Science and Technology of Polymers
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Lecture - 34
Polymer Composites

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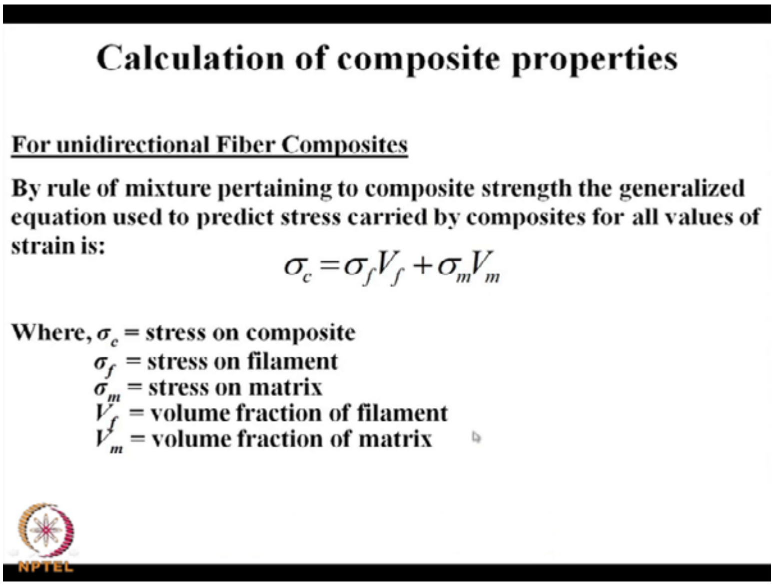

Now, let us look into the calculation of the evaluation of the strength properties, based on the strengths of the fiber and the matrix continuation of the strength of fiber and the matrix to the composite. For unidirectional fiber composites, we can apply rule of mixture to calculate the strength of the composite, say here the stress of the modulus of this stress applied on the stress applied on the fiber and the matrix components, what will be the stress on the final composite.

Say, if we know the volume fraction of the fiber, volume fraction of the matrix and the strength of the fiber and the strength of the matrix can calculate the strength of the composite from this relation, where sigma c is the stress on composite, sigma f is stress on filament of fiber, sigma m stress on matrix, and V f and V m are the volume fraction of the fiber and matrix respectively.

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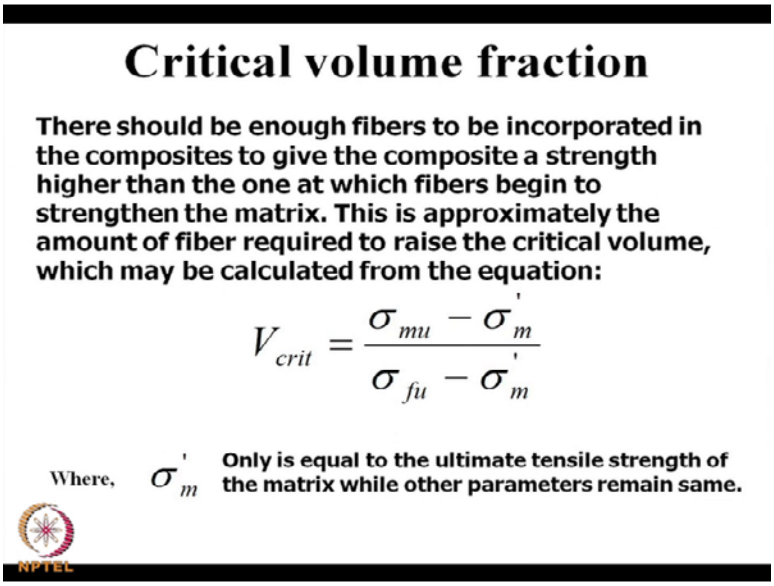

Now, there can be critical volume fraction of the fiber. Critical volume fraction of the fiber in the composite that can also be calculated from the, these parameters, the stress value on the matrix and fiber this critical volume fraction can be calculated.

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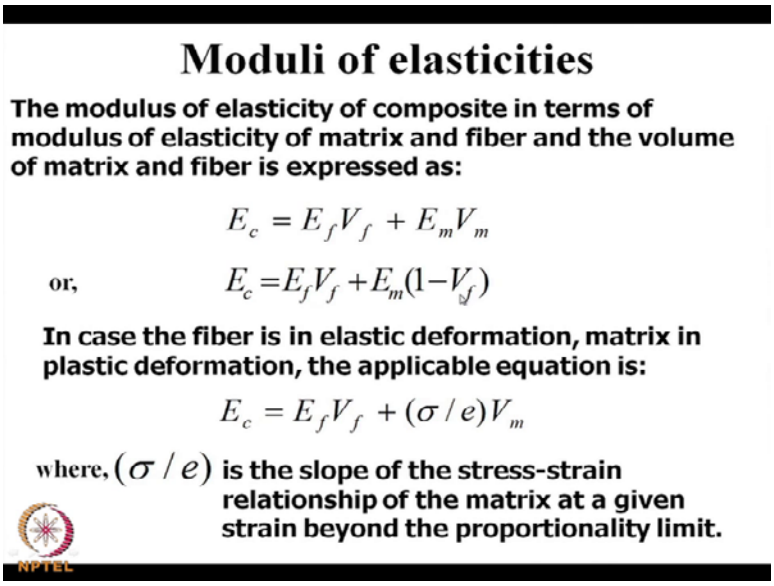

The modulus of elasticity at the composite also can be calculated, the modulus of elasticity of composite in terms of modulus of elasticity of matrix and that of fiber. And the volume of a matrix and fiber can be expressed as E c is equal to E f into V f plus E m into V m and E c or E c is equal to E f into V f plus E m into 1 minus V f.

Now, in case the fiber is in elastic deformation, elastic region matrix in plastic deformation the applicable equation would be this, where sigma by e is the slope of the stress strain e is the strain, is the slope of the stress strain in the relationship of the matrix at a given strain beyond the proportionality limit. For these equations the governing equations by which if we know the strength of the fiber, if we know the strength of the matrix, then we can have a preliminary calculation or one particular composite to be made from such fiber and matrix. So, for selection of one fiber and matrix component, then we can utilize these equations for calculation of the properties of the final composite.

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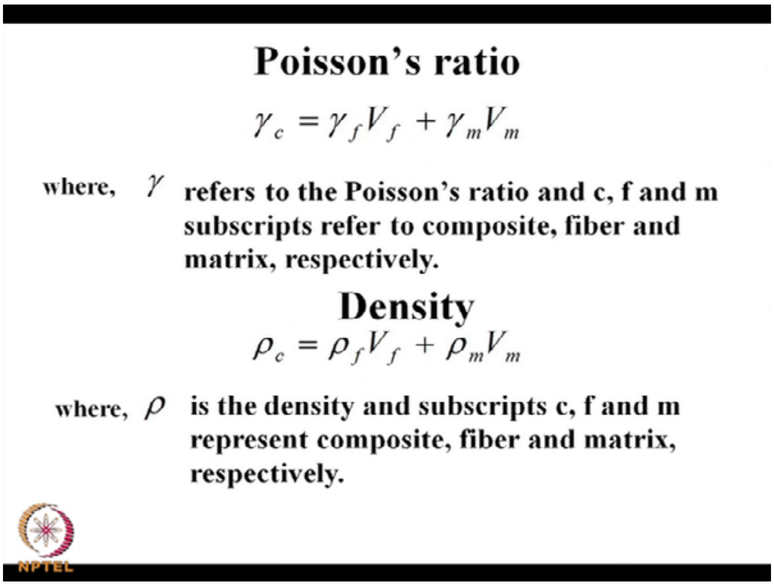

We can also calculate the Poisson's ratio, where this gamma refers to the Poisson's ratio where c f c f and m these subscripts refer to composite fiber and matrix respectively. And this shows the gamma c is the Poisson's ratio of the composite and this is the Poisson's ratio of the fiber volume fraction of the fiber Poisson's ratio of the matrix, volume fraction of the matrix. The density can also be calculated from that of the component fibers and matrix, along with if we know the volume fraction of the fiber and the matrix in the composite.

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Effect of 30 wt% glass fiber reinforcement

Matrix material in composite	Heat deflection temp.(^{0}c)		Tensile strength (MPa)	
	Actually observed	Enhancement on fiber reinforcement	Actually observed	Enhancement on fiber reinforcement
A. Crystalline				
Nylon 66	248	150	180	100
PEEK	300	145	175	75
PBT	210	140	135	75
Nylon 6	210	130	135	100
PP	148	82	85	50
Acetal	164	55	140	70
B. Amorphous				
PES	215	16	145	55
PPO	140	15	125	60
PC	140	10	120	52
ABS	100	10	90	40

Now, let us look into some properties of the composites. On the fiber loading due to the fiber loading on the composites effect of fiber loading on the properties of the composites. Here two different properties are shown heat deflection temperature and tensile strength and the Matrix materials in the composite nylon 6, polyether ether ketone, polybetholen, pererepthalit, nylon 6, polypropylene acetyl, this is crystalline matrix polymers and polymers amorphous state amorphous state or polyether siphoned, polyphilinoxide, polycarbonate, acranilitale, butyraldehyde styrene, tar polymer. Now, after incorporation of 30 weight percent glass fiber in those matrix regions, it is been found there is an enhancement of heat deflection temperature by 150 degree celsius temperature in nylon 66 was the matrix.

In case of peek it was 145 degree increment, enhancement whereas in case of polypropylene it is quite low for acetyl it is quite low, this is quite expected because glass fiber this is a polar material having oxide composition, oxide composition and nylon 6 and polyether ether ketone, polybetholen, pererepthalit, nylon 6 these are having polar linkages. So, these polar polar interaction makes very good addition of this matrix region, in the glass fiber that is why there is enhancement of heat deflection. That means, heat deflection temperature means the composite can stand without any dimensional stability up to these temperatures.

If we look into the strength property tensile strength expressed in mega Pascal, that enhancement is also quite high or in the same sequence as been found in case of heat deflection temperature or these regions with this 30 weight percent glass fiber loading 100 degree for nylon 6, 100 M P A for nylon 6, nylon 6 and nylon 66 where as little less for the other polymers.

So, it shows that these glass fiber can be a good peer for nylon 6 peek polybetholen pererepthalite. Now, this trails could be further improved if we replace the glass fiber with carbon fiber or aramid fiber that data is not available with me at the moment. So, only a representative, reflection of properties are shown with this 30 weight percent glass fiber in those crystalline amorphous polymers.

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Effect of particulate & fibrous reinforcement on properties of nylon 66 composites

Reinforcement	T.S. (MPa)	Flexural mod, GPa	HDT (^{0}C)	Stiffness ratio (Anisotropy index)
None	85	2.5-3.0	95-100	1.0
50% Particulate	95	5.6-6.0	130-170	1.0-1.2
35% Particulate & 15% Fibrous	125	6.0-7.0	220-230	1.4-1.5
50% Glass fiber	200	9.0-9.5	240-250	1.7-1.8

Effect of particulate and fibrous reinforcement on properties of nylon 66 composites, in this case only one aliphatic polyamine was chosen nylon 66, aliphatic polyamine. And, when there is no fiber, no reinforcement, no filler, no fiber, tensile strength of that nylon 6 polymer was 85 flexural strength was 2.5 to 3 Giga Pascal, heat deflection temperature is 95 to 100 degree celsius, stiffness ratio is 1 only. Incorporating 50 percent fiber fibrous particulate filler in this nylon 6 is composite, the tensile strength has been increased from 85 without filler to 95 mega Pascal flexural strength has been increased from 3 to almost 6 heat deflection temperature 100 to 170 and stiffness ratio is also increased.

35 percent particulate and 15 percent is the total figure was 50 percent here total 50 percent was particle only here in this case in this case a combination of particle and fiber 35 percent particle and 15 percent fiber. So, the combination of this particle and fiber you see enormous increase in strength from 95 to 125 mega Pascal. Little increase also in flexural strength and quite a good change in, remarkable change in heat deflection temperature from 170 to 220 or 230 degree celsius the stiffness ratio is also increased. And when 50 percent glass fiber was used you see further improvement is there. So, it shows a combination of particle and fiber is good and if the fiber is very thin continuous fiber. Then in that case also one can have very good mechanical properties of such imposement.

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Properties of fibers, metals & alloys and composites

Materials	S.G.	Tensile Strength (psi x 10^{-5})	Tensile Modulus (psi x 10^{-6})	Specific Strength (psi x 10^{-5})	Specific Modulus (psi x 10^{-6})
S-glass fiber	2.49	6.5	12.45	2.61	5.02
Boron fiber	2.69	4.5	35.50	1.67	17.1
Hi mod C-fiber	2.00	2.5	55.00	1.25	27.5
Hi strength C-fiber	1.74	4.5	35.0	2.70	20.1
Aramid fiber	1.44	4.0	19.0	2.77	13.2
Al-alloy (RR-58)	2.77	0.59	10.0	0.23	3.59
Ti-alloy (Ti-6Al-4V)	4.50	1.50	16.0	0.33	3.55
Steel (FV520)	7.80	1.55	28.0	0.198	3.59
S-glass-epoxy	2.08	2.60	7.6	1.25	3.65
Hi mod C-fibr-epoxy	1.67	1.50	30	0.93	18.7
Aramid fiber-epoxy	1.38	2.00	11	1.44	7.97
Boron fiber-epoxy	1.97	1.95	39	0.99	19.8

Properties of, now this table shows properties of some fibers, metals and alloys and composites. Now, you see look at the properties of S-glass fiber specific gravity is the tensile strength, tensile modulus, specific strength, hence ratio of the strength to specific gravity, specific modulus ratio of the modulus to specific gravity. So, if you compare these properties specific gravity is higher for this glass boron fiber, carbon fiber is little less. High strength carbon fiber is further less, aramid fiber is further less low, and aluminum alloy 2.77 titanium alloy it is as specific steel is quite very high glass epoxy this 2.08 hi–modulus carbon fibre epoxy 1.67 aramid fibre-epoxy 1.38 and boron fiber epoxy 1.97.

So, out of all these different kinds of fibers we find these aramid fiber and carbon fiber are having the lowest specific gravity. That means, that can provide light weight composites now if you compare their specific gravity and their tensile strength and modulus, that way you can say, aramide fiber aramide fiber could be a good selection because if look into specific strength of specific modulus, specific strength and specific modulus is quite good for aramid fiber 2.77 and 13.2. So, from this table one can go for a selection of fiber for making a composite.

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Flexural strength of some FRP composites

Polymer matrix	Fiber	Flexural strength, MPa		
		No fiber	30% Short fiber	65% continuous fiber
None	Glass	--	--	3400 (T.S.)
PP	Glass	30	85	350
Nylon 66	Glass	80	180	600
PET	Glass	60	140	800
PES	Glass	90	145	500
PEEK	Glass	91	150	780
PEEK	C-fiber	90	250	1100

Flexural strength of some fiber reinforce composites, where matrix is for polypropylene nylon 66, polyethylene teritalite, poly ethyl sulphur, polyether ether ketone and fibers were glass fibers and peek with carbon fiber. So, without any fiber flexural strength for these polymers where in these range 30, 80, 60, 90, 91, 90, 30 so less than 30 to 90 now when 30 percent short fiber of these glass or carbon where incorporated, look at the improvement in strength on 30 to 85, 80 to 180, 60 to 140, 90 to 145, 91 to 150 and 90 to 250.

So, you see the effect of carbon fiber and peek, that is why this carbon fiber poly ether ether composites, one can say very strong composites or strongest composites those are used in aircraft or spacecraft, and if you see if somebody can use higher amount of fiber you see the further incremental properties, where if this peek and carbon fiber it is 1100 mega Pascal. Mega Pascal in this flexural strength. So, it indicates that these hyper polymer matrix with carbon fiber can be very good peer for hyper polymer composite.

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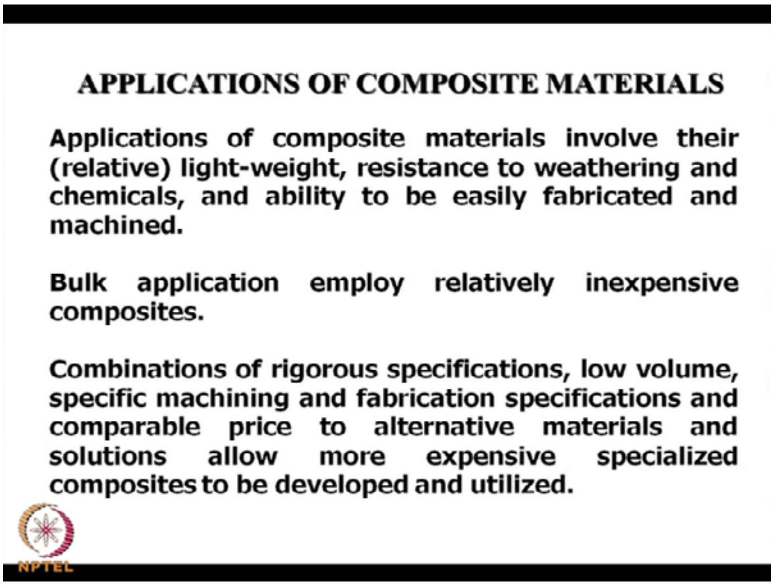

Now, let us look into the applications of these composite materials. Being light-weight, resistance to weathering and resistance to harsh chemicals and their ability to be easily processed and fabricated, easily machined these composites materials find quite variety applications and they can be inexpensive composites or cheaper composites those are necessary for bulk application. For bulk application a special type of composite can be expensive that can be afforded, but for bulk applications and the price of the cost of the composite should be as easy as possible. Now, combinations of rigorous specifications, low volume, specific machining and fabrication specifications and comparable price to alternative materials and solutions allow more expensive specialized composites to be developed and utilized.

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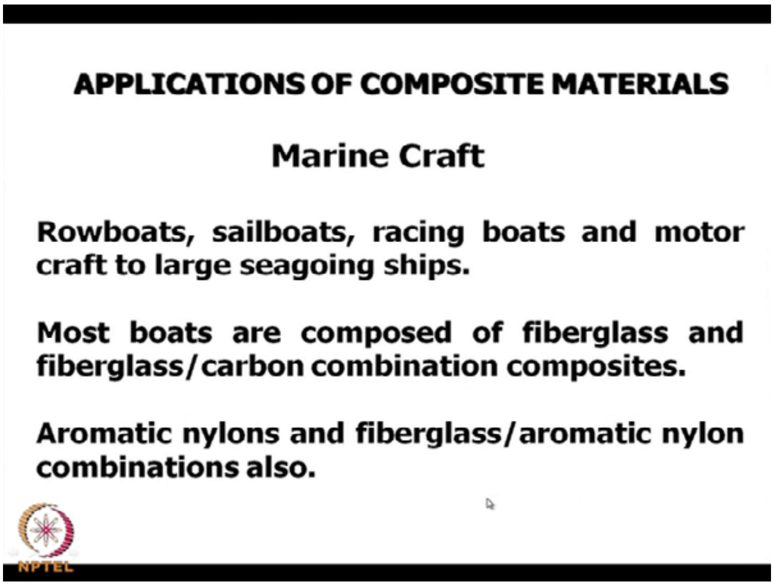

Now, let us look into the marine craft, marine vessels, marine vessels. Now, these rowboats sailboats, racing boats and motor craft to large sea going ships these are the vessels, which are made from composite materials. Now, most of the most of such vessels are composed of fiber glass and fiber glass carbon combination composites. Aromatic nylons and fiber glass aromatic nylon combinations are also used. Now, this would be light weight, this would be hydrophobic, this would be strong, this would be durable in marine environment. So, keeping all these properties under considerations, such combinations can yield such type of vessels from these fiber impost composites.

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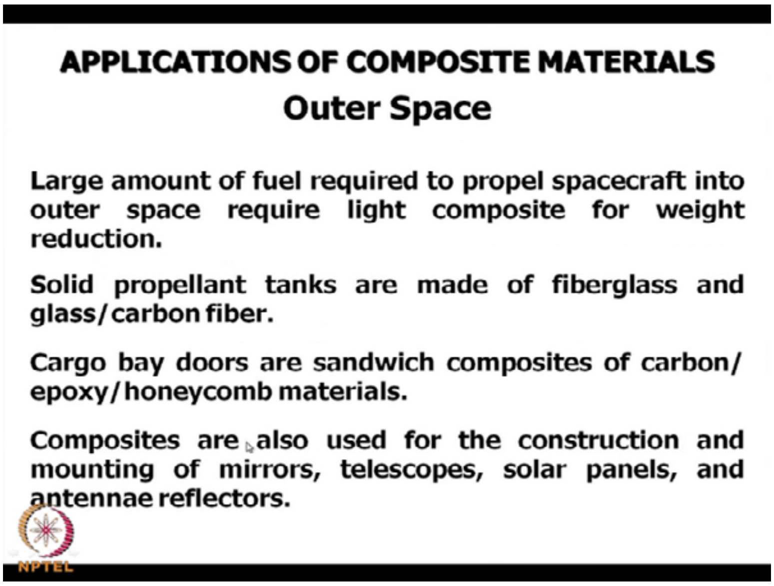

In outer space applications, now in outer space applications the fuel consumption is a prime considerations and in the such outer space applications, large amount of fuel is required to propel spacecraft into outer space that require light composites for weight reduction. Now if the weight is reduced then only fuel consumption can be reduced. So, weight reduction is a prime consideration at the sometime that should be thermal stable as well as very strong.

In that case carbon fiber, which can stand a temperature like say a more than 2400 degree celsius as well as the high strength performance of that fiber higher spit ratio of that carbon fiber, or even carbon nano tube is today. These carbon nano tubes or even graphing can also used as reinforcement for such high performance composites for outer space applications, which can neither, not only reduce the consumption of fuel by reducing the weight as well as that can increase the temperature stability thermal stability etcetera.

Solid propellant tanks are also made of these fiber glass and glass carbon fiber, cargo bay doors are sandwich composites of carbon epoxy honeycomb materials is a special type of design having small quantity of material, but provide rigid structure and very strong high strong high strength composite because of the honeycomb geometry. The composites are also used for the construction and mounting of mirrors, telescopes, solar panels, and antennae reflectors.

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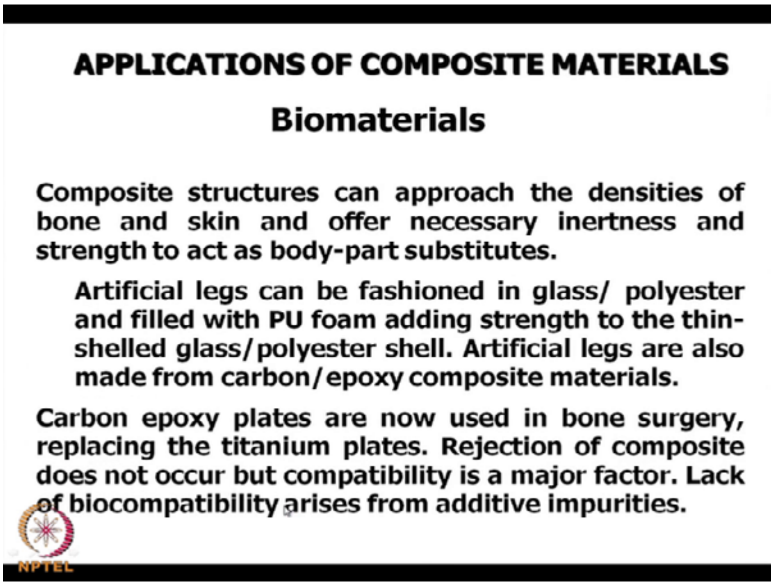

In the biomaterial fuel, biomaterial fuel today different types of biodegradable as well as inert composites are used as implants. Now, composite structures can approach the densities of the bone and skin and that offer necessary inertness. So, that it becomes biologically bio computable physiologically acceptable by the living system and having strength, adequate strength matching with the strength of bone for bone replacement, matching with the strength of skin for skin replacement with such composite material to act as body parts substitutes. So, body parts substitutes are been found rather being made for the artificial composites, which are acceptable are being accepted by the physiological system without any adverse effects.

Now, artificial legs can be fashioned with glass polyester composite as well as with filled polyurethane form, which add strength to the thin shelled glass polyester shell, artificial legs are also made from carbon epoxy composite materials. So, for orthotic application prosthetic and orthotic applications today, these polymer composites are good very good replacement very good material for replacing metals because these handicap persons they have to bear, that load of that artificial legs or artificial limbs. But if those are heavier then the person can tiredness in order to avoid such tiredness, if such strong organs can be made from such composites from light composites then, those are very much useful as orthotic and prosthetic articles provided the cost of those composites are bearable by the person.

So, the cost factor is also should also be kept in mind, now carbon epoxy plates are now used in bone surgery. Screws, nuts, bolts, replacing the titanium plates. Now, there can be total heap replacement, heap joint replacement by from composites. Rejection of composites does not occur, but compatibility is a major factor lack of biocompatibility arises from additive impurities. Means, now those composites contain some chemical additives, composite means that contains polymer, fiber etcetera all these things that contains additives or that polymer are in the composite in the form of fiber or matrix can degrade to form some products.

Now, those products would not be toxic to the physiological environment, or the additive which are present in the composite that should not reach out to the physiological plague, biological plague or to the tissue system or causing any toxic effect to tissue system. That is why people are thinking of developing biodegradable, fully biodegradable composites, although they are very much strong as well as the products of biodegradable compositions are non toxic and non hazardous. Those products of biodegradation and additives from those composites are suppose to be excreted by the normal executive system of the body. Applications of now to give an example for such artificial bone composites people can make people can take synthetic hydroxyapetite.

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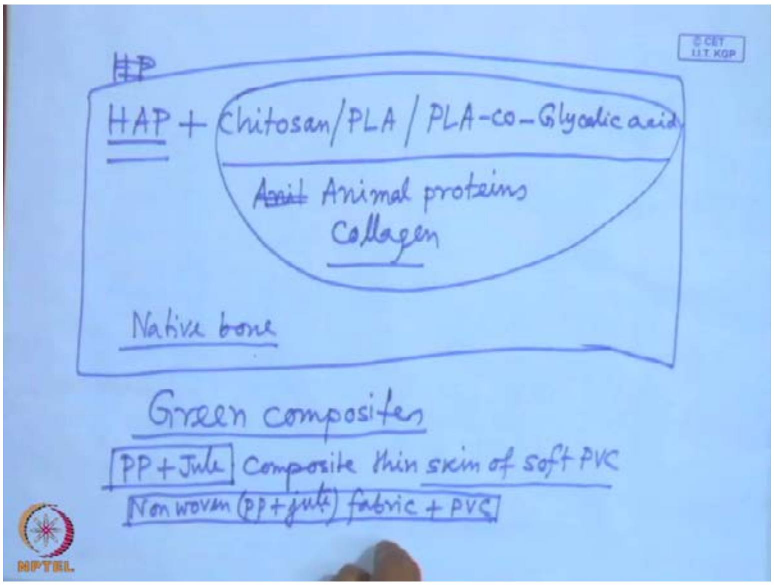

Synthetic hap Hydroxyapetite prepared in the laboratory are in the market of proper particle size that can be used as reinforcement, and some biodegradable polymer like chitosan or poly lactic acid or PLA-CO-Glycolic acid ester, or animal proteins can also be used as matrix material. Or collagen these collagen chitosan PLA PLA-CO-Glycolic acid other animal proteins as the matrix region and hap or some of the inorganic inert inorganic oxides can also be used as the reinforcement for making artificial bone. Now these biodegradable matrix and hap can replace the can be used as artificial bone and which will be replaced by the native bone, what will happen. If these composite is used to replace some broken part of a bone then slowly these polymers will be degraded and that space will be occupied by native bone tissue. So, this is a kind of biodegradable artificial bone material.

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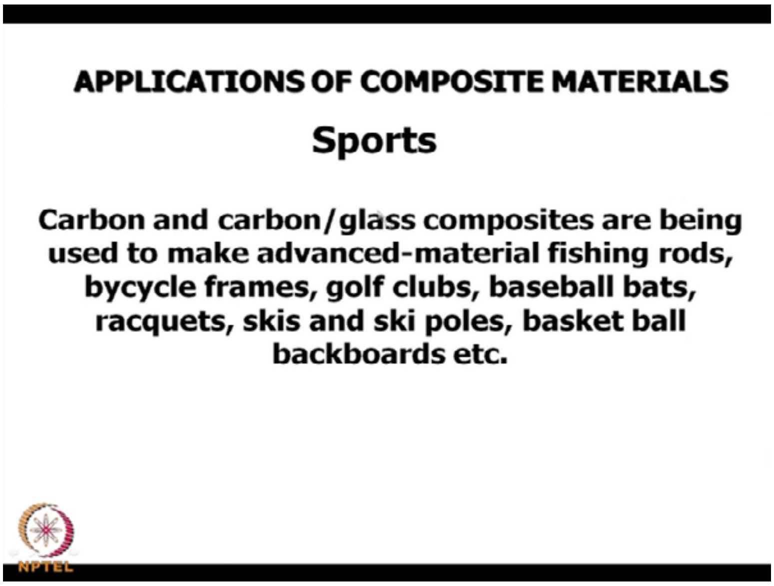

Now, in application of composition sports these carbon and carbon glass composites are been used to make advanced-material say for fishing rods, bicycle frames, golf clubs, baseball bats, racquets, skis and ski poles basket ball backboards etcetera, these would be light and strong these will be light and strong. So, keeping in mind about the weight of the these items these carbon fiber were selected as the reinforcing fiber.

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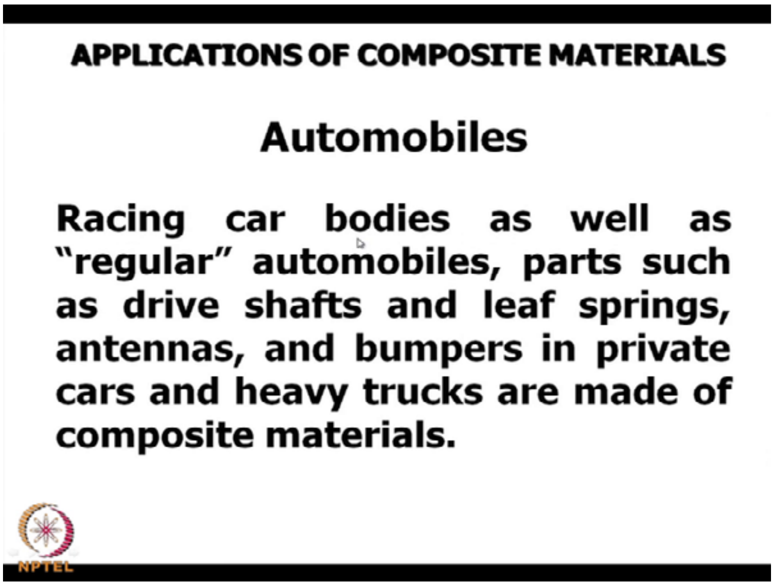

In automobiles, now racing car bodies as well as regular automobiles parts such as drive shafts and leaf springs, antennas and bumpers in private cars and heavy trucks are made of composite materials. I already mentioned that green composites, today are going to replace these are biodegradable these are going to replace that non biodegradable composites. Today in most of the modern car available in our country one can find some interior covering of the door and the roof etcetera, with some composite that composite is made of these polypropylene jute composite is a PP jute composite, with a thin with a thin skin of soft PVC.

They make such composite they take a non woven, PP jute PP non woven PP jute fabric. Over that they place this PVC skin and they apply pressure at elevated temperature say around 170 degree at which temperature 100, 150 to 160 degree at which temperature these PP melts and that covers the jute fiber and consolidates for being a very rigid composite and these surface is covered with this PVC pump skin. So, at that gives a very good aesthetic finish with different colors and texture that is available that is been manufactured in our country. One industry I have seen that is they are manufacturing Birla Corporation.

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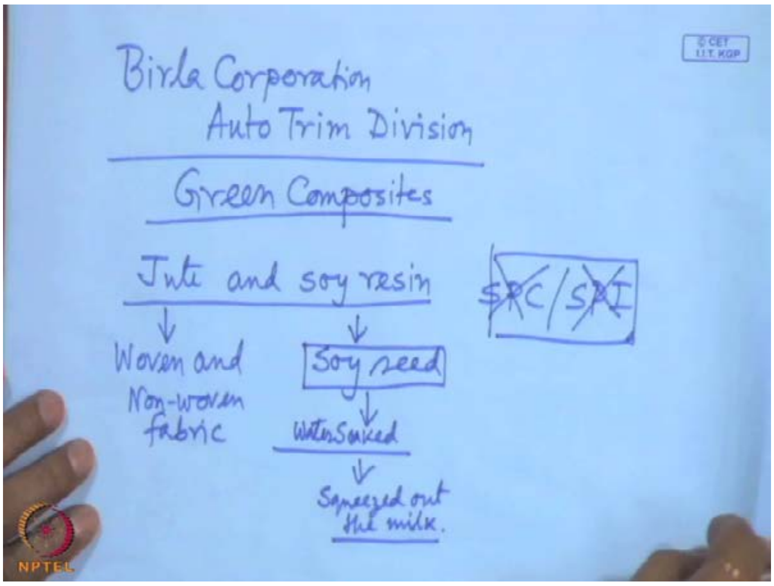

They have one auto trim division. They are making such type of composites for application in automobiles interiors.

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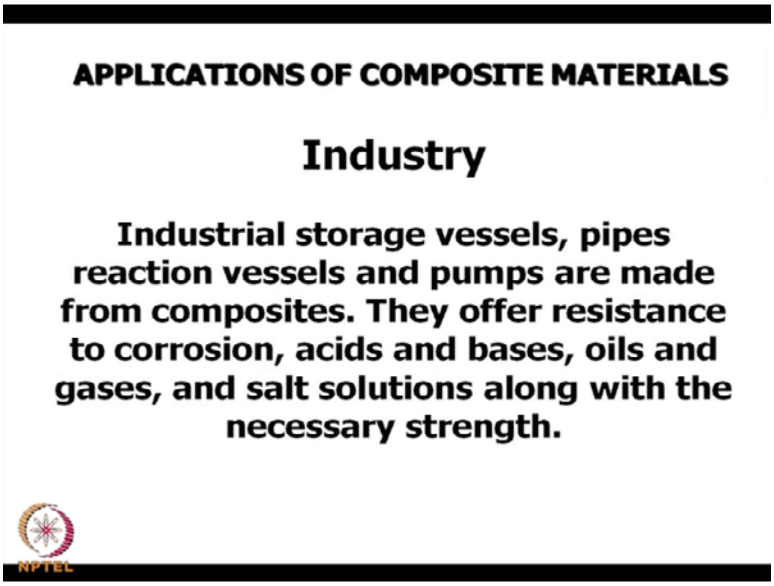

Now in industry. Industrial storage vessels, for different solids only solid and liquid chemicals, pipes, reaction vessels and pumps those are made of composites. They offer resistance to corrosion, acids and bases oils and gases and salt solutions along with the necessary strength.

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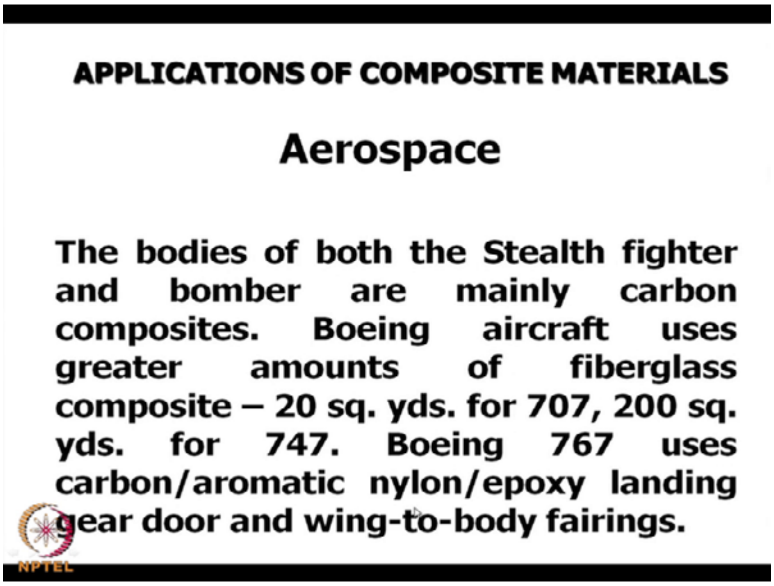

In aerospace field, the bodies of both the stealth fighter and bomber are mainly made of carbon composites, they are strong as well as light. Now, in Boeing aircraft Boeing aircraft uses higher quantity of fiber glass composite say around 20 square yards for

Boeing 707 aircraft, 200 square yards for 747 aircraft, and Boeing 767 uses carbon-aromatic nylon-epoxy composite as landing gear door and wind-to-body fairings.

So, I can continue this discussion on these composites for green composites, we have developed composites from jute and soy resin. This jute fiber has reinforcement in the form of woven and non-woven fabric both and soy resin was made from soy seed without going through that a SPC soy protein concentrate or soy protein isolate, as I mentioned earlier we have not gone through this root because this SPC or SPI or not available not manufactured in our country. So, what we have done, we took these soy seed soaked with water soaked in water, or can say water soaked, this water soaked soy seed after crossing, we squeezed out the milk, this soy milk basically contains.

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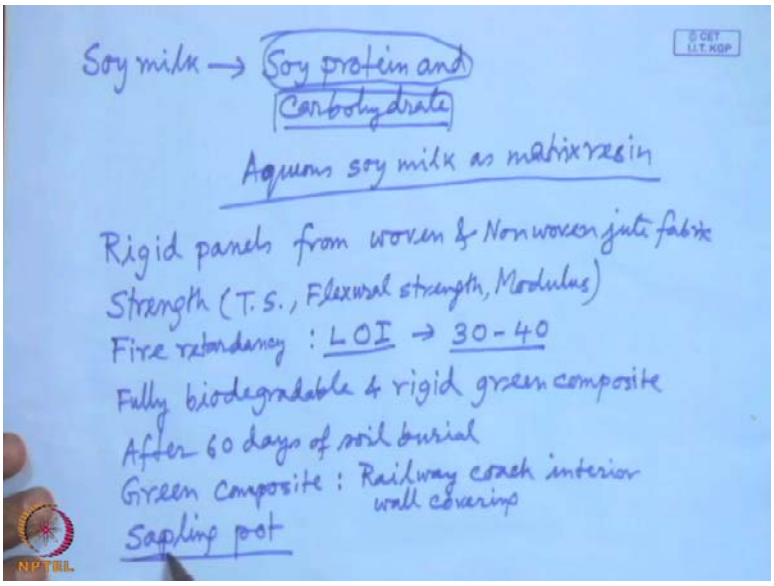

Contains soy protein and some carbohydrates, carbohydrate part. We just filtered the soy milk to remove the carbohydrate part partly in not fully and this aqueous soy protein, this aqueous soy milk was used as the matrix resin the soy milk soaked jute was used for making rigid panels, we made this products, rigid panels from both woven and non woven jute fabric. Now, these rigid panels we have measured the strength properties say tensile strength, flexural strength, modulus we have evaluated the priority fire redundancy of these composite in terms of limiting oxygen index parameter, and we found these LOI value ranges from 30 to 40 which remain in the category of non familiar objects.

So, there have very good fire redundancy properties, they are strong they are rigid and our purpose was to make fully biodegradable and rigid green composite. We have measured the biodegradation evaluated the biodegradation characteristics of these composites, we have found that after 60 days of soil burial in composed condition, the composites become brittle and fragmented.

So, it shows very good degradation properties after 60 days, during 60 days of soil burial in composed condition in humid condition in weight condition, but when it remains in indoor application, it is, it remains it shows very strong, very high strength properties fire redundant all these things. So, we can say we have achieved both these biodegradable characteristics as well as the strength of these composites. So, we have focused this product as green composite green composite or biodegradable composite for use in railway coach interior wall covering

We have also developed one pot, sapling pot this is fully biodegradable material sapling pot. This sapling pot we have tested, we have placed one plant with some earth in this sapling pot we found very good growth of the plant in the in this sapling pot and when this sapling pot placed in the garden after digging the earth. So, that plant growth was excellent as well as after around 40 days we found that sapling pot totally degraded. Advantage is that that pot material was degraded converted to some biomass and that acted as nutrient for the plant itself as manure. So, this way we developed rigid composites from these jute fiber and soy milk resin. Now, the problem these composites has got one problem that is the moisture absorption, if these if we continue if we have to provide.

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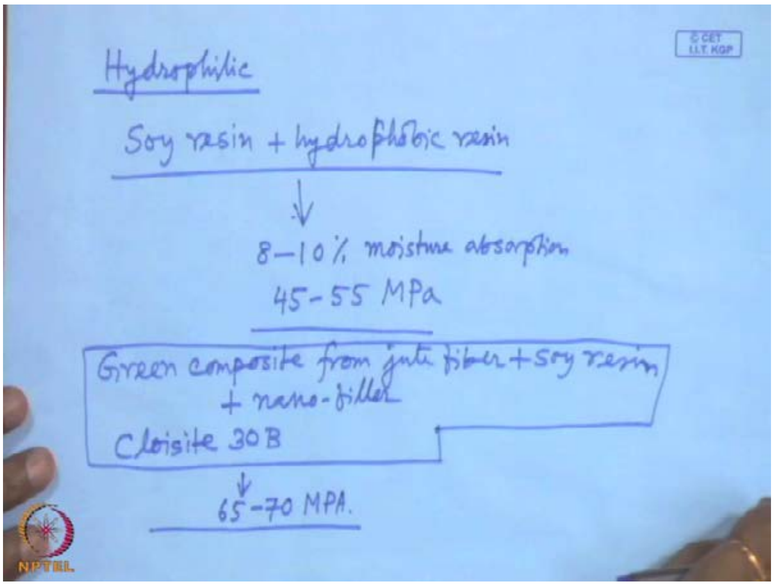

If we have to obtain this biodegradability the products should be hydrophilic, this hydrophilicity is one of the required criteria for biodegradation, but it will be it will not be resistant to moisture. So, in order to have a compromise we also developed composite by mixing soy resin with some hydrophobic resins hydrophobic resins hydrophobic resins in certain proportion. So, that we could achieve the moisture resistance up to moisture resistance up to 8 to 10 percent, moisture absorption and tensile strength of that composite ranging between 45 to 55 mega Pascal.

Also we have developed that green composite from jute fiber and soy resin along with some nano filler, we have taken organically modified nano filler say amount or night clay cloisite 30 B nano filler with this combination. And we achieved very good strength properties and that provided us tensile strength of 65 to 70 mega Pascal, we have compared the properties of this nano filler jute fiber imposed green composite as well as for that biodegradable jute composite without using a nano filler.

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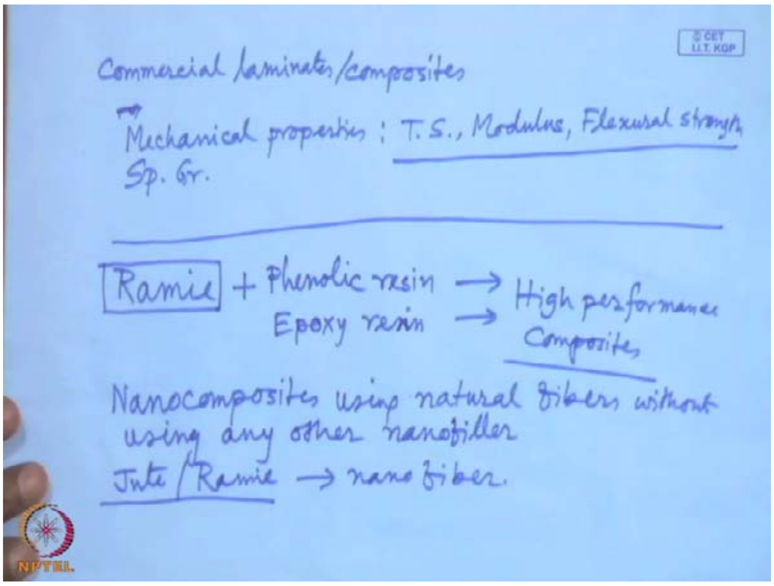

We have compared the properties of these composites with the commercial laminates or composites available in the market we procure from the market, and we evaluated the tensile say mechanical properties. Their specific gravity, their mechanical properties say we have compared tensile strength, modulus, flexural strength all these things specific gravity they are fire agents all these things. We have found that our composites our green composites are in almost all cases the strengths of our jute reinforced green composites using this soy matrix resin, they are having superior or better mechanical properties than those of the commercial laminates and composites. So, it shows that green composites made from this jute fiber and soy resin would be good replacement of other fibers and synthetic matrix resins, there is other natural fibers say Ramie. Ramie is a stronger fiber, stronger natural fiber than jute or seashell or other natural fibers. So, if this fiber can be used as reinforcement for making composites with say phenolic resin or epoxy resin. So, these combinations can give again high performance composites. Now there is another possibility of forming nanocomposites using natural fibers without using any other nano filler. I mean to say that the jute fiber itself jute or ramie fiber itself can be converted to nano fiber.

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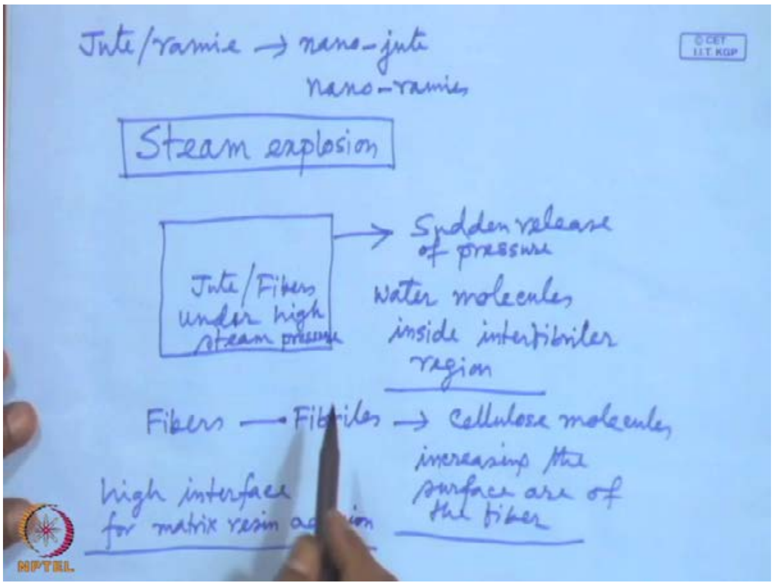

One of the good technique is the converting this jute or ramie to nano jute or nano Ramie would be through steam explosion, what is this? Now, in an auto clip if these fibers jute or ramie fibers are taken in an auto clip immersed in water then by heating, if that water is converted to high pressure steam what will happen that water molecules, which has gun inside the inter. Say interfibriler region of the fibers that area also water molecules are there in the interfibriler region, now that will remain under high steam pressure. Now, if there is a provision of sudden release of pressure should be done, if suddenly this pressure is released water molecules inside the interfibiler region of the fibers.

That will be trying to come out from high pressure to low pressure. So, that will burst the fibers to fibrils to cellulose molecules increasing the surface area of the fiber. Such increased surface area of the fibers through steam explosion can lead to provide high interface for matrix resin adhesion and that would be the future of such strong beam composites using jute fiber, or ramie fiber with epoxy resin or some biodegradable resin or some ah phenol formulate resin. We will stop here.

Thank you.