

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE  
NPTEL  
NPTEL ONLINE CERTIFICATION COURSE  
Structural Analysis of Nanomaterials  
LECTURE – 10  
Selection of Nanomaterials  
Based on Applications  
With  
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## Structural Analysis of Nanomaterials

### Lecture-10 Selection of Nanomaterials Based on Applications



With  
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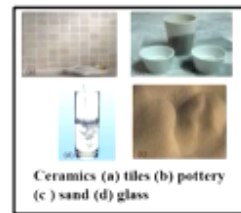
Hello, we are going to discuss in this particular lecture about the selection of nanomaterials based on applications, so basically in this particular lecture we are going to discuss that how we are choosing different types of materials on the basis of different applications or maybe what are the properties generally we have to see for choosing any kind of materials.

### Material Selection:

- ✓ Material selection is a process which is *performed to select the best materials* and have the potential to perform well both in industrially and commercially.
- ✓ It involves seeking the best match between the *property-profiles of the materials* and that required by the *design*.

### Need to study material selection and design consideration:

- An important task for an engineer is to perform i.e. material selection with regards to component design.
- Inappropriate and improper decision can be disastrous for both economic and safety prospective.
- An engineering student should be familiar with and versed in the procedures and protocols that are normally employed in the process.



Ceramics (a) tiles (b) pottery  
(c) sand (d) glass



Polymers (a) polyethylene (b) PVC  
(c) rubber (d) neoprene



Composites (a) carbon fiber (b) fiber glass  
(c) wood (d) textiles

So first we are going to discuss about the materials selections, so generally the material selection is a process which is performed to select the best materials and have the potential to perform well, both in industrially and commercially, it involves seeking the best match between the property profiles of the materials and the required by the designer or maybe the design.

Why we need to study the material selections and the design considerations? Because it is an important task for an engineer is to perform that means material selections with regards to component design, inappropriate and improper decision can be disastrous for both economic and safety prospective, and engineering student should be familiar with and worst in the procedures and protocols that are normally employed in the process. Right hand side you can see we have given the example for various applications like ceramics, like polymer and the composites.

**Design Consideration:**

- It provide in depth detail information about the requirement for a product.
- This includes assumptions, constraints, performance, dimensions, weight and reliability.
- Example:** consider design/material selection for coffee cup.

**Design specification for coffee cup**

- *Avoid burning of user's hand*
- *Might be reuse*
- *Less danger to environment*



Ceramic cup

**Material properties of coffee cup**

- *Low thermal conductivity*
- *Reusable*
- *Recyclable*

**Candidate material: Ceramics and Polymers**

- Both appropriate due to their low thermal conductivity.
- **However:**
  - ✓ *Polymer cup (polyethylene) should not be reused (become poisonous).*
  - ✓ *Depositing polymer cause environmental damage (unrecyclable).*
  - ✓ *Ceramic can be reused and cause less damage to environment .*

**Proposed material: Ceramics**



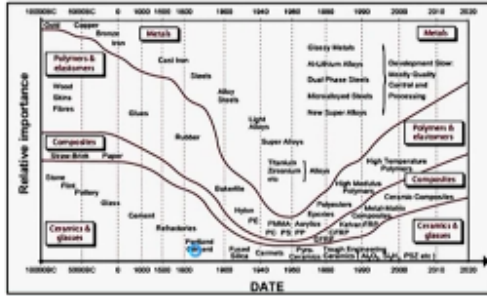
Polymer clay cup

Now what is design considerations, it provide in depth detail informations about the requirement for a product, this includes assumptions, constraints, performance, dimensions, weight and reliability, example consider design, material selection for coffee cup. Design specification for coffee cup avoid burning of user's hand, might be reuse, less danger to environment. Material properties of coffee cup, low thermal conductivity, reusable, and recyclable, so that's why we are using the ceramic cup, because it can satisfy all the requirements.

Candidate materials, ceramics and polymers both appropriate due to their low thermal conductivity, however polymer cup generally made by the polyethylene should not be reused become poisonous, depositing polymer cause environmental damage, unrecyclable, ceramic can be reused and cause less damaged to environment, so that's why proposed material will be the ceramics one.

## History of Evolution of Materials:

- ❖ *Materials of prehistory* (> 10,000 BC) were ceramics, glasses, natural polymers & composites.
- ❖ The discovery of *copper and bronze and then iron (the Bronze Age, 4000 BC- 1000 BC and the Iron Age, 1000 BC-AD 1620)*, replacing the older wooden and stone weapons and tools.
- ❖ Cast iron technology (1620's) established the dominance of metals in engineering; and *the evolution of steels (1850 onward), light alloys (1940's) and special alloys* since then consolidated their position.
  - ✓ By the 1960's, 'engineering materials' meant 'metals'.
  - ✓ Other classes of materials such as Portland cement, refractories, fused silica, rubber, Bakelite and polymers.



(a) Polymers (b) Steel (c) Ceramic Materials

Now history of evolution of materials, if we see the history we can see that material of prehistory that is more than 10,000 BC were ceramics, glasses, natural polymers, and composites were used, the discover of copper and bronze and then iron, the bronze age almost 4,000 BC, 1,000 BC, and the iron age 1,000 BC to AD 1620 is the iron age. Replacing the older wooden and stone weapon and tools, cast iron technology in 1620's established the dominance of metals in engineering, and evolution of steels in 1850 onward, light alloys 1940's and special alloys since then consolidated their positions. By the 1960's engineering materials meant metals. Other classes of materials such as Portland cement, refractories, fused silica, rubber, bakelite and the polymers, and there are of course n number of materials are available.

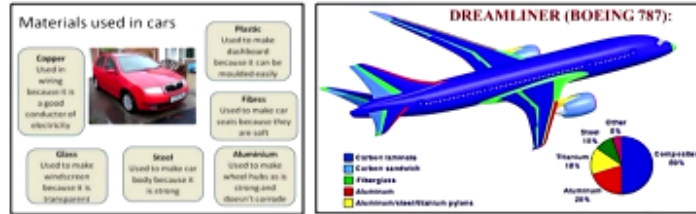
So here all are the examples and till date what is the history of this particular materials means how it has been invented and we are using it, if we talk about the 20<sup>th</sup> century, then composite materials either it maybe synthetic and the plastic becomes available which provided greatest strength and flexibility together with a low density, this proved to be particularly useful in the aircraft and the automobile industry, so generally there is a versatile used of the plastics or maybe the fibers or maybe some other soft materials generally like aluminum we are using for the aircraft and automobile industry hugely.



## 20<sup>th</sup> Century:

❖ Composite materials (synthetic) and plastics became available, which provided greater strength and flexibility together with a low density.

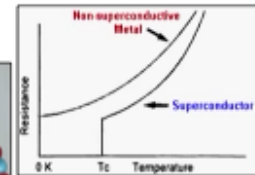
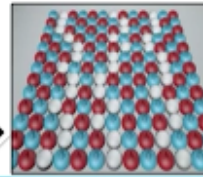
- ✓ These proved to be particularly useful in the *aircraft and automobile industries.*



❖ High temperature superconductors:

- ✓ Enables new materials to be synthesised at a molecular and atomic level.
- ✓ The stripes are zones where electrons either pile up, creating bands of negative charge, or align their spins to create bands of magnetism.

**Example:** Cuprate materials have fluctuating stripes that linked to high-temperature superconductivity



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High temperature super conductors enable new materials to be synthesized at a molecular and atomic level, the stripes are zones where electrons either pile up or maybe the creating bands of negative charge or align their spins to create bands of magnetism. Example cuprate material have fluctuating stripes that linked to high temperature superconductivity.

## Future Trends:

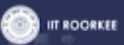
### 1. Advance material:

- ❑ Materials that are utilized in high-technology applications are termed as *advanced materials.*
- ❑ It include semiconductors, biomaterials, and "materials of the future".
- ❑ **Semiconductor:**
  - Have electrical properties that are intermediate between the electrical conductors
  - Different materials such as *metals and metal alloys, insulators (Ceramics and Polymers) etc.*



### ❑ **Biomaterials:**

- ✓ They are employed in components implanted into the human body for replacement of damaged body parts.
- ✓ Different material such as *metals, ceramics, polymers, composites, and semiconductors.*



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What is the future trends of this kind of materials? First one is the advanced materials, materials that are utilized in high technology, applications are termed as advanced materials, it includes semi-conductors, biomaterials, and materials of the future. Semi-conductor, so have electrical properties that are intermediate between the electrical conductors we know, different materials

such as metals and metal alloys insulators, like ceramics and polymers etcetera, so there are plenty of places where for the semi-conductor industry we are using this kind of advanced materials.

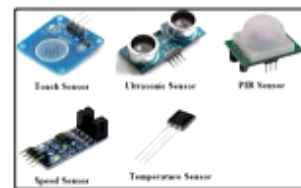
What is biomaterials? They are employed in components implanted into the human body for replacement or damaged body parts, so generally for the knee replacement, hip replacement we are using this kind of materials. Different materials such as metals, ceramics, polymers, composites and the semi-conductors we are using, we are using it for the drug delivery devices, skin cartilage, dental implants, biosensors , dental implants so, so many cases we are using this kind of advanced materials.

## 2. Smart Materials:

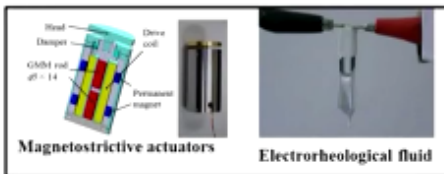
- ❑ **Smart (or intelligent) materials** are a group of new and state-of-the-art materials now being developed that will have a significant influence on many of our technologies.
- ❑ These materials are able to sense changes in their environments and then respond to these changes in predetermined manners

- ❑ Applications:

- **Sensor:** A device, module, or subsystem whose purpose is to detect changes in its environment and send the information to other electronics.
  - ✓ Different type of sensor are used such as *Temperature sensor* , *Speed sensor* , *Ultrasonic sensor* , *PIR( measure IR radiations)* etc.



- **Actuator:** Performs a responsive and adaptive actuators may be called upon to change *shape, position, natural frequency*



### materials used for actuators

- ✓ Shape memory alloys.
- ✓ Piezoelectric ceramics.
- ✓ Magnetostrictive materials.
- ✓ Electro rheological fluids.



If we talk about the smart materials, so generally the smart materials are a group of new and state of the art materials, now being developed that will have a significant influence on many of our technologies, these materials are able to sense changes in their environments and then respond to these changes in predetermined manners.

What are the applications? The first application is the sensor, a device, module or maybe the subsystem whose purpose is to detect changes in its environment and send the information to other electronics. Different types of sensors are used such as temperature sensor, speed sensor, ultrasonic sensor, PIR that means measure IR radiations etcetera.

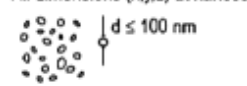

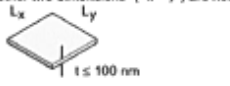

Actuator performs a responsive and adaptive actuators maybe called upon to change the shape, positions, and the natural frequency. Material used for actuators, generally the shape memory alloys, piezoelectric ceramics, magnetostrictive materials, electro rheological fluids generally we are using.

### 3. Nanomaterial:

- ✓ A material having particles or constituents of nanoscale dimensions, or one i.e. produced by nanotechnology.
- ✓ Nanomaterial uses Top-Down science, Bottom-Up approach and nanotechnology.

Classification of Nanomaterials based on the Number of Dimensions		
Dimensions	Direction of confinement	Example
0-D	X, Y, Z	Nanoparticles
1-D	X, Y	Rods, Wires, Tubes
2-D	X	Nano-films, Nano-coatings
3-D	Nil	Nano-composite thick film

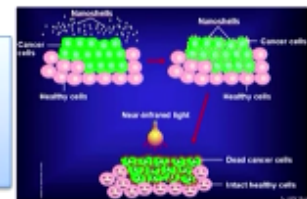
<p>0-D All dimensions (x,y,z) at nanoscale <math>d \leq 100</math> nm Nanoparticles</p> 	<p>1-D Two dimensions (x,y) at nanoscale, other dimension (L) is not <math>d \leq 100</math> nm Nanowires, nanorods, and nanotubes</p> 	<p>2-D One dimension (t) at nanoscale, other two dimensions (<math>L_x, L_y</math>) are not <math>t \leq 100</math> nm Nanocoatings and nanofilms</p> 	<p>3-D No dimension at nanoscale.</p> 
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Then come to the nanomaterial, a material having particles or constituents of nanoscale dimensions or one that is produced by nanotechnology. Nanomaterial uses top-down science, bottom-up approach and nanotechnology. So classification of nanomaterials based on the number of dimensions, this one we are going to briefly discuss next in our future slides, so dimensions 0-D generally X, Y, Z, that is the nanoparticles, 1-D we are having that X, Y directions into the nanoscale and another one into the micro scale, so rods, wires and the tubes. 2-D only one direction is into the nanoscale, nano-films, nano-coatings, and 3-D all are into the bulks scale, that is nil, nano-composite.

### Uses of Nanomaterial:

#### ❑ Nano shells as Cancer Therapy:

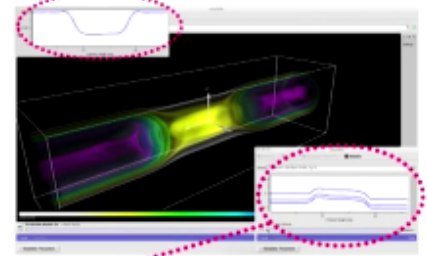
- Nano shells are injected into cancer area and they recognize cancer cells.
- Apply near-infrared light, the heat generated by the light-absorbing.
- Nano shells have successfully killed tumor cells while leaving neighboring cells intact.



*A cut along the center of the nanowire through the volume electron density data on a logarithmic scale; the channel fills with charge*

#### ❑ Nano-electronic devices:

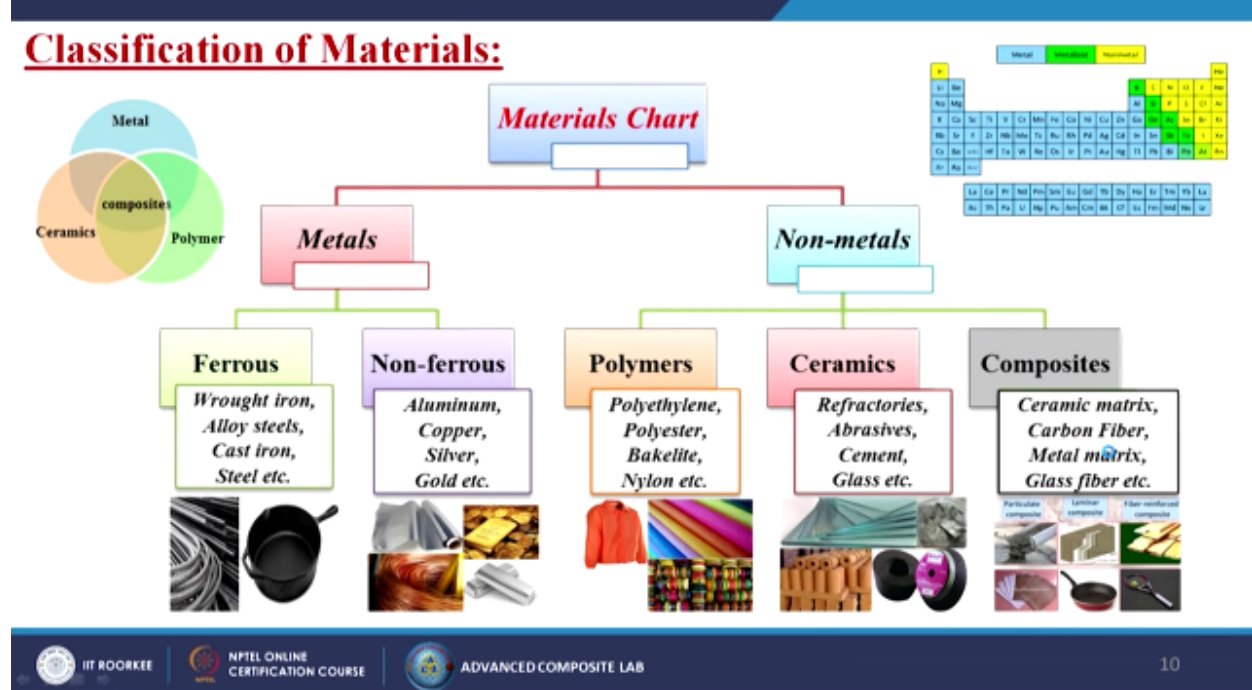
- There is formation of an electron charge and the electrostatic potential inside a circular nanowire.
- **3-D:** shows the charge density buildup inside the central nanowire transistor region.
  - ✓ As electrons penetrate into middle, the transistor turns on and forms a conducting channel.
  - ✓ The central barrier is lowered allowing electrons to travel through.



*Electrostatic potential as seen by the electrons*

Now uses of nanomaterial, so generally the nano shells as cancer therapy, nano shells are injected into cancer area and they recognize the cancer cells. Apply near-infrared light, the heat generated by the light absorbing. Nano-shells has successfully killed tumor cells while leaving neighboring cells intact. A cut along the center of the nanowire through the volume electron density data on a logarithmic scale, the channel fills the charge itself, so this is the example. So nano-electronic device there is formation of an electron charge and the electro-static potential inside a circular nanowire, 3-D shows the charge density buildup inside the central nanowire transistor region, how? As electrons penetrate into middle, the transistor turns on and forms a conducting channel itself, the central barrier is lowered allowing electrons to travel through, so this is the electrostatic potential as seen by the electrons itself, so this is the case.

## Classification of Materials:

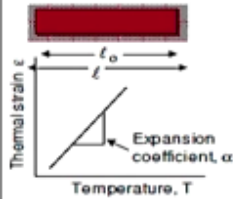


Now classification of materials, so if we see the materials chart we are having metals and nonmetals, so metals it's divided into two parts, ferrous, nonferrous, like wrought iron, alloy steels, cast iron, steel, these all are the ferrous, if we don't have the Fe component then it is nonferrous like aluminum, copper, silver, gold. Polymers like polyethylene, polyester, bakelite, ceramics, refractories, abrasives, cement and glasses, and composites, like ceramic matrix, carbon fiber, metal matrix composites, polymer matrix composites and the glass fiber etcetera.

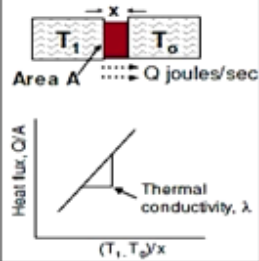


## Some Basic Properties of Material:

### Thermal expansion



### Thermal conduction



### General

**Weight:** Density  $\rho$ ,  $\text{mg/m}^3$

**Expense:** Cost/kg  $C_m$ , \$/kg

### Mechanical

**Stiffness:** Young's modulus  $E$ , GPa

**Strength:** Elastic limit  $\sigma_y$ , MPa

**Fracture strength:** Tensile strength  $\sigma_{ts}$ , MPa

**Brittleness:** Fracture toughness  $K_{ic}$ ,  $\text{MPa}\cdot\text{m}^{1/2}$

### Thermal

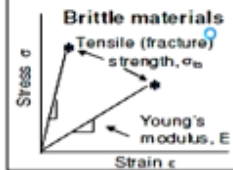
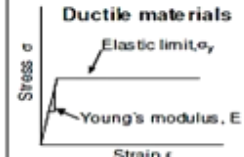
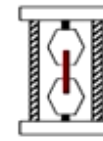
**Expansion:** Expansion coefficient  $\alpha$ ,  $1/\text{K}$

**Conduction:** Thermal conductivity  $\lambda$ ,  $\text{W/m}\cdot\text{K}$

### Electrical

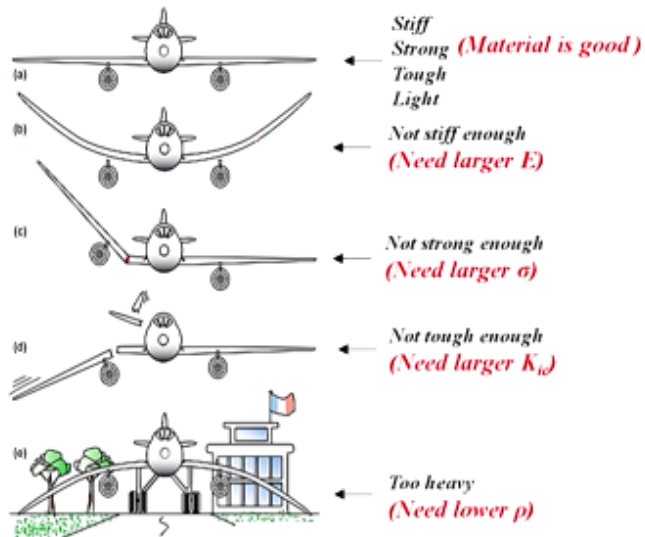
Conductor and Insulator?

### Mechanical properties



Some basic properties of materials, if we talk about so thermal expansion, so general the weight density rho that is the milligram per meter cube, expense cost for KG, CM or maybe the dollar per KG. Mechanical properties like stiffness, strength, fracture strength, brittleness. For thermal maybe the expansion, conduction, for electrical conductor or it may be the insulator.

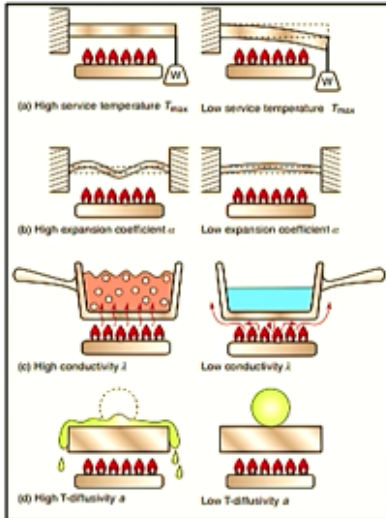
## Mechanical Property Illustrated:



Now mechanical property illustrated, if I am going to give an example of an aircraft, so generally we need the stiff, strong, tough and light, that material is good. Not stiff enough, so need larger E over there that means Young modulus, not strong enough need larger sigma,

need larger KIC, too heavy need lower density over there, so like this way general we can select the materials.

### Thermal Property Illustrated:



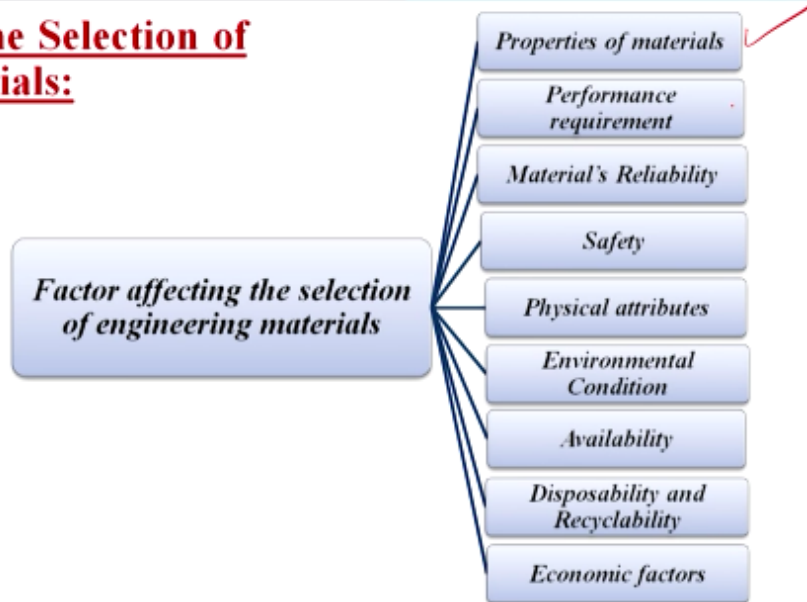
#### When properties of a material change with temperature:

- ✓ Its strength falls, it starts to 'creep' (to sag slowly over time), it may oxidize, degrade or decompose as in (a).
- ✓ A rod is constrained, as in (b), and then heated, expansion forces the rod against the constraints, causing it to buckle.
- ✓ Materials with high  $\lambda$  (thermal conductivity) as in cooking pans, radiators and heat exchangers as in (c) for high and low  $\lambda$  for the cooking vessel.
- ✓ lighting the gas under a cold slab of material with a bole of ice-cream on top as in (d).

Now thermal property, so suppose when properties of a material change with temperature, it's strength falls, it starts to creep to sag slowly over time, it may oxidize, degrade or decompose as in A, so in this case high service temperature  $T_{max}$ , low service temperature  $T_{max}$  so it is degrading. A rod is constrained as in B, and then heated expansion forces the rod against the constraints, causing it to buckle, so the buckling is taking place.

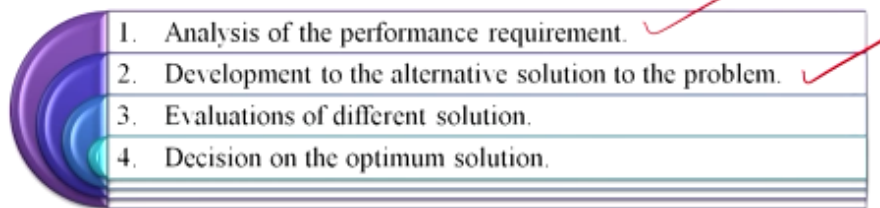
Materials with high  $\lambda$ , thermal conductivity as in cooking pans, radiators, and heat exchangers as in C, for high and low  $\lambda$  for the cooking vessel. Lighting the gas under a cold slab of material with a bowl of ice-cream on top as in the D so diffusivity.

## Factor Affecting the Selection of Engineering Materials:

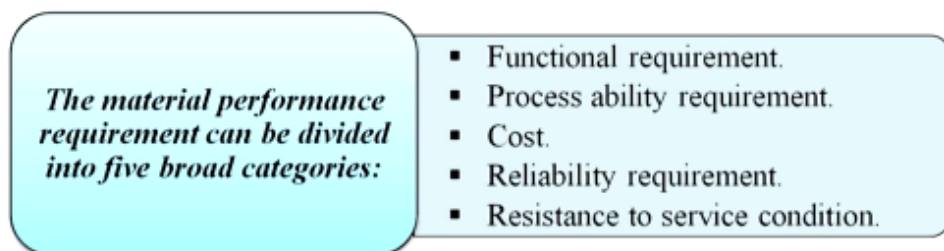


Factors affecting the selection of engineering materials, factors affecting the selection of engineering materials like properties of materials, performance requirement, materials reliability, safety, physical attributes, environmental conditions, availability, disposability and recyclability, and the economic factors.

## General Step in Material Selection:



### 1. Analysis of the Performance Requirement:



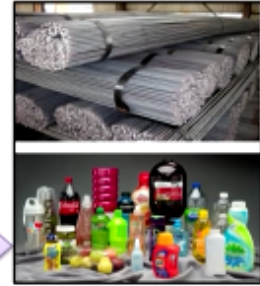
General step in material selections, first analysis of the performance requirement, development to the alternatives solution to the problem, evolution of different solution, decision on the optimum solutions, so first analysis of the performance requirement, so what are the performance

requirement can be divided into 5 broad categories, functional requirement, process ability requirement, cost, reliability requirement and the resistance to service conditions.

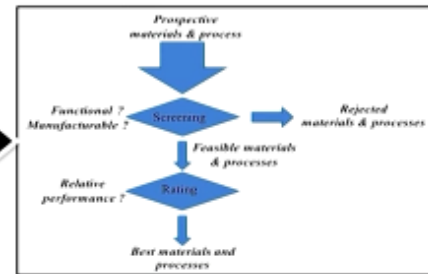
## 2. Developing an Alternative Solution:

- ✓ The rest of selection process involves the search for the material that would best meet those requirement.
- ✓ The starting point is the entire range of engineering material.
- ✓ The importance of this phase is that it creates alternatives without much regards to their feasibility.

**Example:** Steel may be the best material for one design concept while Plastic is for different concept, even though both provide similar function.



**Material Selection Strategy**



Next developing an alternative solution, the rest of selection process involves the search for the material that would best meet this requirement. The starting point is the entire range of engineering material, the importance of this phase is that it is creating alternatives without much regards to their fusibility. Examples, steel may be the best material for one design concept, while plastic is for different concept, even though both provide the similar function, so generally the material selection strategy, first is the prospective materials and process, then screening based on the functional and manufacturable, otherwise reject or material and process, then fusible material process, rating, what is that? Relative performance and last the, after following this one we'll get the best materials and the best process.

### **Screening: Material approach**

#### **Application information**

1. **Applied load**
  - Magnitude ✓
  - Cyclic nature
  - Rate
  - Duration
2. **Ambient condition**
  - Temperature
  - Moisture
  - Sunlight
  - Chemical vapor
3. **Safety**
4. **Cost**

### **Screening: Manufacturing approach**

#### **Part information**

1. Production volume
2. Overall part size
3. Feature capability
  - ✓ Rotational symmetry
  - ✓ Undercut (internal / external)
  - ✓ Uniform wall
  - ✓ Cross section (uniform / regular)

### **Screening: Geometry**

- Structural designers either assume a material before optimizing the geometry or select the best material for an existing geometry of a structure.
- Either approach does not guarantee the optimal combination of geometry and material.
- Therefore, designers ought to consider geometry optimization and material selection simultaneously.

**Note :**All these above condition of material's selection can be done by using **Ashby's Diagram**.



So selection of materials depends on product functions, and product function is depend on material, manufacturing process and the geometry, so product function is interdependent on this three properties. Screening, we have to consider all three, do we select a few feasible materials first and then select the specific manufacturing process or do we select manufacturing process first and then select the specific material. Screening, material approach, application informations like applied load, magnitude, cyclic nature, rate and durations, and second one is the ambient conditions, temperature, moisture, sunlight, chemical vapor, third is the safety, and fourth is the cost.

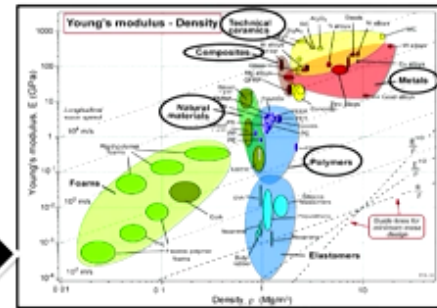
Screening from manufacturing approach, part informations, like production volume, overall part size, and the feature capability, like rotational symmetry, undercut it maybe internal or maybe the external, then uniform wall, cross sections, whether it is uniform or maybe the regular. Screening geometry, structural designers either assume a material before optimizing the geometry or select the best material for an existing geometry of a substructure, either approach does not guarantee the optimal combination of geometry and material. Therefore, designers ought to consider geometry optimizations and material selection simultaneously. Note, all these above condition of material selections can be done by using Ashby's diagram.

## Ashby's Diagram:

### 1. Young's Modulus $E$ and density $\rho$ :

- ✓ This chart guides selection of materials for light, stiff components.
- ✓ The moduli of engineering materials span a range of  $10^7$  and densities span a range of 3000.
- ✓ The contours show the longitudinal wave speed in m/s.

- $\nu = 1/3$ ;  $G = 3/8E$ ;  $K = E$  (metals, ceramics, glasses & glassy polymers).
  - $\nu = 0.5$ ;  $G = E/3$ ;  $K = 10E$  (elastomers, rubbery polymers).
- where,  $\nu$  is Poisson's ratio,  $G$  the shear modulus and  $K$  the bulk modulus.



The guide lines show the loci of points for which:

- ❖  $E/\rho = C$  (Minimum weight design of stiff ties, Minimum deflection in centrifugal loading, etc.)
- ❖  $E^{1/2}/\rho = C$  (Minimum weight design of stiff beams, shafts and columns)
- ❖  $E^{1/3}/\rho = C$  (Minimum weight design of stiff plates)

- The value of the constant  $C$  increases as the lines are displaced upwards and to the left.
- Materials offering the greatest stiffness-to-weight ratio lie towards the upper left hand corner.



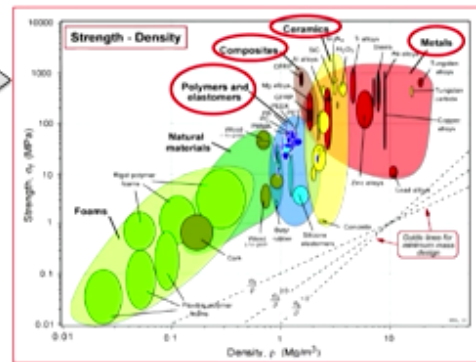
What is Ashby's diagram? So generally Young modulus  $E$  and density  $\rho$ , this chart guides selection of materials for light, stiff components, the moduli of engineering materials span a range of  $10^0$  to the power  $7$  and density span a range of 3000. The contour show the longitudinal wave speed in meter per second, so density in this and Young modulus in this, and all the materials like polymers, foams, composites, metals, all are coming over this, then based our requirement we have to choose the materials. Say suppose  $\nu = 1/3$  and  $G = 3/8E$ , so  $K$  is more or less equal to  $E$ , metals, ceramics, glasses or maybe the glassy polymers, where  $\nu = 0.5$   $G$  is more is equal to  $E/3$ , and  $K$  more is equal to  $10E$ , it's for elastomers or maybe the rubbery polymers where  $\nu$  is the Poisson's ratio,  $G$  the shear modulus, and  $K$  the bulk modulus.

So the guideline show the loci of points for which  $E/\rho = C$ , minimum weight design for stiff ties, minimum deflection in centrifugal loading. Root over  $E/\rho = C$ , minimum weight design of stiff beams, shafts and columns.  $E$  to the power  $1/3$  /  $\rho = C$  that is minimum weight design of stiff plates. The value of the constant  $C$  increases as the lines are displaced upward and to the left, materials offering the greatest stiffness to weight ratio lie towards the upper left hand corner.

## 2. Strength $\sigma_f$ and density $\rho$ :

This is the chart for designing light, strong structures.

- ❖ The "strength" for metals is the 0.2% offset yield strength.
- ❖ For polymers, it is the stress at which the stress-strain curve becomes markedly non-linear and, a strain of about 1%.
- ❖ For ceramics and glasses, it is the compressive crushing strength and 15 times larger than the tensile (fracture) strength.
- ❖ For composites it is the tensile strength.



The guide lines show the loci of points for which:

- $\sigma_f/\rho = C$  (Minimum weight design of strong ties and maximum rotational velocity of disks).
- $\sigma_f^{2/3}/\rho = C$  (Minimum weight design of strong beams and shafts).
- $\sigma_f^{1/2}/\rho = C$  (Minimum weight design of strong plates).

- ❖ The value of the constant  $C$  increases as the lines are displaced upwards and to the left.
- ❖ Materials offering the greatest strength-to-weight ratio lie towards the upper left corner.



Strength  $\sigma_f$  and density  $\rho$ , this is the chart for designing the light and strong structure, so like density in the X axis and the strength into the Y axis, so actually we are having based on physical properties we are having different charts, so from that charts we have to choose the exact material for our application, so this is the chart for designing light and strong structures, the strength for metals is the 0.2% offset yield strength, for polymer it is the straight at which the stress strain curve becomes markedly nonlinear and a strain of about 1%, for ceramics and glasses it is the compressive crushing strength and 15 times larger than the tensile strength. For composites it is the tensile strength.

The guidelines show the loci of points for which  $\sigma_f/\rho = C$  that is the minimum weight design of strong ties and maximum rotational velocity of disks.  $\sigma_f^{2/3}/\rho = C$ , that is minimum weight design of strong beams and shafts.  $\sigma_f^{1/2}/\rho = C$ , that is the minimum weight design of strong plates. The value of the constant  $C$  increases as the lines are displayed upward and to the left. Materials offering the greatest strength to weight ratio lie towards the upper left corner.

### 3. Approximate material prices, $C_m$ and $\rho C_m$ :

- ❖ Cost bothersome because it does.
- ❖ Supply, scarcity, speculation and inflation contribute to the considerable fluctuations in the cost-per-kilogram of a commodity
- ❖ Glass, Steel, Aluminum, and common polymers cost between 0.5 and 2 \$/kg.
  - ✓ Because they have low densities, the cost/m<sup>3</sup> of commodity polymers is less than that of metals.

Approximate material prices like CM and the rho CM, cost bothersome because it does, supply scarcity, speculation, and inflation contribute to the considerable fluctuations in the cost per kilogram of a commodity. Glass, steel, aluminum and common polymers cost between 0.5 to 2\$ per KG, because they have low densities, the cost per meter cube of commodity polymers is less than that of metals.

### 3. Evaluations of different solution:

#### Rating: Material Indices:

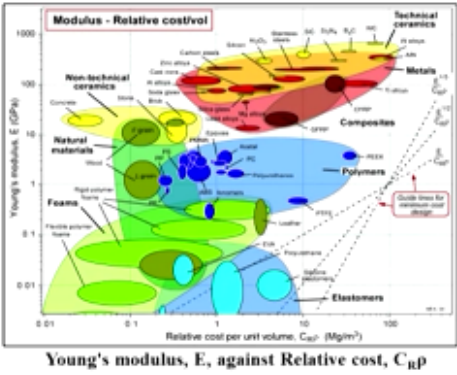
- ❖ In design for minimum cost, material selection is guided by indices that involve modulus, strength and cost per unit volume.
- ❖ Given the same cost and volume and find which is stronger?
- ❖ Given the same cost and volume and find which is stiffer.

$$\text{Index} = \text{strength} / \text{cost}$$

$$\text{Index} = \text{young's modulus} / \text{cost}$$

- Cheap stiff materials lie towards the top left.
- $E^{1/2} / C_{R,V} \rho = C$  (Minimum cost design of stiff beam and column).
- $E^{1/2} / C_{R,V} \rho = C$  (Minimum cost design of stiff plates).

- ❖ The value of the constant C increases as the lines are displayed upwards and to the left.
- ❖ Materials offering the greatest stiffness per unit cost lie towards the upper left corner.



Now the third one, evaluations of different solutions, rating material indices, so in this case we are having X axis relative cost per unit volume, and the Y axis is the Young modulus, so in design for minimum cost, material selection is guided by indices that involve modulus, strength,



and cost per unit volume, given the same cost and volume and find which is stronger? Given the same cost and volume and find which is stiffer, so index = strength/cost, index = Young's modulus/cost, so that means cheap stiff materials lie towards the top left. If root over E/C RV rho = C, minimum cost design of stiff beam and column, root over E/C RV rho = C, C minimum cost design of stiff plates. The value of the constant C increases at the lines are displayed upward and to the left, materials offering the greatest stiffness per unit cost lie towards the upper left corner.

### **Comparing and ranking alternative I:**

#### ***Weighted properties method I:***

- In this method each material requirement is assigned a certain weight depending on its importance.
- Weighted property value is obtained by multiplying scaled value of property by weighting factor( $\alpha$ ).
- Weighted property values of each material are then summed to given performance index( $\gamma$ )
- The material with highest performance index is optimum for the application.

$$B \text{ (Scaled property)} = \frac{\text{Numerical value of property} \times 100}{\text{Maximum value in the list}}$$

#### **4. Decision on the Optimum Solution:**

- After ranking of alternatives, the most promising performance indices can each now be used to develop a detail design.
- Each detail design will exploit the points of *strength of material and avoid weak points for requirement of the manufacturing process* needed for material.
- After completing the different designs.
  - ✓ Solution are then compared.
  - ✓ Taking cost in consideration in order to arrive at the optimum design-material-process combination.

Comparing and ranking alternative I, weighted properties method I, in this method each material requirement is assigned a certain weight depending on its importance, weighted property value is obtained by multiplying scaled value of property by weighting factor alpha, weighted property values of each material are then summed to given performance index gamma, the material with highest performance index is optimum for applications, B = the scaled property, numerical value of property x 100 by the maximum value in the list.

Next decision on the optimum solutions, after ranking of alternatives the most promising performance indices can each now be used to develop a detailed design, each detailed design will exploits the points of strength of material and avoid weak points for requirement of the manufacturing process needed for material. After completing the different designs solutions are then compared, taking cost in considerations in order to arrive at the optimum design material process combination.

## Material Selection for Chemical Protective Covering:

- ❑ When chemicals exposed to the human body, can produce undesirable reactions such as mild skin irritation, to organ damage, or even death.
- ❑ Anyone who risks exposure to these chemicals should wear **chemical protective clothing (CPC)** to prevent direct skin contact and contamination.
- ❑ Protective clothing includes gloves, boots, suits, and respirators may be required.







### Selection of gloves material:

- ✓ **Breakthrough time:** Length of time until first detection of the toxic chemical species inside the glove.
- ✓ **Exposure rate:** How much of the toxic chemical passes through the glove per unit time.
- ✓ It also include material degradability, flexibility, and puncture resistance.

Now material selection for chemical protective covering, when chemicals exposed to the human body can produce undesirable reactions, maybe some kind of skin irritations to organ damage or even death, anyone who risks exposure to these chemicals should wear the chemical protective clothing to prevent direct skin contact and contaminations, protective clothing includes gloves, boots, suits and respirators may be required, so here we have given so many examples of different chemical protective covering, like selection of glove material first is the break through line, length of time until first detection of the toxic chemical species inside the glove, and second exposure rate, how much of the toxic chemical passes through the glove per unit time, and third it also include the material degradability, flexibility, and the puncture resistance.


### Different gloves material and their uses:

Material	Uses	Advantage	Image
✓ <b>Latex (natural rubber)</b>	Incidental contact	Good for biological and water-based materials.	
<b>Nitrile</b>	Incidental contact (disposable exam glove)	✓ Excellent general use glove. ✓ Good for solvents, oils, greases, acids and bases	
<b>Butyl rubber</b>	Extended contact	Good for ketones and esters	
<b>Polyvinyl chloride (PVC)</b>	Specific use	Good for acids, bases, oils, fats, peroxides, and amines	

Different glove materials and their uses, like latex natural rubber uses incidental contact, advantage good for biological and water based materials, so this is the image of the latex based gloves, so we can make the gloves of nitrile or maybe the butyl rubber or maybe the PVC, each are having different uses and different advantages.

**For Combustion Engine:**

- A device is required to facilitate ignition in combustion engines with:
  - ✓ Thermal shock resistance
  - ✓ Wear, corrosion and oxidation resistance
  - ✓ Resistant to chemical attack by **S and Pb.**
- For selection of material we are using Ashby's Diagram.

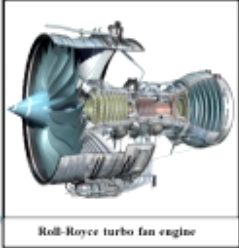


Ignition in combustion engines

*The selected material is Alumina Coated Tungsten*




**For Roll-Royce Fan Engine:**

- A device is required to rotate in the *Roll-Royce turbo fan engine* with following condition:
  - ✓ High stiffness, toughness and thermal shock resistance
  - ✓ High wear, oxidation and corrosion resistance
  - ✓ Low density
- For all above requirement we are using Ashby's Diagram and select the material.



Roll-Royce turbo fan engine

*The selected material is nickel alloy*

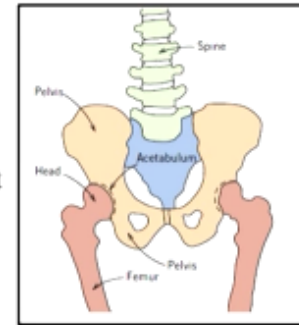
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Now for the combustion engine, a device is required to facilitate ignition in combustion engines with thermal shock resistance, wear corrosion and oxidation resistance, resistant to chemical attack by sulphur and lead. For selection of material we are using the Ashby's diagram. The selected material in alumina coated tungsten this is the image. For Rolls Royce fan engine a device is required to rotate in the Roll Royce turbo fan engine with following conditions like high stiffness, toughness and thermal shock resistance, high wear oxidation and corrosion resistance and the low density, for all above requirement we are using the Ashby's diagram and select the material, so this is the nickel alloy generally we are using for this particular purpose.

## **For Hip Implant:**

Hip implant is called as total hip replacement

- ❖ Damage to hip joint causes: Trauma, Necrosis and Osteoarthritis
- ❖ Surgeon will remove damage cartilage and bones then replace hip prostheses.
- ❖ Come up with the list of design consideration for total hip replacement prostheses.
  - Encompass design and material consideration.



### ***Engineering design consideration for hip replacement:***

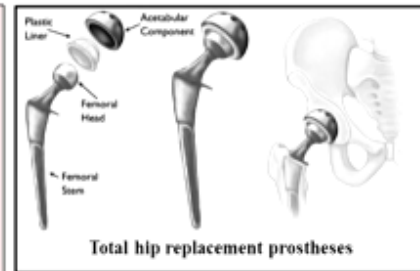
- Static load (stand, sit etc.) and dynamic load (running, walking etc.)
- Weight
- Biocompatibility
- Life (longer than 20 years)
- Temperature (temp. 98.6 F and highly autoclaved)
- Modulus of elasticity
- Surgical procedure
- Cost

- As bone is incredible complex material and its property depends on direction and loading .
- ***Using Wolff's law:***
  - ✓ Bone remodeling can be done and adapt to magnitude and direction of load.

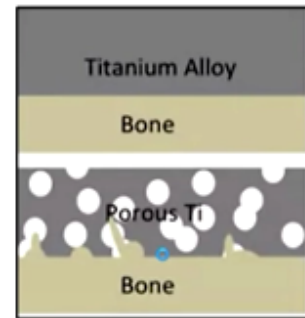
For hip implant, for hip implant is called as total hip replacement, damage to hip joint causes by trauma or maybe the necrosis, or maybe the osteoarthritis, surgeon will remove damage cartilage and bones, then replace the hip prostheses. Come up with the list of design considerations for total hip replacement prosthesis. Encompass design and the material considerations.

Engineering design consideration for hip replacement like static load, stand or sit and the dynamic load like the running and walking, then weight, then biocompatibility, then life, then temperature, because it has to meet there in the human body, so it has to go up to this temperature or maybe the higher. Modulus of elasticity, surgical procedure and the cost, as bone is incredible complex material and its property depends on direction and loading using the Wolff's law, bone remodeling can be done and adapt to magnitude and direction of load.

- **As old hip prostheses uses:**
  - ✓ Titanium
  - ✓ Steel
- Both the materials are very much stiffer and higher modulus in bone and cause stress shielding
- **Stress shielding:** is defined as when implant take more load than the bone due to implant loosening and pain



- *But now the new material will used for implant hip prostheses is porous titanium.*
- As it allow two thing:
  1. Bond grow into implant and it will provide very strong connection between implant.
  2. Modulus of elasticity is more as compared to titanium.



As old hip prostheses uses like titanium and the steel materials, both the materials are very much stiffer and higher modulus in bone and cause the stress shielding. Now what is stress shielding? It is defined as when implant take more load than the bone due to implant loosening and pain, so here you can see that total hip replacement prostheses looks like this, but now the new material will used for implant hip prostheses is porous titanium, so here in this particular case we are using the porous titanium because it will allow the two things, first bond grow into implant and it will provide the very strong connection between implant, second modulus of elasticity is more as compared to titanium.

**Mechanical properties of metal implants and human bone:**

Material	Tensile strength MN/m <sup>2</sup>	Yield strength MN/m <sup>2</sup>	Elongation at fracture	Vickers hardness (Hv)	Young's modulus GN/m <sup>2</sup>	Fatigue limit GN/m <sup>2</sup>
316l SS(annealed)	650	280	45	190	211	0.28
Wrought Co-Cr alloy	1540	1050	9	450	541	0.49
Cast Co-Cr alloy	690	290	8	300	241	0.30
Titanium	710	270	30	-	121	0.30
Ti-6Al-4V	1000	970	12	-	121	-
Human bone	137.3	-	1.49	26.3	30	-



Metallic hip implant



Silicon nitride based spinal and orthopedic implants

An injection molded CF/PEEK composite stem for THR

CF/PEEK:  
Carbon Fiber/Polyether Ether Ketone

Now some mechanical properties of metal implants and the human bones, like 316L stainless steel annealed conditions, we are having the tensile strength of 650, yield strength 280, elongation at fracture 45, so based on our applications where we are going to use this particular implants so we have to choose, nowadays the widely used composite is TI-6AL-4V because it is having the tensile strength of 1000, yield strength is 970, and then we are having that elongation at fracture 12, some cases we are using the cobalt chromium alloy also, so this all are the examples generally we are using.

### **For Femoral Component of Total Knee Replacement:**

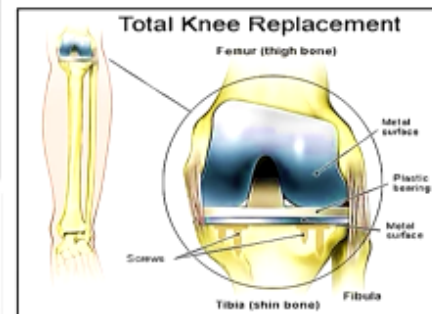
- ✓ During knee replacement surgery, an orthopedic surgeon will resurface your damaged knee with artificial components, called implants.
- ✓ Implants are made of metal alloys, ceramic material, or strong plastic parts.
- ✓ Components are designed so that metal always borders with plastic, which provides for smoother movement and results in less wear of the implant.



#### **Components:**

- ❖ **Tibial component:** Placed on the top of lower leg.
- ❖ **Plastic insert:** Placed between femoral and tibial component.
- ❖ **Patellar (Knee cap):** Placed on knee cap.
- ❖ **Femoral component:** Placed on the end of high bone.

Use of components made from *metals and polyethylene* allow for joint mobility between the joint surfaces with little wear.

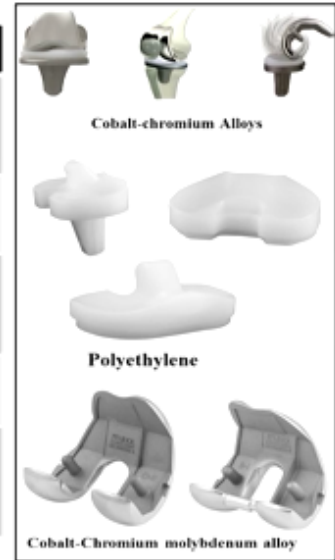


Now for femoral component of total knee replacement, during knee replacement surgery and orthopedic surgeon will resurface your damaged knee with artificial components called implants. Implants are made of metal alloys, ceramic material or maybe the strong plastic parts, components are designed so that metal always borders with plastic which provides for smoother movement and result in less wear replacement, so from this particular image you can see that how we are doing the knee replacement.

Components like tibial component placed on the top of lower leg, plastic insert placed between the femoral and tibial component, then patellar knee cap placed on knee cap, and the femoral component placed on the end of high bone, so there are four parts generally, so use of components made from metals and polyethylene allow for joint mobility between the joint surface with the little wear, so these case in this particular region we are doing the knee replacement.

**Material properties for selection of total knee replacement:**

Material	Properties
Cobalt-chromium Alloys	<ul style="list-style-type: none"> <li>✓ Hard</li> <li>✓ Corrosion resistant</li> <li>✓ Tough and Bio-compatible metals</li> </ul>
Titanium and Titanium Alloys	<ul style="list-style-type: none"> <li>✓ Bio-compatible</li> <li>✓ Titanium alloy in knee implants is Ti6Al4V</li> </ul>
Tantalum	<ul style="list-style-type: none"> <li>✓ Flexibility</li> <li>✓ Corrosion resistant</li> <li>✓ Biocompatibility</li> </ul>
Polyethylene	<ul style="list-style-type: none"> <li>✓ Tibial and Patellar components in knee replacements are made of polyethylene</li> </ul>
Zirconium	<ul style="list-style-type: none"> <li>✓ Biocompatible</li> <li>✓ Zirconium alloy implants eliminate the risk to nickel-allergic patients</li> </ul>



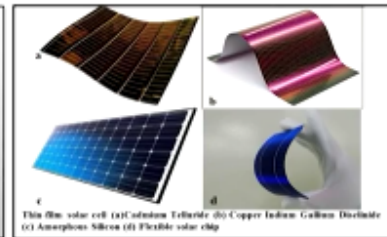
Material properties for selection of total knee replacement, material like cobalt chromium alloys properties, it is hard, corrosion resistance, tough and bio-compatible metals, so like this way we are using the titanium and titanium alloys, tantalum, polyethylene, zirconium because every material is having different properties, so based on their where we are going to use this kind of implant, so we are going to choose the different kind of metal composites.

**For Thin-Film Solar Cells:**

A thin-film solar cell (TFSC), or a thin-film photovoltaic cell (TFPV), is a junction device obtained by placing two electronically dissimilar materials together with a thin electronic barrier in between to separate charge.

**Properties of ideal photovoltaic materials are:**

- Direct band gap semiconductor with a band gap of approx. 1.5 eV.
- High solar optical absorption coefficient approx.  $10^5 \text{ cm}^{-1}$ .
- High quantum efficiency of excited carriers.
- Long diffusion length and recombination velocity.
- Ability to form electronic junctions with good stability.



**Some examples of material used for thin-film solar cell:**

Cadmium Telluride, Copper Indium Gallium Disulphide, Amorphous Silicon, Copper Indium Gallium Diselenide.

- ✓ These materials along with an organic semiconductor called **perylene diamine** were taken for the analysis of the best material for the absorbent layer for thin-film solar cells.

For thin film solar cells, a thin film solar cells TFSC, or a thin film photovoltaic cell maybe TFPV is a junction device obtained by placing two electronically dissimilar materials together with a thin electronic barrier in between to separate charge. Properties of ideal photovoltaic

materials are direct band gap semi-conductor with a band gap of approx 1.5 electron volt, high solar optical absorption coefficient approx 105 per centimeter, high quantum efficiency of excited carriers, long diffusion length and recombination velocity, ability to form electronic junctions with good stability.

Some examples of materials generally we are using for the thin film solar cell are cadmium telluride, copper indium gallium disulphide, amorphous silicon, copper indium gallium diselenide, these materials along with an organic semi-conductor called perylene-diamine were taken for the analysis of the best material for the absorbent layer for thin-film solar cells.

**For Aeronautical Structural Application:**

In aeronautical applications, strength allied to lightness is most important in material selection, when the material is stable in environment conditions.

**Main group of materials used in aircraft construction:**  
*Wood, Fiber Reinforced Composites, Steel, Aluminum alloys, Titanium alloys etc.*



**Materials properties for structural application:**

- Ultimate stress and Yield stress
- Stiffness and ductility
- Temperature limits
- Corrosion, fatigue & crack growth resistance
- Fracture toughness
- Fragility at low temperatures
- Maintainability and Reliability

**Different types of aeronautical materials:**

class of material	Material	density (kg/m <sup>3</sup> )	σ <sub>y</sub> (MPa)	Elastic Modulus (GPa)	Elongation %	Temperature limits (°C)	Cost \$/lb
aluminum (reference)	2024 T3	2800	510	72.5	10	280	3
aluminum	7075 T6	2800	586	71.7	4	250	3
maraging steel	C-250	7920	1620	183	5	1000	5
steel	4340	7830	1900	170	11	1100	1
titanium	8Al-1Mo-1V	4370	1000	121	8	800	15
wood	spence	560	67.5	14.5	0	200	2
composites	glass-epoxy	1960	730	44.6	0	350	2.9
composites	graphite-epoxy	1540	1080	312	0	350	32
composites	Boron-Aluminum	2800	840	241	0	600	320

For aeronautical structure applications, in aeronautical application strength allied to lightness is most important in materials selection, when the material is stable in environment conditions, main group of materials used in aircraft reconstruction or maybe the construction is wood, fiber reinforced composites, steel, aluminum alloys, titanium alloys nowadays widely used. Nowadays we are using the cable or fiber also, so these all are the parts generally where we are using different types of materials based on the applications because some places we need the maximum wear resistance, some places we need the maximum strength, some places we need the maximum chemical inertness so based on that in a aircraft there are several parts and several parts we are using several kind of materials, and for that what are the material properties for the structural applications? We need the ultimate stress and yield stress, stiffness and ductility, temperature limits, corrosion fatigue and crack growth resistance, fracture toughness, fragility at low temperatures, maintainability and the reliability, of course there are different types of aeronautical materials, we are using the aluminum, we are using the maraging steel, titanium, wood composites and as I told already that nowadays we are using the cable or fiber, because it is having the highest strength and very, very light weight in nature.



## Summary:

- ✓ Material selection is a process which is performed to select the best materials
- ✓ Design consideration provide in depth detail information about the requirement for a product.
- ✓ The evolution of materials of prehistory (> 10,000 BC, the Stone Age) , discovery of copper and bronze and then iron and future trends.
- ✓ General steps in material selection are analysis, development, evaluation and decision.
- ✓ There are some example of material selection such as in total knee replacement, protective cover ,thin film solar cell etc.

So now we have come to the last part of this particular lecture, so we have to summarize the whole lecture, so in this particular lecture we have discussed about the materials selection process which is performed to select the best materials based on their applications. Design consideration provide in depth detail information about the requirement for a particular product, the evaluation of materials of pre-history that is more than 10,000 BC means the stone age, discovery of copper and bronze and then iron and future trends. General steps in material selection are analysis, development, evaluation and decision. There are some examples of material selection such as in total knee replacement, protective cover, thin film solar cells parts, in this particular lecture we are given a wide examples, but nowadays we are using this kind of advanced materials in the every applications of our day to day life. Thank you.

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**Acknowledgement**

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