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Kolmetz Handbook Of Process Equipment Design

ENGINEERING MATERIALS AND THEIR STRENGTH FUNDAMENTALS

(ENGINEERING DESIGN GUIDELINES)

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INTRODUCTION

Scope

Many times, a materials problem is one of selecting the right material from the many thousands that are available. There are several criteria on which the final decision is normally based. the in-service conditions must be characterized, for these will dictate the properties required of the material. On only rare occasions does a material possess the maximum or ideal combination of properties. Thus, it may be necessary to trade off one characteristic for another.

Strength of materials is general expression for the measure of capacity of resistance possessed by solid masses or pieces of various kinds to any causes tending to produce in them a permanent and disabling change of form or positive fracture.

Strength of materials deals with the relations between the external forces applied to elastic bodies, and the resulting deformations and stresses. In the design of structures and machines, the application of the principles of strength of materials is necessary if satisfactory materials are to be utilized and adequate proportions obtained to resist functional forces.

Strengths are the magnitudes of stresses at which something of interest occurs, such as the proportional limit, 0.2 percent-offset yielding, or fracture. In many cases, such events represent the stress level at which loss of function occurs.

This Training Module provides an overview one of the basic fundamentals of engineering. The knowledge of the types of engineering materials and the strength of those materials is essential to construct safe process equipment. This module will help develop the basics of material choices, and their underlying strength.

A wealth of information can be established by looking at the structures of a material. Engineering Materials is the study of information about materials that in general have been used in many industrial application such as Irons, Carbon Steels, Alloy Steels, Stainless Steel, Non – Ferrous Metals, Plastics, Composites, and Ceramics. The strengths and weakeness, corrosion, and when to utilize these material is very important.

General Considerations

I. Material Standards and Specifications

A standard is a document, definition, or reference artifact intended for general use by as large a body as possible, a specifications, which involves similar technical content and similar format, usually is limited in both its intended applicability and its users.

Standards have been a part of technology since building began. Standarization minimizes diversity, assures acceptability of products, and facilitates technical communication. There are many attributes of materials that are subject to standarization in example : Composition, Physical Properties, Mechanical Properties and etc.

However, a specification is defined as 'a document intended primarily for use in procurement which clearly and accurately describes the essential technical requirements for items, materials, or services inculding the procedures by which it will be determined that the requirements have been met'. A second definition defines a specification as 'a source statement of a set of requirements to be satisfied by product, a material or a process indicating whenever appropriate, the procedure by means of which it may be determined whether the requirements given are satisfied.

Noted that :

(1) A specification may be standard, a part of standard, or independent of a standard,

(2) As far as practicable, it is desired that the requirements are expressesd numerically in terms of appropriate units, together with their limits.'.

The objectives of standarization are;

1. Economy of production by way of economies of scale in output, optimization of varieties in input material,
2. Improved managerial control, assurance of quality,
3. Improvement of interchangeability,
4. Facilitation of technical communication,
5. Enchancement of innovation and technological progres
6. Promotions of the safety persons, goods, and the environment.

Material specifications may be classified as to whether they are applied to the material, the process by which it is made, or the performance or use that is expected of it.

II. Engineering Material

Materials that are used as raw material for any sort of construction or manufacturing in an organized way of engineering application are known as Engineering Materials. The most convenient way to study the properties and uses of engineering materials is to classify them into families of material that are described as follow :

A. Metals

Materials in this group are composed of one or more metallic elements (such as iron, aluminum, copper, titanium, gold, and nickel), and often also nonmetallic elements (for example, carbon, nitrogen, and oxygen) in relatively small amounts. With regard to mechanical characteristics, these materials are relatively stiff and strong, yet are ductile, and are resistant to fracture, which accounts for their widespread use in structural applications[7].

B. Ceramics

Ceramics are compounds between metallic and nonmetallic elements; they are most frequently oxides, nitrides, and carbides. In addition, those also composed of clay minerals (i.e., porcelain), as well as cement, and glass. With regard to mechanical behavior, ceramic materials are extremely brittle (lack ductility), and are highly susceptible to fracture. Despite this, they have attractive features. They are stiff, hard, and abrasion resistant (hence their use for bearings and cutting tools); they retain their strength to high temperatures; and they resist corrosion well[1].

C. Polymers

Polymers include the familiar plastic and rubber materials. Many of them are organic compounds that are chemically based on carbon, hydrogen, and other nonmetallic elements (viz.O,N, and Si). Furthermore, they have very large molecular structures, often chain-like in nature that have a backbone of carbon atoms. They are not as stiff nor as strong as these other material types. Typically, these materials have low densities and based on those, many times their stiffnesses and strengths on a per mass basis are comparable to the metals and ceramics. In addition, many of the polymers are extremely ductile and pliable (i.e., plastic), which means they are easily formed into complex shapes.

D. Composite

A composite is composed of two (or more) individual materials, which come from the categories such as metals, ceramics, and polymers.The design goal of a composite is to achieve a combination of properties that is not displayed by any single material, and also to incorporate the best characteristics of each of the component materials[7]. Fiber-reinforced composites are, of course, the most familiar. Most of those at present available to the engineer have a polymer matrix reinforced by fibers of glass, carbon or Kevlar (an aramid).

III. Mechanical Behaviors and Properties of Materials

The fundamental concepts in mechanics of materials are considered by description as follow.

A. Stress and Strain Behaviours

In the design process, one of an important problem is to ensure that the strength of the mechanical element to be designed always exceeds the stress due to any load exerted on it. Stress is the force per unit area and is usually expressed in pounds per square inch. If the stress tends to stretch or lengthen the material, it is called tensile stress; if to compress or shorten the material, a compressive stress; and if to shear the material, which is caused by forces perpendicular to the area on which they act, it is called shearing stress. Tensile and compressive stresses always act at right-angles to (normal to) the area being considered; shearing stresses are always in the plane of the area (at right-angles to compressive or tensile stresses)[14].

(a) Tensile stress (b) Compressive stress (c) shearing stress

Figure 1 : stress types

Strain is known as deformation produced by stress, strain is the ratio of the change in length caused by the applied force, to the original length. Typically, material is done tensile test to know stress – strain curve by static loading of a standard specimen or specifing the strain rate as the indenpedent variable, in which case the loading rate is continuously adjusted to maintain the required strain rate. Stress-strain curve is a characteristic of the particular material being tested and conveys important information about the mechanical properties and type of behavior[20].

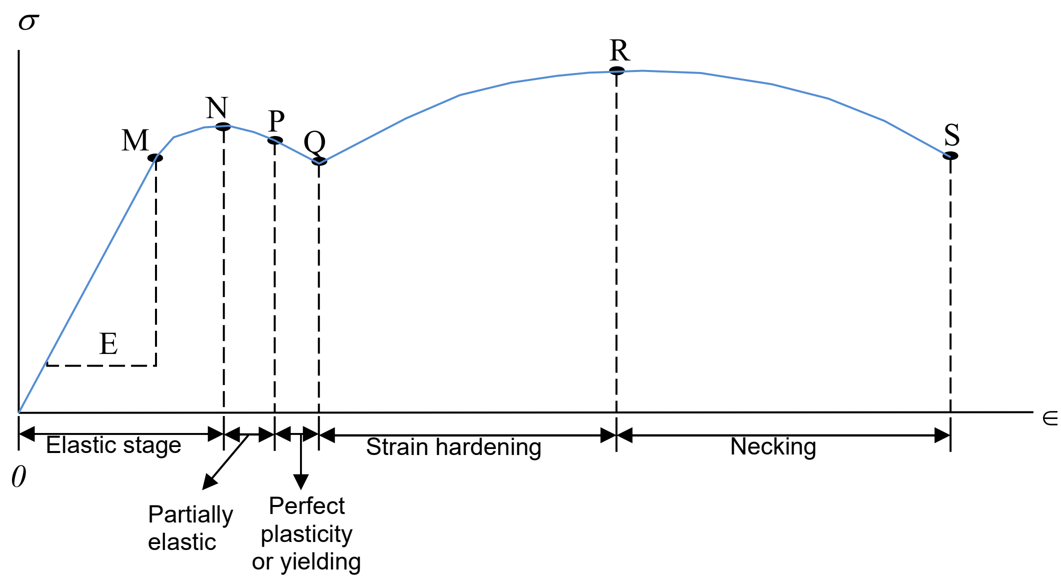

Figure 2 : stress-strain curve

The figure explains that the points at curve are :

a. Proportional Limit

   The proportional limit is the highest stress at which stress is linearly proportional to strain. This is also the point at which the curve first begins to deviate from a straight line The point lies at M and the slope in this stage is called Young's Modulus E.

b. Elastic Limit

   Elastic limit is the maximum stress to which a test specimen may be subjected and still return to its original length upon release of the load. At point N elastic limit is reached. For most materials and applications this can be considered the practical limit to the maximum stress a component can withstand and still function as designed.

c. Yield

Yield point is a point on the stress-strain curve at which there is a sudden increase in strain without a corresponding increase in stress. Commonly, there are two points P and Q, the upper and lower yield points. Not all materials have an obvious yield point, especially for brittle materials.

The yield strength is the minimum stress which produces permanent plastic deformation. The yield strength also is indicative of the ease of forming or shaping metals by mechanical stress. The yield strength is usually defined at a specific amount of plastic strain, or offset, which may vary by material and or specification. The offset is the amount that the stress-strain curve deviates from the linear elastic line. The most common offset for structural metals is 0.2%[6].

d. Ultimate Tensile Strength

The ultimate tensile strength (UTS) is the maximum load sustained by the specimen divided by the original specimen cross-sectional area. This point lies at R. When this point is reached, the deformation or extension continues even with lesser load and ultimately fracture occurs at point S.

Combined Stresses refer to the situation in which stresses are present on each of the faces of a cubic element of the material. For a given cube orientation the applied stresses may include shear stresses over the cube faces as well as stresses normal to them.

B. Fatigue

Generally, fatigue is understood as the gradual deterioration of a material which is subjected to repeated loads. In fatigue testing, a specimen is subjected to periodically varying constant-amplitude stresses by means of mechanical or magnetic devices. The most common loading is alternate tension and compression of equal numerical values obtained by rotating a smooth cylindrical specimen while under a bending load. A series of fatigue tests are made on a number of specimens of the material at different stress levels.

C. Creep

In metals, creep is plastic deformation caused by slip occuring along crystallographic directions in the individual crystals, together with some flow of the grain-boundary material. After complete release of load, a small fraction of this plastic deformation is recovered with time. Most of the flow is nonrecoverable for metals. The most common are the long-time creep test under the stress-relaxation test and the constant-strain-rate test. The long time creep test is conducted by applying a dead weight to one end of a lever system, the other end being attached to the specimen surrounded by a furnace and held at constant temperature.

D. Hardness

Hardness has been variously described as resistance to local penetration, to scratching, to machining, to wear or abrasion, and to yielding. The multiplicity of definitions, and corresponding multiplicity of hardness-measuring instruments, together with the lack of a fundamental definition, indicates that hardness may not be a fundamental property of a material but rather a composite one including yield strength, work-hardening, true tensile strength, modulus of elasticity, and others.

DEFINITIONS

Amorphous - Not having a crystal structure; noncrystalline.

Bending stress - A physical quantity of combination amount of distance from 'centre – pooint' material and bending moment that divided by second moment area of section.

Bolts– A conjuction inbetween two separate material for a non-permanent fastening.

Combined Stresses– An event when stresses are present on each of the faces of a cubic element of material.

Creep – Plastic deformation caused by slip occuring along crystallographic directions in individual crystals.

Crystalline polymer- A polymer with ordered structure that has been allowed to disentangle and form crystals such as HDPE. Thus, isotactic polypropylene, cellulose, and stretched rubber are crystalline polymers.

Ductility - The ability of a material to be bent, formed, or stretched without rupturing. Measured by

elongation or reduction of area in a tensile test or by other means.

Elastic limit - The maximum stress to which a test specimen may be subjected and still return to its original length upon release of the load.

Endurance limit - The maximum stress below which a material can presumably endure an infinite number of stress cycles.

Eutectic - upon cooling, a liquid phase transforms isothermally and reversibly into two intimately mixed solid phases; the lowest melting composition in a material system.

Factor of Safety – The ratio of the actual strength to the required strength

Fatigue – Gradual deterioration of material which is subjected to repeated loads.

Failure Event– An event that established as a result of crack propagation without plastic deformation at a stress well below the elastic limit.

Glass transition temperature (Tg)- A characteristic temperature at which glassy amorphous polymers become flexible or rubber-like because of the onset of segmental motion

Hardness–Resistance of materials to any force load from its outside surface such as local penetration, scratching, machining, abrasion or yielding.

Melting point (Tm)- The first-order transition when the solid and liquid phases are in equilibrium.

Modulus - The ratio of stress to strain, as of strength to elongation, which is a measure of stiffness of a polymer.

Proportional limit - The highest stress at which stress is linearly proportional to strain.

Strain–How much an extension of any materials from its original length.

Stress –An amount of force load to a certain area of material.

Spherulites- Aggregates of polymer crystallites.

Stress Concentration Factor (K)–A highest value of stress at discontinuity divided to an amount of stress at its minimum cross-section area.

Torsion –The twisting of an object due to an applied torque.

Ultimate Tensile Strength (UTS)–The maximum load sustained by the specimen divided by the original specimen cross-sectional area.

Welds–An activity to join two separate material by an addition of metals or thermoplastics by causing coalescence.

Yield point - A point on the stress-strain curve at which there is a sudden increase in strain without a corresponding increase in stress.

NOMENCLATURE

A	: Area of cross section, in^2 (m^2)
a	: Thickness of the fork, in (m)
B	: Bulk compliance, psi^{-1} (Pascal / $N/m^2)^{-1}$
b	: The thickness of the eye, in (m)
C	: Distance across corners, in (mm)
c	: Radius, in (m)
D	: Diameter, in (m)
D	: Outside or major diameter of thread, in (mm)
D	: Tensile compliance, psi^{-1} (Pascal / $N/m^2)^{-1}$
E	: Young's Modulus, psi (Pascal / N/m^2)
F	: Force, lbf (N)
f	: Frequency, Hz (s^{-1})
G	: Shear Modulus, psi (Pascal / N/m^2)
h	: Height fallen mass, in (m)
I	: Second moment of area of section lbm.in^2 (kg.m^2)
J	: Polar moment of inertia, in^4 (m^4)
K	: Bulk Modulus, psi (Pascal / N/m^2)
L	: Length, in (mm)
M	: Bending moment, lbf.in (Nm)
m	: Weibull's modulus constant
N	: Shaft speed, rpm
P	: Load, lb (N)
P	: Power, hp (watts)
p	: Mean perimeter, in (m)
S	: Elastic section modulus, I/c, in^3 (m^3)
T	: Torque, lb.in or lb.ft (N.m)
t	: Thickness, in (m)
V	: Volume fraction, dimensionless
v	: Velocity, in/s (m/s)
v	: Poisson's ratio, dimensionless
x_s	: Steady extension, in (m)

Greek Letter

δ	: Total elongation, in (m)
$\in$	: strain, in/in (m/m)
τ	: shear stress, psi (Pascal / N/m^2)
τ_m	: Maximum shear stress, psi (Pascal / N/m^2)
γ	: shear strain, in/in (m/m)
ρ	: radius of curvature of the path, ft (m)
σ	: Stress, psi (Pascal / N/m^2)
σ	: bending stress, psi (Pascal / N/m^2)
σ_m	: Maximum tensile stress, psi (Pascal / N/m^2)
σ_s	: Steady stress, psi (Pascal / N/m^2)
ϕ	: angle twist, rad