Medical Biomaterials
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Lecture – 31
Polymers Blends/Composites

Hello everyone welcome to the course on medical bio materials. We will continue on the topic of polymer blends composites. We have been discussing about these blends and composites and we will spend some more time on that.

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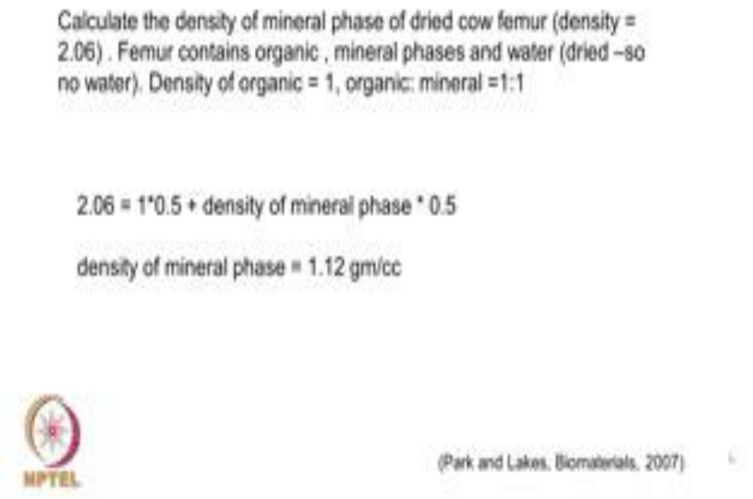

Calculate the density of mineral phase of dried cow femur (density = 2.06) . Femur contains organic , mineral phases and water (dried –so no water). Density of organic = 1, organic: mineral =1:1

2.06 = 1*0.5 + density of mineral phase * 0.5

density of mineral phase = 1.12 gm/cc

(Park and Lakes, Biomaterials, 2007)

So, let us look at a problem; calculate the density of mineral phase of dried cow femur density is 2.06. This is a dried femur for example, if you take this cow femur it will contain a mineral phase just like hydroxyapatite on them there will be organic phase like collagen and then there will be water. So, the density is 2.06, this femur contain organic mineral and water because it is dried there is no water, the density of organic is 1. So, organic to mineral is 1 is to 1. So, we can use the mixture rules, it is quite simple.

So, density of the femur is 2.06 then, we have density of organic is 1 into 0.5, density of mineral phase that is what we have to calculate into 0.5. So, this is equal to 2.6, this is the density of the femur. So, we can calculate this from this. So, the density of the femur is equal to volume fraction of the organic into density of organic plus volume fraction of the mineral into density of the mineral. Water we have ignored because its dried. So, the density of mineral is given as 1.12 gram per C C. This problem has taken from this reference.

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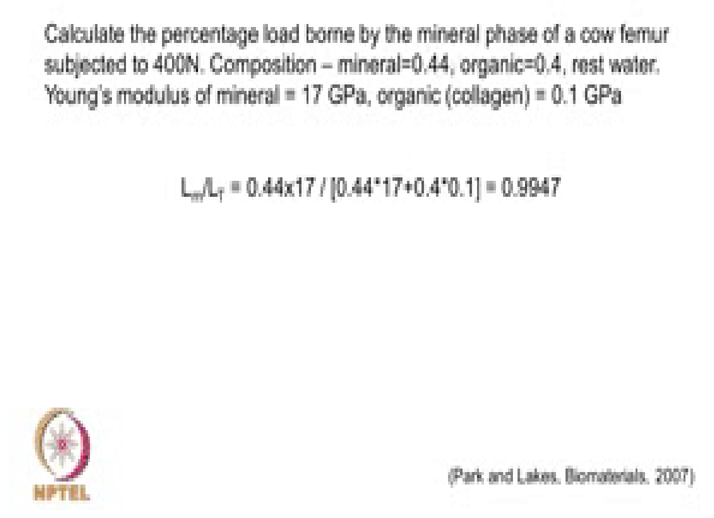

Calculate the percentage load borne by the mineral phase of a cow femur subjected to 400N. Composition – mineral=0.44, organic=0.4, rest water. Young's modulus of mineral = 17 GPa, organic (collagen) = 0.1 GPa

$$L_m/L_T = 0.44 \times 17 / [0.44*17+0.4*0.1] = 0.9947$$

(Park and Lakes, Biomaterials, 2007)

Look at another problem; calculate the percentage load borne by the mineral phase of a cow femur subjected to 400 Newton. As you know, it has got mineral; it has got organic and then water. So, mineral is about 44 percent, organic is 40 percent and there is water. So, water will not take any load. So, mineral and organic Youngs modulus of mineral phase is 17 Giga Pascal. Youngs modulus of organic which is collagen, it is 0.1 Giga Pascal. So, the load borne will be proportional to the ratio of the composition, that is simple actually. That will be the ratio of the composition because we will only take the mineral and organic here; we will ignore the water part of it.

So, load of the mineral phase, load borne by the mineral phase divided by load total that will be Youngs modulus of load mineral is point I mean sorry 17 Giga Pascal and it is 44 percent. So, 0.44 into 17 divided by the total 0.44 into 17 plus 0.4 into 0.1, do you understand? This the total, that is 0.4 into 17 plus 0.4 into 1 and then the mineral part is

0.44 into 17. So, that gives you 0.9947; that is 99 percent of the load will be borned by the mineral phase because the Youngs modulus of the mineral phase is so much, Youngs modulus of the organic phase is very very little. So, it is assumed that it will be in the same ratio as the Youngs modulus and the volume fraction understand. So, it is quite a simple problem. So, when we have multiple materials especially say in composites then the load borne by each of the item will be based on their Youngs modulus, respective Youngs modulus and their respective volume fraction. So, you need to remember that.

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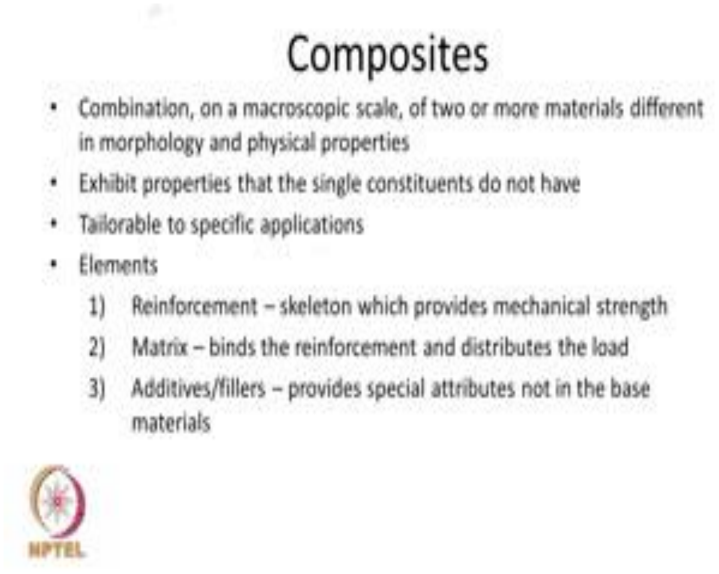

Composites

- Combination, on a macroscopic scale, of two or more materials different in morphology and physical properties
- Exhibit properties that the single constituents do not have
- Tailorable to specific applications
- Elements
  1) Reinforcement – skeleton which provides mechanical strength
  2) Matrix – binds the reinforcement and distributes the load
  3) Additives/fillers – provides special attributes not in the base materials

So, composites as you know combinations on a macroscopic level two or more materials different in morphology and physical properties. Like we are putting say silicate and a polymer or carbon fibres and a polymer or some alumina and some other polymer like that you know two different materials of two different morphologies as well as physical properties. For example, like I showed you the composite material, the inorganic may have a very high Youngs modulus, the polymers may have the very low Youngs modulus that is the physical property change. They exhibit properties that the single constituents do not have so; obviously, it will not be based on the single component, but it will be based on their individual pure values and the ratios. It is tailorable to specific applications. So, we can have different compositions of the organic and the inorganic material if I am having carbon nano fibre, I can change the composition of the fibre. If I am a glass beads in a polymer, I can change the composition of the glass beads.

So, reinforcement it provides the mechanical strength, matrix that is the polymer binds the reinforcements and distributes the loads. So, suppose I have 1 percent fibre and I have say 99 percent PMMA then, that matrix distributes the load. Sometimes we need to add additives fillers to provide special attributes; that means, for mixing say the inorganic with the polymer we may have to add some surfactants, surface active agents or some other hydrophilic polymers and so on actually. That is called additives and fillers; that is how a composite is made up of.

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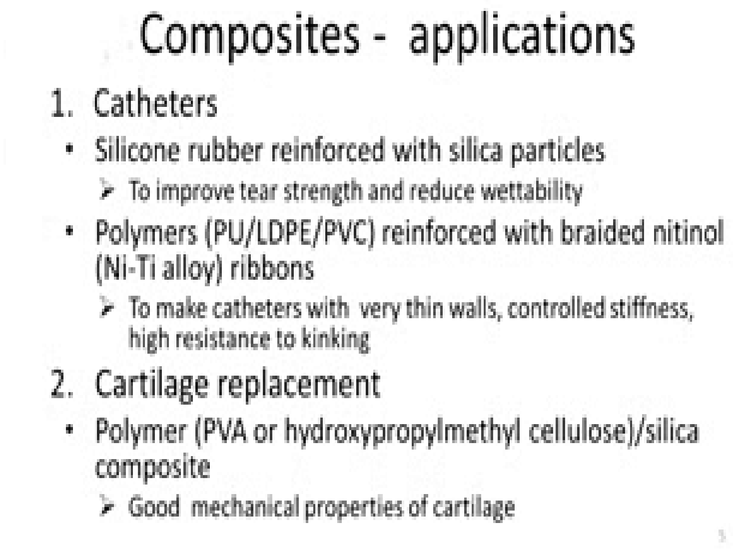

Composites - applications

1. Catheters
   - Silicone rubber reinforced with silica particles
     - To improve tear strength and reduce wettability
   - Polymers (PU/LDPE/PVC) reinforced with braided nitinol (Ni-Ti alloy) ribbons
     - To make catheters with very thin walls, controlled stiffness, high resistance to kinking
2. Cartilage replacement
   - Polymer (PVA or hydroxypropylmethyl cellulose)/silica composite
     - Good mechanical properties of cartilage

Application catheters; they are used silicon rubber reinforced with silica particles. It provides, the silica particles, provides improves tear strength and reduce wettability. Polymers like P U, L D P E, P V C reinforced with nitinol; nitinol is a nickel titanium alloy. So, with this we can achieve very very thin walls, we can have control stiffness, high resistance to kinking. Otherwise if you have just these polymers they, tubing may get kinked, so we add this alloy. Cartilage replacement we can have poly P V A or hydroxypropylmetheyl cellulose with silica. This gives you, the silica gives very good mechanical properties to the cartilage.

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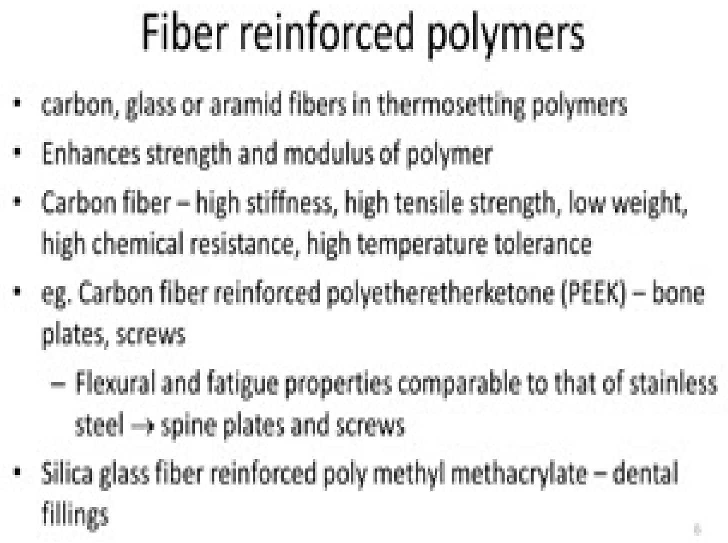

Fiber reinforced polymers

- carbon, glass or aramid fibers in thermosetting polymers
- Enhances strength and modulus of polymer
- Carbon fiber – high stiffness, high tensile strength, low weight, high chemical resistance, high temperature tolerance
- eg. Carbon fiber reinforced polyetheretherketone (PEEK) – bone plates, screws
  - Flexural and fatigue properties comparable to that of stainless steel → spine plates and screws
- Silica glass fiber reinforced poly methyl methacrylate – dental fillings

Carbon glass or aramid fibres in a thermosetting polymers. So, lot of these are added to give strength, to give toughness, it enhances strength, it enhances modulus. Carbon fibre, high stiffness, high tensile strength, low weight, high chemical resistance, high temperature tolerance, so that is why carbon is used quite a lot. Carbon reinforced polyetheretherketone for bone plate screws, flexural and fatigue properties comparable to that of stainless steel, spine plates and screws.

Whereas, this polymer may be very light, so by adding this carbon we are getting very good flexural fatigue and flexural properties equivalent to stainless steel. Silica glass fibre reinforced PMMA used in dental fillings, the fibre gives the toughness.

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- Carbon fiber reinforced polyethylene
  - An insert in knee prostheses
  - Increased compressive and tensile strength, elastic modulus, fatigue strength
  - Undergoes less wear
  - Undergoes less percentage deformation even under high stress
- Carbon fiber reinforced polysulfone
  - Plates, screws, spinal segmental replacement implant
  - Semi-rigid
  - Could replace metal alloys in orthopaedic implants

Carbon reinforced polyethylene used in knee prosthesis. There is lot of attrition, there is lot of bending, flexural, the carbon fibre gives, it gives improved, compressive, tensile, elastic, modulus fatigue strength undergoes less wear, undergoes less percentage deformation even under high stress. Whereas, polyethylene may have higher wear, may have more deformation. Carbon fibre reinforced polysulfone plates, screws, spinal segmental, replacement implants it is quite semi rigid actually it is not fully rigid, but it is not soft like this polymer. It could replace metal alloys in orthopaedic. Advantage is it could replace and they are quite light weight also.

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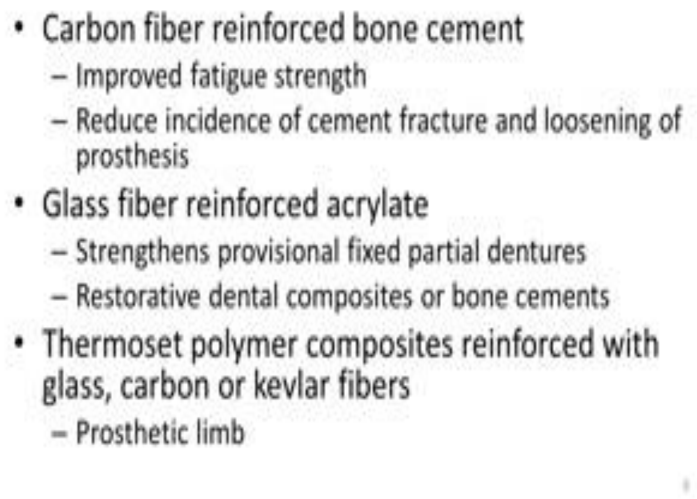

- Carbon fiber reinforced bone cement
  - Improved fatigue strength
  - Reduce incidence of cement fracture and loosening of prosthesis
- Glass fiber reinforced acrylate
  - Strengthens provisional fixed partial dentures
  - Restorative dental composites or bone cements
- Thermoset polymer composites reinforced with glass, carbon or kevlar fibers
  - Prosthetic limb

Carbon fibre reinforced bone cement, improved fatigue strength because of the carbon fibre. It reduces the incidence of cement fracture and loosening of the prosthesis.

Glass fibre reinforced acrylate again it is very good for dental composites, bone cements, it gives strengthens the fixed partial dentures. Thermoset polymers composites reinforced with glass, carbon Kevlar, prosthetic limb. So, you see these carbon fibres, glass fibres they give strength, flexural strength, yield strength, module, improvement in modulus improvement in wear, when you compare polyethylene in our PMMA type of polymers. Also they are used quite a lot in medical instrumentation. Carbon fibre reinforced polymer used in tables of MRI CT scanners that gives you strength, that gives you stiffness and of course, they are light weight if I am going to use a complete metal it is going to be very very heavy. So, a polymer will be very light weight, we can strengthen it by carbon fibre. Radiolucent; so it will prevent penetration of light wave, radio waves. Non magnetic to obtain clear sliced images of whereas; if I have some metal they could start interfering because of their own inherent magnetism. Surgical clamps, head rest frames, x ray film cassettes, CT scan couches. So, lot of medical instruments are nowadays being area where metals are getting replaced with a polymer reinforced carbon fibre or glass fibres and so on actually because of the light weight.

Now, we can also achieve good tailored properties by blending polymers; two polymers blended together. So, we get properties which are not found in individual polymer one method is.

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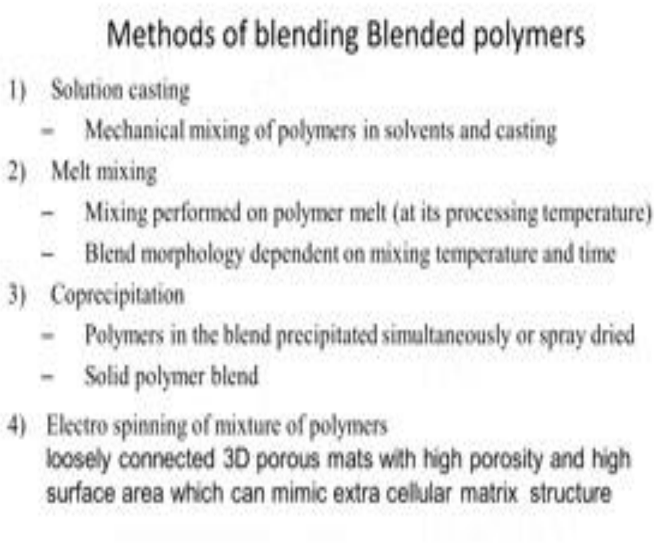

Methods of blending Blended polymers

1) Solution casting
   - Mechanical mixing of polymers in solvents and casting
2) Melt mixing
   - Mixing performed on polymer melt (at its processing temperature)
   - Blend morphology dependent on mixing temperature and time
3) Coprecipitation
   - Polymers in the blend precipitated simultaneously or spray dried
   - Solid polymer blend
4) Electro spinning of mixture of polymers
   loosely connected 3D porous mats with high porosity and high surface area which can mimic extra cellular matrix structure

There are many methods of these blending; one is called the solution casting. It is a mechanical mixing of polymer in solvents and casting. Melt mixing that is means you melt the polymer here, we are not using any solvent, but we are melting the polymer at its processing temperature and then mix them. So, the blend morphology depends on the mixing temperature and times here whereas, in the previous case you are dissolving the polymer and casting. Co precipitation; polymers in the blend precipitated simultaneously or spray dried or solid polymer blend. So, you blend them together as a co precipitate.

Electro spinning of mixture of polymers; that means, if we take two polymers in the solution and then electro spin it. So, you get loosely connected 3 D porous match with high porosity, high surface area which can make extra cellular matrix.

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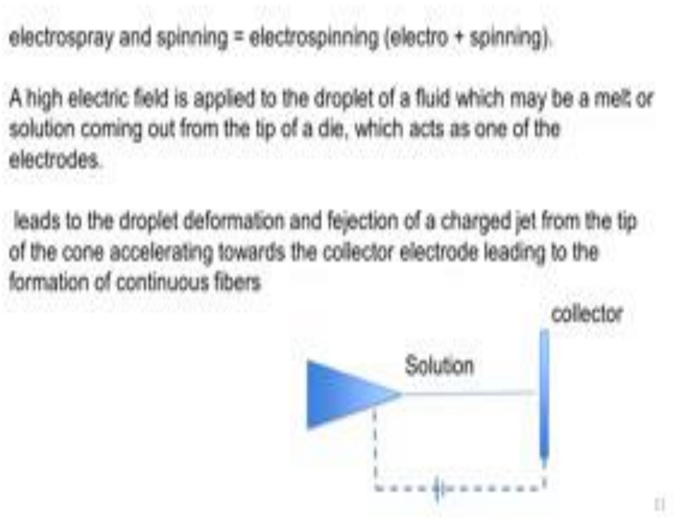

electrospray and spinning = electrospinning (electro + spinning).

A high electric field is applied to the droplet of a fluid which may be a melt or solution coming out from the tip of a die, which acts as one of the electrodes.

leads to the droplet deformation and fejection of a charged jet from the tip of the cone accelerating towards the collector electrode leading to the formation of continuous fibers

So, what is this electro spinning? Let us look at the electro spinning porouses. It is a combination of electrical field and spinning. So, you can spin the polymer blend like younds. So, we can get a mat of younds. So, what do you do? You take the solution the mixture of polymers and then you force it through the nozzle and then you apply a high electric field here. So, you may have a melt or a solution coming out of the tip of the die and it has charge.

Then you apply another charge on the collector plate, it leads to the droplet deformation and ejection of charged jet from the tip of the cone. So, it gets accelerated towards the collector electrode leading to the formation of continuous fibre. So, you force this melt polymer solution or the polymer in solvent, mixture of polymers in solvents you apply a high voltage. So, the droplets which come out are charged then, you connect the other side of the voltage. So, they go and get deposited and collected. So, that is the advantage of this. This is called electro spinning and this is called electro spinning. So, we can get very nano sized fibre, diameter we can get younds of them and quite used in wound dressing applications. It is also used when you are trying to make scaffolds because the younds are very small in diameter and they are very porous many gaps. So, cell growth is very facilitated that is called electro spinning.

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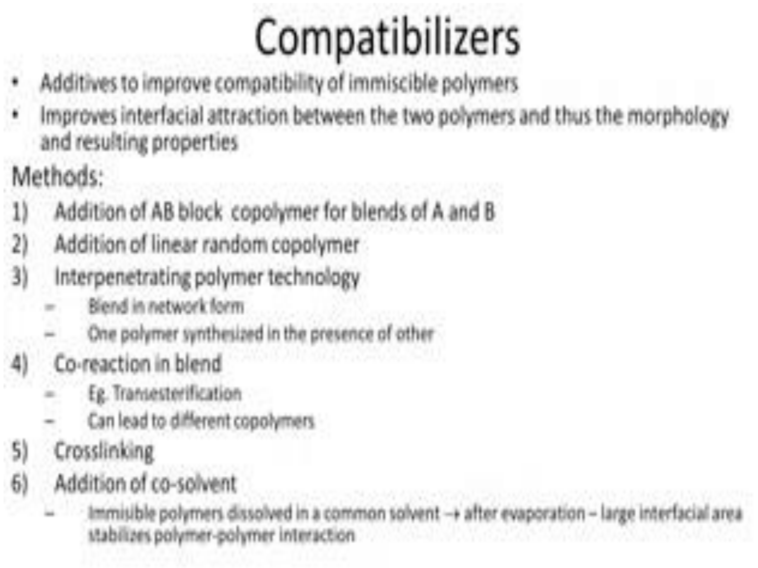

Compatibilizers

- Additives to improve compatibility of immiscible polymers
- Improves interfacial attraction between the two polymers and thus the morphology and resulting properties

Methods:

1) Addition of AB block copolymer for blends of A and B
2) Addition of linear random copolymer
3) Interpenetrating polymer technology
   - Blend in network form
   - One polymer synthesized in the presence of other
4) Co-reaction in blend
   - Eg. Transesterification
   - Can lead to different copolymers
5) Crosslinking
6) Addition of co-solvent
   - Immisible polymers dissolved in a common solvent → after evaporation – large interfacial area stabilizes polymer-polymer interaction

So, these are different ways by which we can mix polymer and prepare polymer blends. Sometimes we need to add some additives they are called compatibilizers to improve the compatibility of immiscible polymers. So, you may have a hydrophobic polymer, you may have a hydrophilic polymer. So, we may have to add something, sometimes we add PVA which is very hydrophilic, these are all called compatibilizers. They improve the interfacial attraction between these two polymers and thus the morphology and the resulting properties. So, many times you will see PVA is widely used. So, addition of AB block co polymer for blends of A and B. Addition of linear random co polymer; random copolymer will be amorphous, it will not be crystalline. So, it may blend better with two immiscible polymer.

Interpenetrating polymer blend in network form one polymer synthesized in the presence of the other, co reaction in the blend, like you can do transesterification in the presence of another polymer. So, this can lead to different co polymers or we can do cross linking we have two polymers then I say, I use butyraldehyde or I use some other cross linking agent so that there is a fixed covalent bond formed between the (Refer Time: 14:26). Addition of co solvent, so what we do is immiscible polymers dissolved in a common solvent after evaporation large interfacial areas stabilises this polymer polymer interaction. That is called the addition of co solvents. So, many methods are there, they are all called compatibilizers to improve the mixing or blending of two polymers. If the blending is not good you may end up having the heterogeneous mixture of polymer A and polymer B regions where you may have more of A and less of B and regions where you will have more of B and less of A, which is not desirable. We want a very uniform macroscopic mixing of these two polymers.

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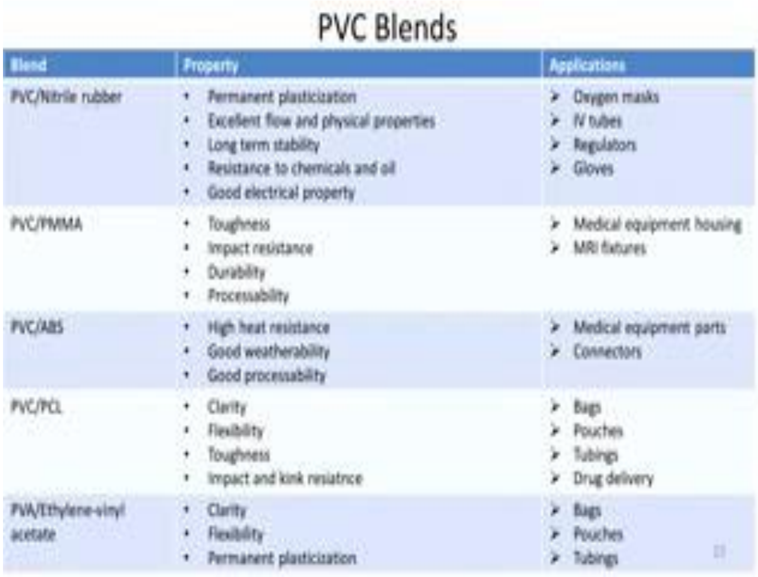

PVC Blends

Blend	Property	Applications
PVC/Nitrile rubber	• Permanent plasticization • Excellent flow and physical properties • Long term stability • Resistance to chemicals and oil • Good electrical property	➢ Oxygen masks ➢ IV tubes ➢ Regulators ➢ Gloves
PVC/PMMA	• Toughness • Impact resistance • Durability • Processability	➢ Medical equipment housing ➢ MRI fixtures
PVC/ABS	• High heat resistance • Good weatherability • Good processability	➢ Medical equipment parts ➢ Connectors
PVC/PCL	• Clarity • Flexibility • Toughness • Impact and kink resiatnce	➢ Bags ➢ Pouches ➢ Tubings ➢ Drug delivery
PVA/Ethylene-vinyl acetate	• Clarity • Flexibility • Permanent plasticization	➢ Bags ➢ Pouches ➢ Tubings

For example if you look at PVC blends, PVC is widely used, PVC is quite inert, PVC nitrile rubber. Nitrile rubber gives the very good flexural property, permanent plasticization, excellent flow physical properties, long term stability, resistance to chemical and oil good electrical property this is used oxygen masks, IV tubes, regulator gloves. So, we need good flexibility because PVC is not, so flexible by adding this nitrile rubber (Refer Time: 15:46) that. PVC with PMMA gives you toughness, impact resistance, durability, processability. So, they are used in medical equipment housing, MRI fixtures. PMMA has good toughness, PMMA is very transparent, it is widely used in dental application, PVC is very inert, have good lubricity. So, mixing them they are used in medical equipment, PVC with ABC; high heat resistance, good weatherability, good processability; again in medical instrument.

PVC with PCL: clarity, flexibility, toughness used in bags, pouches, tubing, drug delivery, PVA; ethylene vinyln, acetate, clarity, flexibility, bags, pouches, tubings. So, you see even PVC although it is used quite a lot in medical application especially in drain tubes, catheters, for short duration, it is some of its disadvantages are overcome by adding another polymer to improve those properties. Especially as you can see lot of bags, pouches, medical instrument parts, housing gloves, external, lot of external bio materials are prepared using this.

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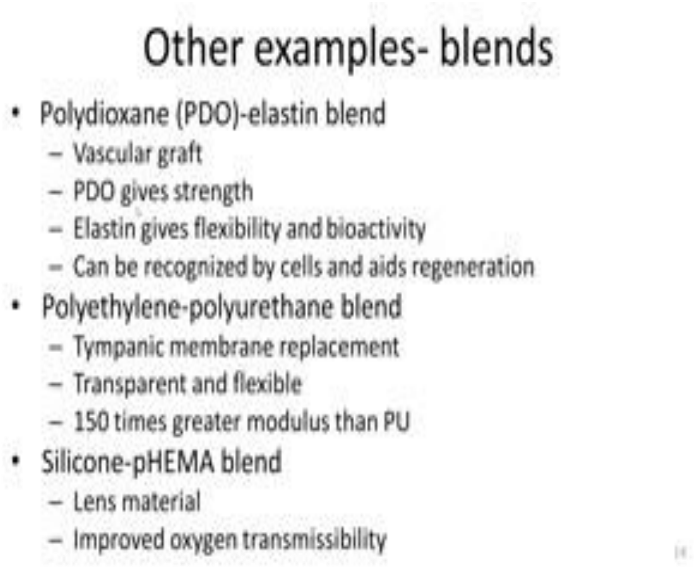

Other examples- blends

- Polydioxane (PDO)-elastin blend
  - Vascular graft
  - PDO gives strength
  - Elastin gives flexibility and bioactivity
  - Can be recognized by cells and aids regeneration
- Polyethylene-polyurethane blend
  - Tympanic membrane replacement
  - Transparent and flexible
  - 150 times greater modulus than PU
- Silicone-pHEMA blend
  - Lens material
  - Improved oxygen transmissibility

Other example of blends; polydioxane, elastin blend, vascular graft, polydioxane gives strength, elastine gives flexibility and bio activity, so which can be recognised by cells. So, this polymer gives the strength, this gives you the bio activity and recognition. So, they are used in vascular grafts.

Polyethylene, polyurethane blend; tympanic membrane and replacement, transparent and flexible their flexibility comes from polyurethane it has got a higher modulus than polyurethane. Silicon pHEMA lens material because this is any way used hydroxyl, ethyl methyl, acrylate is used in soft contact lenses. Silicon we are improving the oxygen transmitability as well as it gives you stability as well.

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Other examples- blends

- Polycarbonate-polyester blend
  - Diagnostic equipment, respiratory therapy devices, portable defibrillators
  - Strong, rigid and tough
  - Chemical resistance
- Carboxymethyl cellulose-PVP blend
  - Wound dressing
  - Mechanical strength better than CMC
  - Flexibility better than PVP
  - High water uptake
  - Enhanced biodegradability

Polycarbonate polyester; polycarbonate is very strong rigid tough. So, these blends are used diagnostic equipment, respiratory therapy devices, they are also chemically resistance because polycarbonate is also chemically resistance. So, it becomes very tough polymer. Carboxymethyl cellulose PVP; polyvinylpyrrolidone and this is a natural polymer, used in wound dressing. CMC does not have any strength, PVP gives the strength. So, together they have very good strength as well as flexibility they have good water uptake enhanced bio degradability. So, you can see PVP carboxymethyl is very useful for wound dressing applications.

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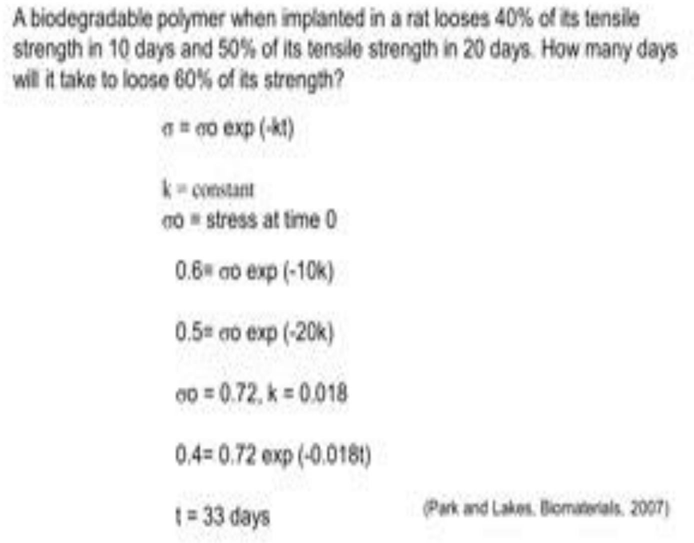

A biodegradable polymer when implanted in a rat looses 40% of its tensile strength in 10 days and 50% of its tensile strength in 20 days. How many days will it take to loose 60% of its strength?

$\sigma = \sigma o \exp(-kt)$

k = constant

σo = stress at time 0

$0.6 = \sigma o \exp(-10k)$

$0.5 = \sigma o \exp(-20k)$

$\sigma o = 0.72, k = 0.018$

$0.4 = 0.72 \exp(-0.018t)$

t = 33 days

(Park and Lakes, Biomaterials, 2007)

So, lot of examples of blends being used mixing two polymers together. So, that we can achieve properties which is not available with one single polymer and sometimes we may have to add compatibilizers; that means, third polymer which improves their mixing or we can do a cross linking and so on actually. Then we also looked at composites where we are adding an inorganic material like your glass or carbon fibre or particles into your polymer. So, it gives lot of strength and better elastic modulus. So, let us look at one or two problems on this topic. A bio degradable polymer when implanted in a rat looses 40 percent of its tensile strength in 10 days and 50 percent of tensile strength in 20 days. So, how many days it will take to loose 60 percent of its strength? That is quite simple. So, we can assume exponential decay in bio degradability. So, we can say strength is equal to original strength exponent minus k t; k is a constant, sigma 0 is strength at time 0. So, in 10 days it loses 40 percent. So, there will be 60 left behind in 20 days it loses 50 percent strength left behind, we can calculate sigma 0 and k and then for the next part of the problem for a 60 percent loss of strength what is the time that is what we have to do. So, you understood problem.

So, the first part 40 percent it lost in 10 days. So, remaining is 6.6 is equal to sigma 0 exponent minus 10 k; 10 is your days, 50 percent loss in 20 days. So, 0.5 sigma 0 exponent minus 20 k so k is not known, sigma 0 is not known. Two unknowns, two equations sigma 0 is 0.72 k is equal to 0.018. Units of k, is the day inverse because t is day. Now how many days will it take to lose 60 percent of its strength; that means, 40 percent is left behind; 0.4, 0.72, 0.018 t. So, we need to calculate t that is 30 days. So, quite a simple problem, but it is very interesting problem to work at, it gives you nice idea about. The main point here is we assume the bio degradability leading to loss and strength follows a exponential type of decay; that means, it is like a first order loss sigma is equal to sigma 0 exponent minus k t.

It might not be true, but it is good enough for us to assume. So, that we can use these equation and the old data to calculate for the new unknown, that is a advantage. So, this example was taken from this particular reference. So, I thank them.

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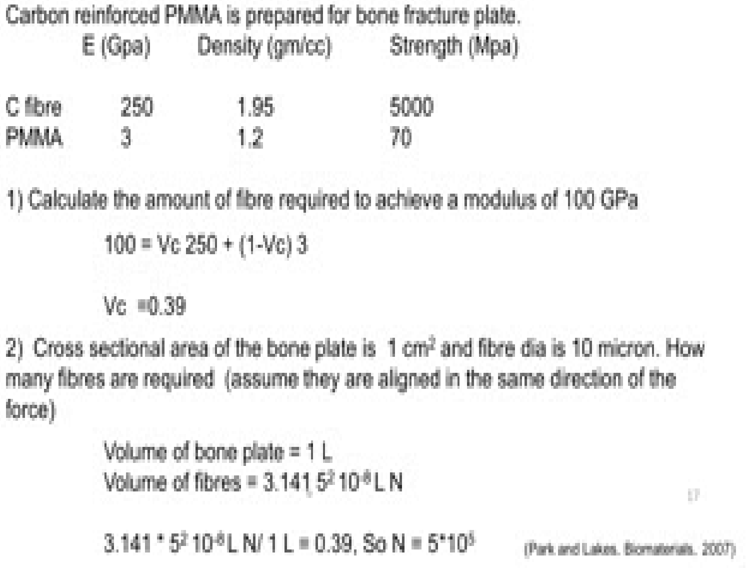

Carbon reinforced PMMA is prepared for bone fracture plate.

	E (Gpa)	Density (gm/cc)	Strength (Mpa)
C fibre	250	1.95	5000
PMMA	3	1.2	70

1) Calculate the amount of fibre required to achieve a modulus of 100 GPa

$$100 = V_c\ 250 + (1 - V_c)\ 3$$

$$V_c = 0.39$$

2) Cross sectional area of the bone plate is 1 cm^2 and fibre dia is 10 micron. How many fibres are required (assume they are aligned in the same direction of the force)

Volume of bone plate = 1 L

Volume of fibres = $3.141\ 5^2\ 10^{-8}$ L N

$3.141 * 5^2\ 10^{-8}$ L N/ 1 L = 0.39, So N = $5*10^5$

(Park and Lakes, Biomaterials, 2007)

Let us look at another problem; this is related to a composite problem. So, look at this carbon reinforced PMMA is prepared for bone fracture application, fracture plate. So, as you know carbon fibre has very high modulus 250 Giga Pascal. PMMA has very very low 3 Giga Pascal look at the density is 1.95, 1.2.

Strength of carbon fibre 5000 Mega Pascal, strength of PMMA is 70. Calculate the amount of fibre required to achieve a modulus of 100 Giga Pascal. So, we have two materials mixed together for a composite, we want to achieve 100 Giga Pascal. So, we can follow the mixture rules, volume fraction of carbon multiplied by 5000 plus volume fraction of PMMA multiplied by 70 will give you 100 and of course, volume fraction of this plus that should be equal to 1. So, we can calculate what should be the amount of fibre to be added? Quite simple; look at this 100 volume fraction of carbon fibre into 250 volume fraction of PMMA 1 minus volume fraction of carbon into 3. So, we can get from volume fraction for carbon fibre is equal to 0.39.

So, I need to add 0.39 or 39 percent carbon fibre and remaining 61 percent PMMA to achieve a modulus of 100 Giga Pascal or same thing we can do if you want to look at the strength the same. So, the same volume fraction ratio is what it follows and that is called the mixture rules understand. So, we can multiply by the corresponding volume fractions to get the overall modulus or if you want for calculate the maximum strength it can take, you can multiply their volume fraction to these strength and then add them up.

The second part of the problem cross sectional area of the bone plate is 1 centimetre square and the fibre diameter is 10 micron. How many fibres are required? Assume they are aligned in the same direction of the force. So, volume fraction of the fibre is 0.39 cross sectional area of bone plate is 1 centimetre square. So, if I assume L as the length of the bone plate and volume of the bone plate will be 1 into L, I am having 10 micron diameter. So, if I take it as a circular pi D square by 4 it will come multiplied by N that will be the volume fraction for the fibre, total fibre occupied that will come from here 0.39. So, from there we can calculate number of fibres.

So, volume of 1 of the bone plate 1 into L; L is the length of the bone plate, volume of the fibre pi 3.141 multiplied by radius is 5 pi R square, 5 square this is for converting micron to centimetre. Length is the length of the fibre because the fibre is along the bone plate, N is the number of fibres we take. So, this will be equal to the volume of one fibre, area into length multiplied by N fibres. So, this divided by this should be equal to 0.39 because that will be the total volume fraction of the fibres. Do you understand this problem? So, 3.141 multiplied by 5 square multiplied by 10 minus 8 L N divided by 1 L that will be the volume fraction of the fibres, which we are calculating the previous this 0.39. So, N is equal to 5 into 10 power 5.

So, 5 lakh fibres are needed of 10 micron diameter for this bone plate of 1 centimetre square area to achieve a volume fraction of 0.39. Do you understand? So, cross section of a bone plate is 1 centimetre square if I take length of the bone plate is L 1 into L will be the volume, take one fibre pi R square L R is 5 microns. So, pi into R square 5 square, this is converting the micron into centimetres. As you know 10 power 4 micron is 1 centimetre that is why you got 10 power minus 8 L there are N fibres. So, we have put N here. Now this term divided by this term should give you 0.39. So, from there we can calculate N. So, I need 5 lakh fibres to achieve a volume fraction of 0.39, the cross sectional area of the bone plate is 1 centimetre square.

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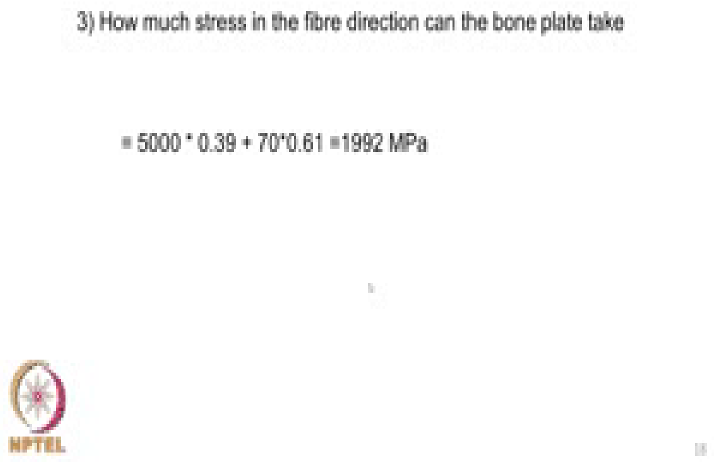

3) How much stress in the fibre direction can the bone plate take

= 5000 * 0.39 + 70*0.61 =1992 MPa

Third part, how much stress in the fibre direction can the bone plate take? Stress; same thing, like I said before; 0.39 is volume fraction of your fibres. So, 0.61 will be the volume of PMMA, 5000 is the strength of the carbon fibre that is stressed 70 Mega Pascal is that of PMMA. So, we use the same mixture rules. So, 5000 into 0.39 plus 70 into 0.61, that will give you 1992 Mega Pascal. That will be the stress, this whole bone plate will take, but of course, you need to assume, you need to consider that the fibres are all aligned in the same direction as your bone plate, but in reality some of the fibres may not be aligned. So, they will not be able to take in the same force, only the fraction that is aligned will take in the force whereas, those that are not aligned will take in much lesser force. So, in reality the stress, the composite may take in may be much lesser than this. This could be the best case scenario. So, with that we conclude on the topic of composites and blends, polymer based blends as well as polymer and inorganic material based composites.

Thank you very much for your time.