بسم الله الرحمن الرحیم

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Faculty of Materials Science and Engineering

# Selection of Engineering Materials

## Fifth Session
## (Materials Selection Process- 3)

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# Materials Selection

- ✓ In order to assistance in materials selection, computers and related software containing material properties (such as key to steel, etc.) are used.
- ✓ You can also use existing resources such as Metals Handbook (volumes 1, 2 and 3), Materials Engineering annual publication, Reference Books of ASM, ASTM, SAE, Handbook of Polymers and Ceramics, etc.

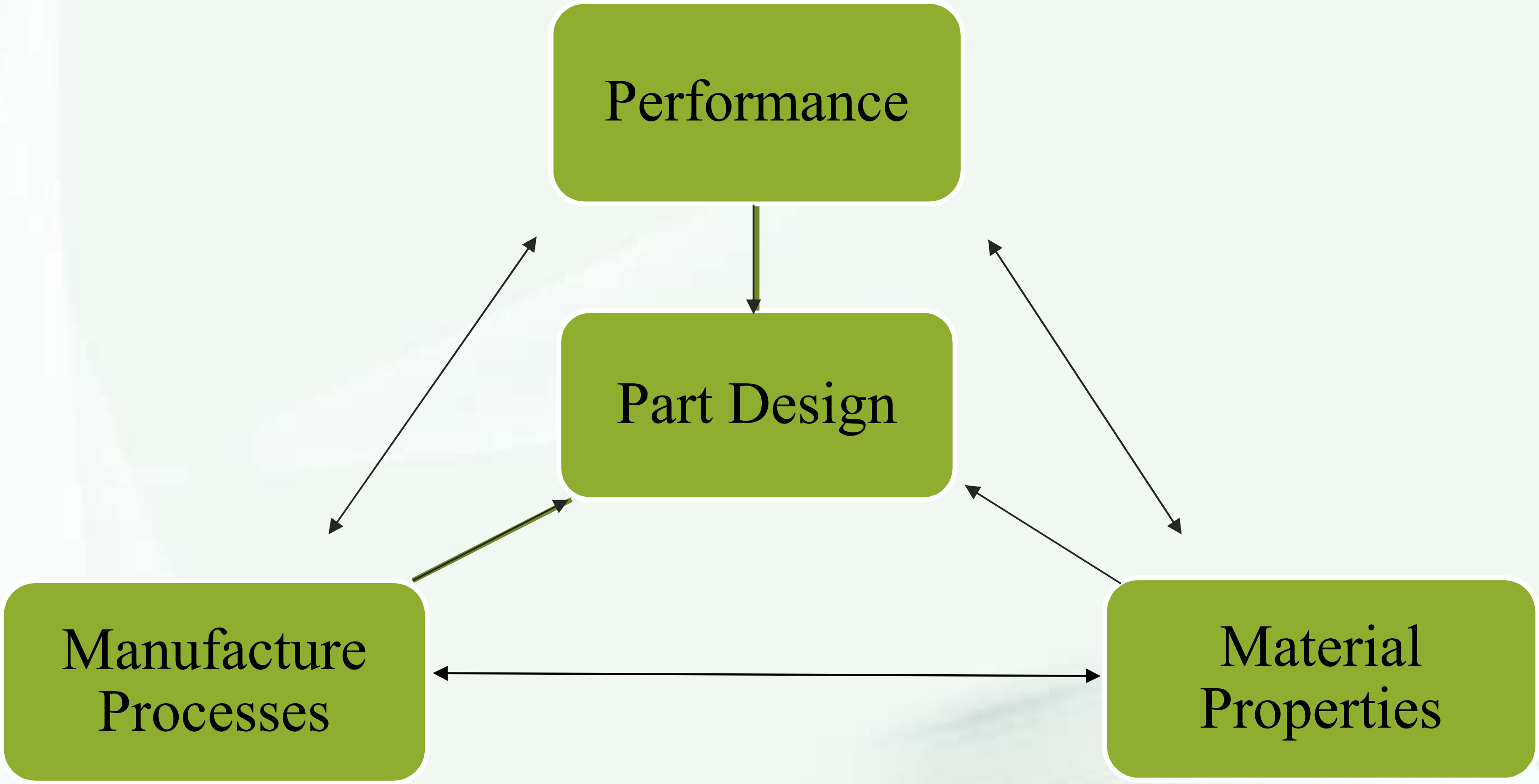
# Materials Selection

## Materials Selection based on Different Criteria of Material Properties

- ✓ In a successful design, product performance, material properties and processes should be considered.

- ✓ There should also be checked secondary relationships between material properties and manufacturing processes, the performance and manufacturing processes and between the performance and properties of the materials should be checked.

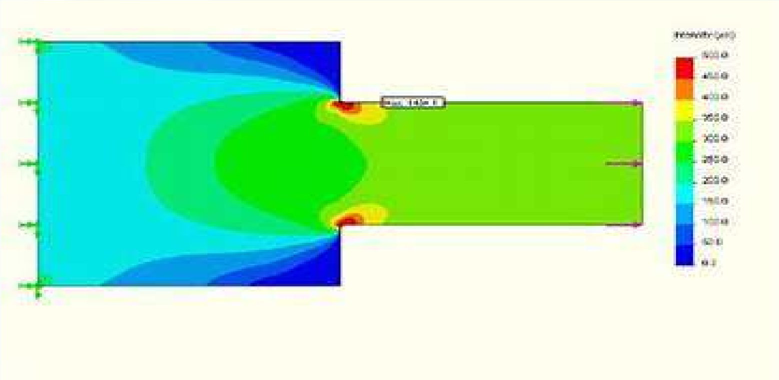
# Materials Selection

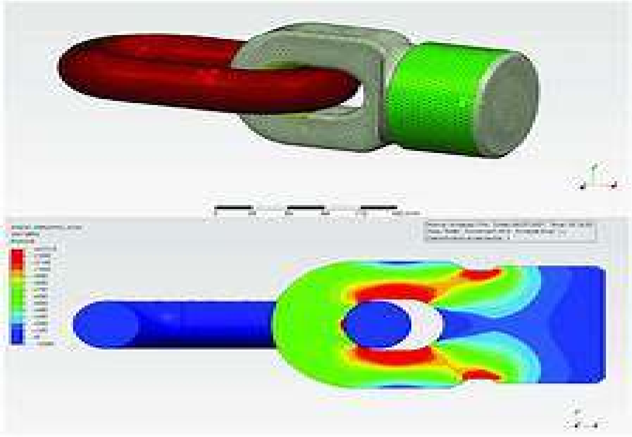


# Materials Selection

## Part Geometry Effect

- ✓ In most cases, the components of machines and engineering parts must follow specific patterns that cause changes in their cross section.
- ✓ The presence of notch, hole, screw, pin, gear teeth, etc. will change the cross-section of the parts and will cause local concentration of stress.





## Part Geometry Effect

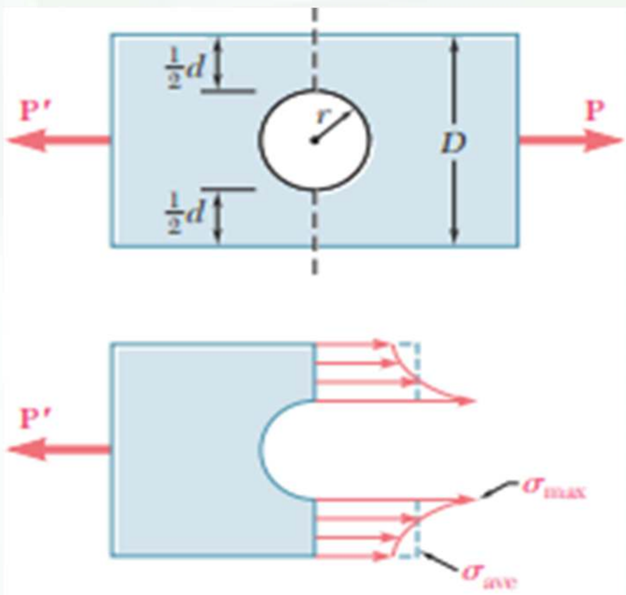
$\sigma_{max}$ :Maximum stress in discontinuity

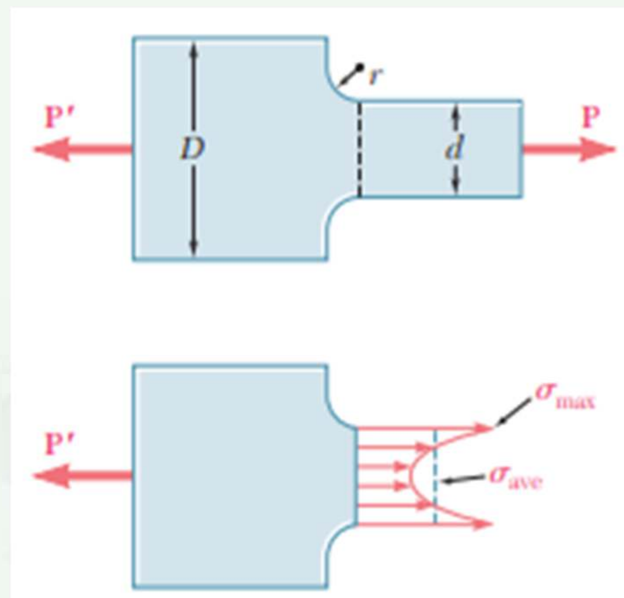
$\sigma_{avg}$ :Nominal stress

$K_t$ :The stress concentration coefficient

$\sigma_{avg} = \sigma_{nominal}$

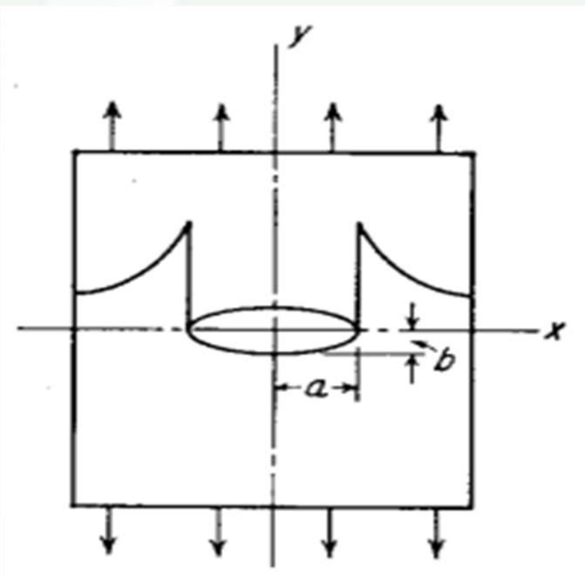
$$K_t = \frac{\sigma_{max}}{\sigma_{nominal}}$$



## Part Geometry Effect

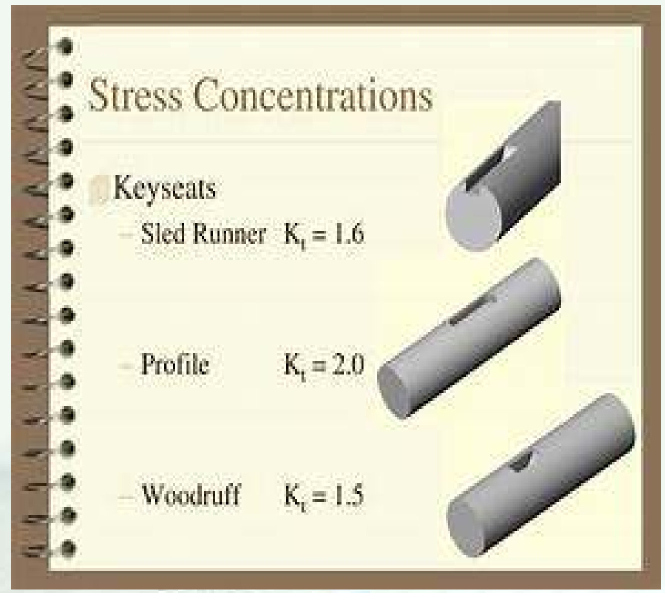
The stress concentration coefficient depends on the geometry of the part. For example, for an oval hole in an infinite flat plane, is:




$$\sigma_{max} = \sigma\left(1 + 2\frac{a}{b}\right)$$

$$K_t = \frac{\sigma_{max}}{\sigma_{nominal}}$$

$$K_t = 1 + 2a/b$$




2a: Dimension of the hole perpendicular to the tension axis

2b: Dimension of the hole parallel to the stress axis

For a circular hole, a = b, so $K_t = 3$

# Materials Selection

## Part Geometry Effect

- ✓ In ductile and tough materials, local yielding in a very small area under higher stress causes a large reduction in stress concentration. Therefore, generally, in static loading for these materials, the factor of stress concentration is not considered, but for brittle materials with low ductility, surface hardened or severely cooled work, this factor should be considered.

## Part Geometry Effect

- ✓ Stress concentration should also be considered in the design of parts under cyclic loading (fatigue). In this case, $K_f$ is used for fatigue stress concentration factor or strength reduction factor. $K_f$ is simply the ratio of the fatigue limit of unnotched specimens (without crack) to the fatigue limit of notched specimens (with crack).

## Part Geometry Effect

The notch sensitivity is expressed by the variable q.

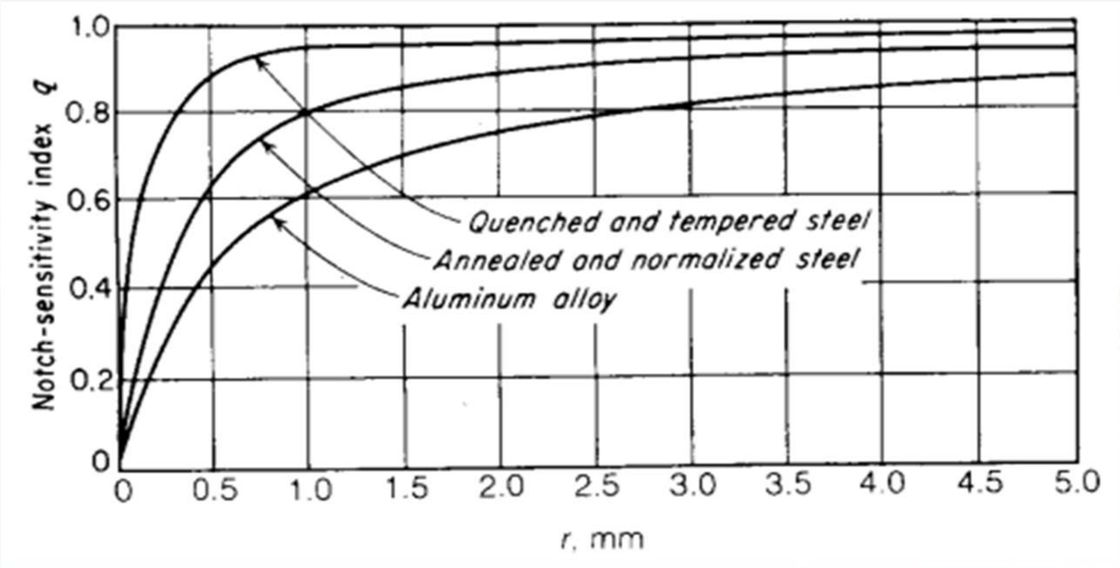
$$q = \frac{K_f - 1}{K_t - 1}$$

$K_f$: the ratio of fatigue strength without the presence of stress concentration to fatigue strength in the presence of stress concentration

$K_t$: the stress concentration factor, which is indicative of the intensity of the notch effect and is obtained from the ratio of the maximum local stress at the tip of the notch to the average stress

## Part Geometry Effect

- ✓ By changing q from zero to one, the sensitivity of the material to the presence of stress concentration increases. Generally, increasing the strength of materials makes them more sensitive to the points of stress concentration and causes an increase in the amount of q.



## Part Geometry Effect

- ✓ q also increases with the increasing of the size of the specimen, so stress concentration points in larger parts are more dangerous.
- ✓ If $K_t=K_f$, the q value is one and the material is completely notch sensitive.
- ✓ If the material is not sensitive to the notch at all, the value of $K_f$ is equal to one and q=0.

# Materials Selection

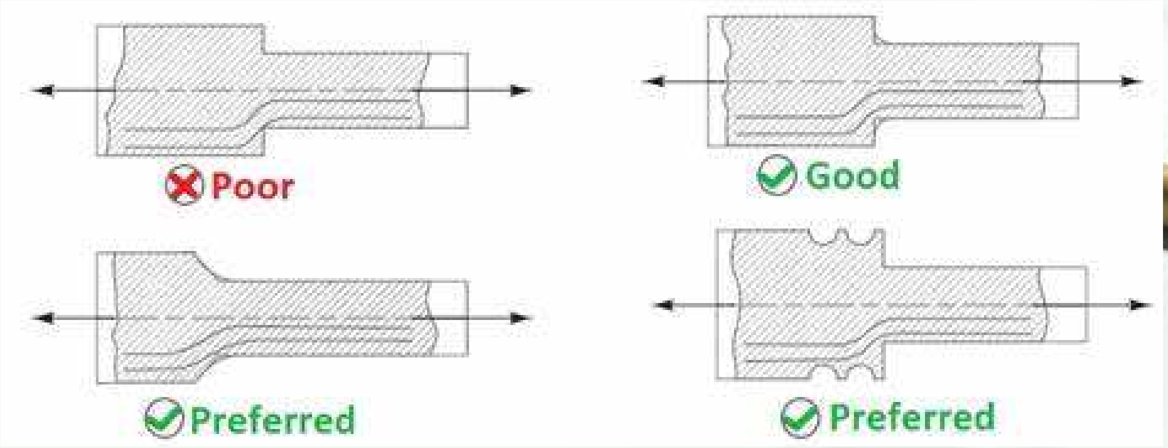
## Part Geometry Effect

- ✓ In design, $K_t$ is generally estimated according to the geometry of the part. Then, by choosing the material, the value of q is determined and $K_f$ is extracted with the existing relationship. In case of any doubt, it is better to assume $K_t=K_f$ to be on the safe side.
- ✓ In general, due to the high impact of stress concentration and the possibility of failure due to the origin of stress concentration, design rules must be followed, especially for high strength materials under fatigue loads to minimize the amount of stress concentration.

# Materials Selection

## Rules (Solutions) to Reduce Stress Concentration in Parts

- ✓ Sudden changes in the section should be avoided. If necessary, these section changes should be designed by chamfers and rounded corners instead of sharp corners or usage of tension relieving notches.
- ✓ Notches and recesses should be in large radius in all corners.
- ✓ At the end of threads and splines, should be tension relieving notches.



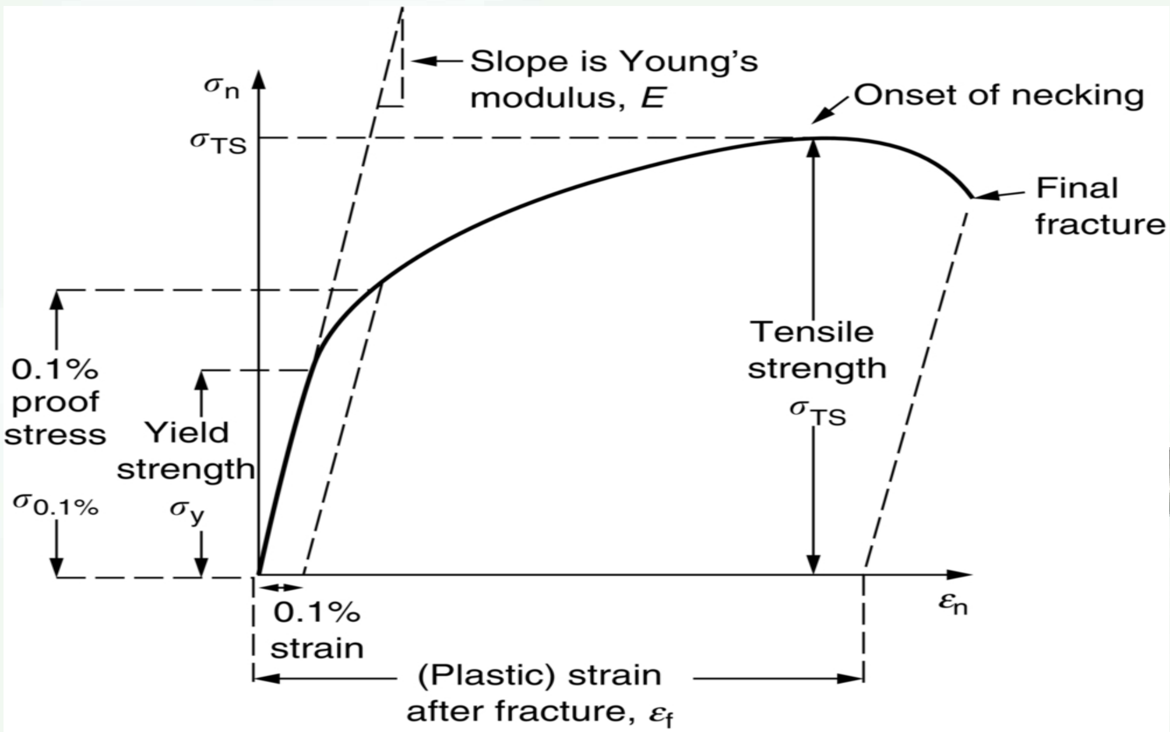
# Materials Selection

## Rules (Solutions) to Reduce Stress Concentration in Parts

- ✓ Avoid sharp internal corners and external sharp edges.
- ✓ Holes should be polished smooth.
- ✓ Holes, characteristic signs and part number should not be in high stress areas.
- ✓ Weakening features should not be aligned in the same direction to avoid accumulation of stress concentration effects.

# Materials Selection based on Strength Criterion

- ✓ Strength is the first property of any engineering material that is considered for structural applications. Ultimate tensile strength, yield strength, compressive strength and hardness are generally considered for the material's resistance to deformation.



# Materials Selection based on Strength Criterion

## Strength Criterion for Metals

- ✓ For metals, tensile and yield strength are considered during application. Metals are divided into 4 groups in terms of strength.

a) Metals with Low Strength: Yield Stress < 250 MPa

Most pure metals have little strength, which depends on their purity.

| | |
|---|---|
| Aluminum with a purity of 99.99% | Yield Stress = 12 MPa |
| Aluminum with a purity of 99% | Yield Stress = 39 MPa |

# Materials Selection based on Strength Criterion

b) Metals with Medium Strength: 250 MPa < Yield Stress < 750 MPa

To obtain average strength in most metals, they must be alloyed.

c) Metals with High Strength: 750 MPa < Yield Stress < 1500 MPa

Many medium carbon and low alloy steels and most titanium alloys are in this range.

d) Metals with Very High Strength: Yield Stress > 1500 MPa

Like some steels

# Materials Selection based on Strength Criterion

| Low Strength | Medium Strength | High Strength | Very High Strength |
|---|---|---|---|
| Gold | Cobalt Base Superalloys | Molybdenum and Its Alloys | Cobalt and Its Alloys |
| Cast Magnesium Alloys | 7XXX Series Aluminum Alloys | Carbon Steels | Nickel and Its Alloys |
| Lead and Its Alloys | 2XXX Series Aluminum Alloys | Iron Based Superalloys | Hardened Low Alloy Steels |
| Tin and Its Alloys | Ductile Cast Iron | Tantalum and Its Alloys | Stainless Steels |
| 1XXX Series Aluminum Alloys | Uranium | Bronzes | High Strength Steels |
|  | Zirconium and Its Alloys | Cast Copper Alloys |  |
|  | Magnesium Alloys | Titanium and Its Alloys |  |

# Materials Selection based on Strength Criterion

Cast metals reinforced by fibers have good strength but poor ductility. These composites are generally the following:

| Matrix | Fibers | Application example |
|---|---|---|
| Al, Cu, Mg, Pb | graphite | Rockets, Shuttles and Bearings |
| Ti, Mg, Al | B | Jet Engine Blade and Antenna |
| Mg, Pb, Al | $Al_2O_3$ | Battery Plates |
| Al, Ti, and Cobalt Base Superalloys | SiC | High Temperature Structures and High Temperature Engine Components |
| Superalloy | Mo | Engine Components in High Temperature Conditions |
| Superalloy | W | Engine Components in High Temperature Conditions |

## Strength Criterion for Polymers

- ✓ The behavior of polymers under stress is different and more complex than metals, and time and temperature also affect their properties.
- ✓ Thermoplastic polymers have a tensile strength of 55-103 MPa and the tensile strength of thermoset polymers is higher. In general, the strength of polymers is low, but polymers can be reinforced with reinforcing materials, especially ceramic and polymer fibers (composite) to improve their mechanical properties.

# Materials Selection based on Strength Criterion

## Strength Criterion for Ceramics

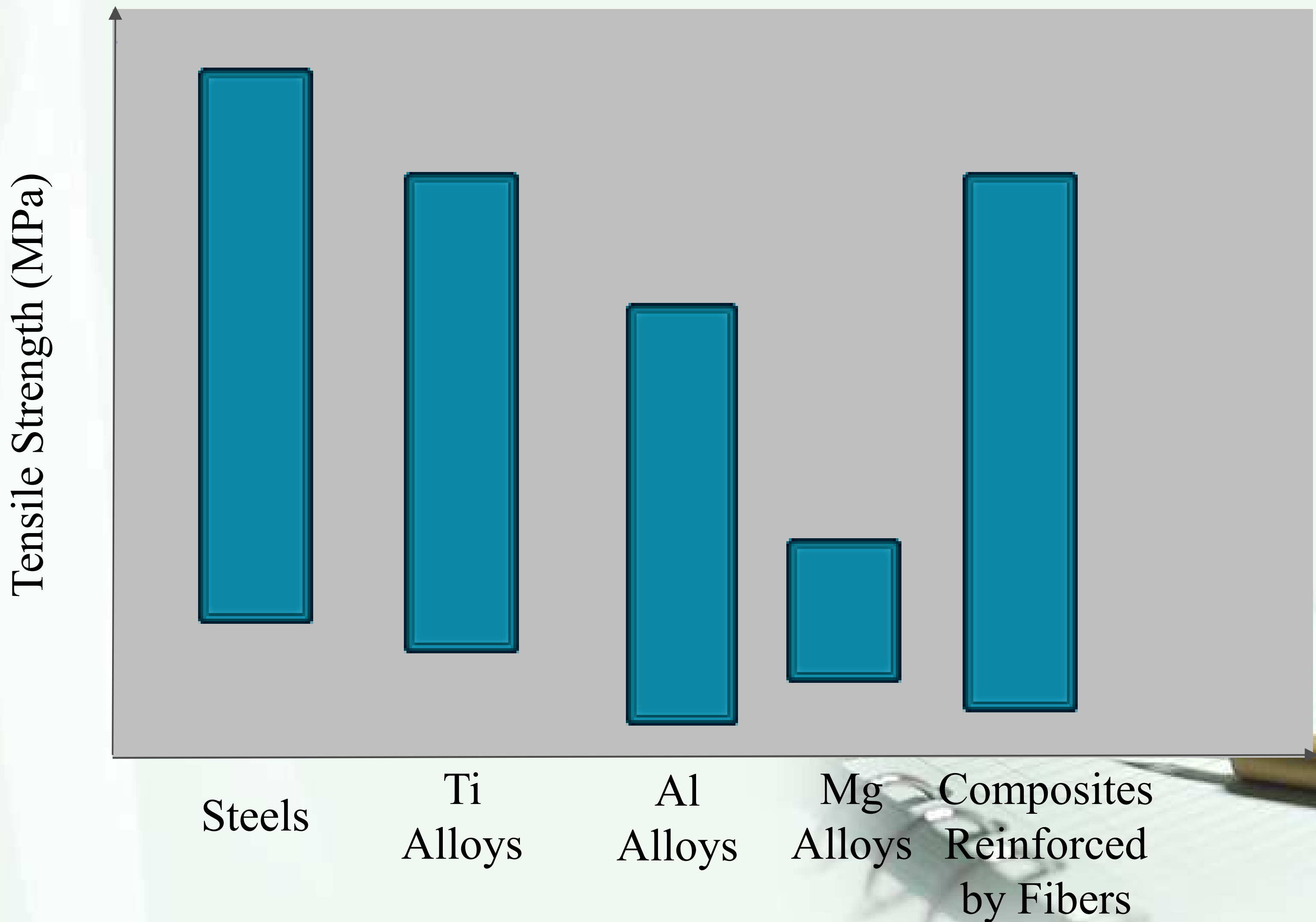
- ✓ The strength of ceramics depends on the preparation method, surface and mechanical treatment, and test conditions.
- ✓ Ceramics are weak against tensile stresses and resistant to compressive stresses. But for metals, the compressive strength is about the tensile strength.
- ✓ The compressive strength of ceramics can be even more than 10 times their tensile strength. For example, for alumina, the tensile strength is about 138 MPa and the compressive strength is about 2400 MPa.

# Materials Selection based on Strength Criterion

## Comparison of Engineering Materials Based on Tensile Strength and Specific Tensile Strength

- ✓ In some applications such as aerospace industries, transportation, structures and portable devices, the weight of the specimen is so important. In this case, it is important to compare and select materials based on the ratio of strength to specific weight (specific strength). In the case of examining tensile strength alone, steels are superior materials to Al, Mg, Ti alloys and many composites, but the subject changes in specific strength.

# Materials Selection based on Strength Criterion



# Materials Selection based on Strength Criterion