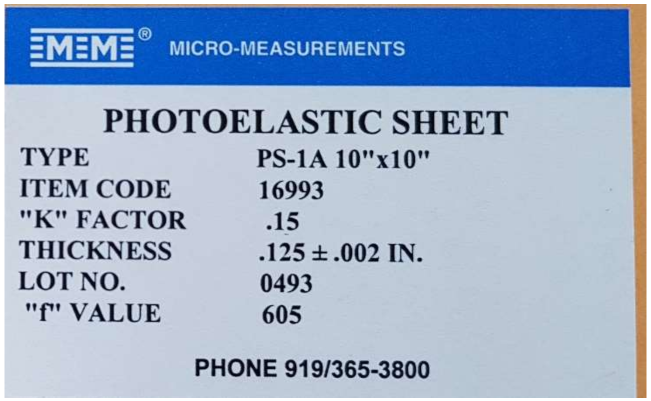
$$\sigma_1 - \sigma_2 = KN = 1.26 \times 2.5 = 3.15 MPa$$

Material Properties

E (Modulus) = 2.5GPa

v (Poisson's ratio) = 0.3

k (Stress-optic coefficient) = 7 MPa/fringe/mm



광탄성 적용 사례