– Engineering Design

Design is the formulation of a plan to satisfy a particular need, real or imaginary. "Engineering design" can be defined as the process of applying science and engineering methods to prescribe a component or a system in sufficient detail to permit its realization.

"Mechanical design" means the design of components and systems of of a mechanical nature – machine, structurs, devices, and instruments. For the most part, mechanical design utilize the stress analysis methods and materials engineering.

The ultimate goal in mechanical design process is to size and shape the components (elements) and choose appropriate materials and manufacturing processes so that the resulting system can be expected to perform its intended function without failure.

Generally, its assumed that a good design meets performance, aesthetics, and cost goals.

– Factor of Safety

Engineers employ a safely factor to ensure against the foregoing unknown uncertainties involving strength and loading. This factor is used to provide assurance that the load applied to the element doesnot exceed the largest load that can carry. Thus, the safety factor is

$$N = \frac{\text{material Strength}}{\text{allowable stress}}$$

$N \geqslant 1$ safe

$N < 1$ unsafe

– Failure Resulting from Static Loading

A static load is a stationary force or couple applied to a member. To be stationary, the force or couple must be unchanging in magnitude, point or points of application, and direction. A static load can produce axial tension or compression, a shear load, a bending load, a torsion load, or any combination of these. To be considered static, the load cannot change in any manner.

A part may fail if it yields and distorts sufficiently to not function properly. Also, a part may fail by fracturing and separating.

– Classification of Materials

Engineering materials may be classify to two general classes:

1. Ductile. $[\sigma_t = \sigma_c]$
2. Brittle. $[\sigma_c > \sigma_t]$

Here, if the material's percentage elongation is greater than 5%, then a material is considered ductile.

– Failure of Ductile Materials under Static loading

While ductile materials will fracture if statically stressed beyond their ultimate tensile strength, their failure in machine parts is generally considered to occur when they yield under static loading.

Historically, several theories have been formulated to explain this failure:

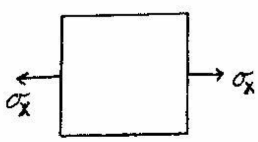
1. Max. shear stress theory.
2. Distortion energy theory.
3. Max. normal stress theory.

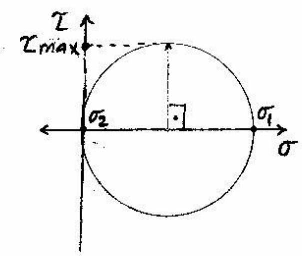
- Max. shear Stress Theory (For ductile materials)

The max. shear stress theory predicts that yielding begins whenever the max. shear stress in any element equal or exceeds the max. shear stress in a tension-test specimen of the same material when that specimen begins to yield. This theory is also referred to as "Tresca yield criterion"

For simple tensile stress, the max. shear stress occurs on a surface 45° from the tensile surface with a magnitude of

$$\tau_{max} = \frac{1}{2}\sigma_y = \tau_y \quad \cdots\cdots (1)$$





In general

$$\tau_{max} = \frac{1}{2}\left|\sigma_1 - \sigma_2\right| \quad \cdots\cdots (2)$$

Equating the above two equations

$$\Rightarrow \quad \sigma_1 - \sigma_2 = \sigma_y \quad \cdots\cdots (3)$$

For design purpose, Eq. (3) can be modified to incorporate a factor of safety, N. Thus,

$$\boxed{\tau_{max} = \frac{1}{2N}\sigma_y} \quad \text{or} \quad \boxed{\sigma_1 - \sigma_2 = \frac{\sigma_y}{N}} \quad \text{or} \quad \boxed{\tau_{max} = \frac{\tau_y}{N}}$$

Assuming that $\sigma_1 > \sigma_2$ there are three cases to consider Eq. (3)

$$\left.\begin{array}{l} \text{case 1: } \sigma_1 \geqslant \sigma_2 \geqslant 0 \\ \text{case 2: } \sigma_1 \geqslant 0 \geqslant \sigma_2 \\ \text{case 3: } 0 \geqslant \sigma_1 \geqslant \sigma_2 \end{array}\right\} \cdots\cdots (4)$$

Eq. (4) are represented in Fig (1)

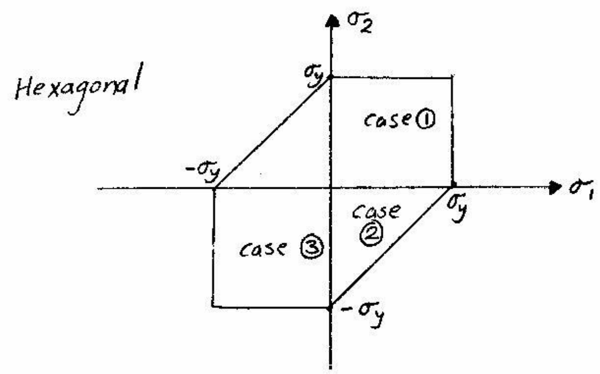


Fig. ① : Representation of Tresca yield Criterion

- Distortion Energy Theory (For ductile materials)

The microscopic yielding mechanism is now understood to be due to relative sliding of the materials' atoms within their lattice structure. This sliding is caused by shear stress and is accompanied by distortion of the shape of the part. The energy stored in the part from this distortion is an indicator of the magnitude of the shear stress present.

$$\boxed{(\sigma_1^2 - \sigma_1 \sigma_2 + \sigma_2^2)^{\frac{1}{2}} = \frac{\sigma_y}{N}}$$

— ⑤ In term of principal stresses

the term $\sigma_1^2 - \sigma_1\sigma_2 + \sigma_2^2 = \bar{\sigma}$ ($\bar{\sigma} \equiv$ effective stress)

$$\boxed{(\sigma_x^2 + \sigma_y^2 - \sigma_x \sigma_y + 3\tau_{xy}^2)^{\frac{1}{2}} = \frac{\sigma_y}{N}}$$

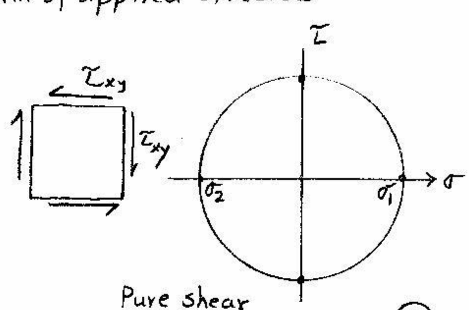
— ⑥ In term of applied stresses

For pure shear case

$\sigma_1 = \tau = -\sigma_2$

Eq. ⑤ becomes

$$\tau_{max} = \sigma_1 = \frac{\sigma_y}{\sqrt{3}\,N} = 0.577\,\frac{\sigma_y}{N} \quad \text{---- ⑦}$$



Pure shear

The representation of Eq. (5) is shown in Fig. (2) below

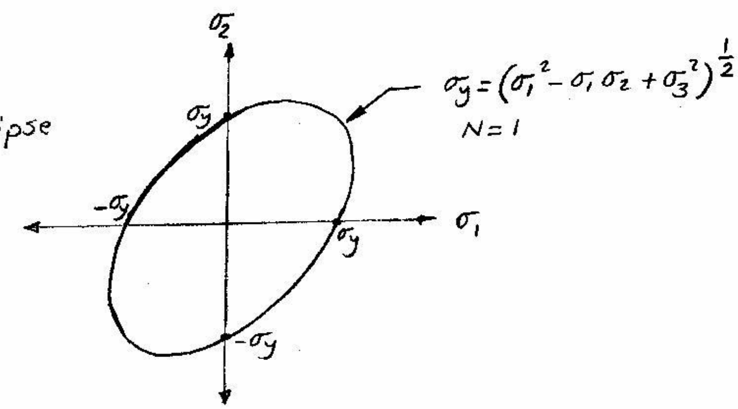


Fig (2): Representation of Distortion Energy Theory

*NOTE

The distortion energy theory is also called von Mises theory.

<u>Max. Normal Stress Theory (For ductile materials)</u>

This theory stats that failure will occur when the normal stress in the spacimen reaches some limit or normal strength such as tensile yield strength or ultimate tensile strength.

$$\boxed{|\sigma_1| = \frac{\sigma_y}{N}} \quad |\sigma_1| > |\sigma_2| \qquad \text{or} \qquad \boxed{|\sigma_2| = \frac{\sigma_y}{N}} \quad |\sigma_2| > |\sigma_1|$$

*NOTE

This theory is not safe for ductile materials

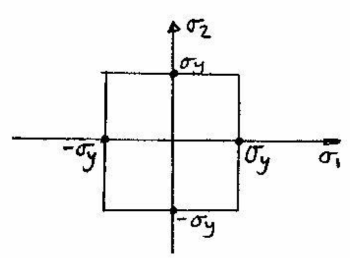


Fig. (3): Representation of max. normal stress theory