Manufacturing of Composites
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Lecture – 23
Polymer Matrix and Nano Composites

So, lecture number 23. So, in this lecture we will be more focused towards polymer matrix and nano composites. So, basically what are we trying to focus is we are trying to focus on nano materials getting integrated into the polymer matrix for producing a composite. So, when we were talking about forms that is fibre forms or forms which are getting reinforced, we were looking into which are like fibre, we were looking into particulate, we were looking into whisker and nano is one more particulate type where and which the dimensions one of the dimension will be in nanometre scale.

So, why is that required because there are certain requirements where in which we would like to add more interface in the material. So, when we add more interface in the material fracture toughness increases in ceramic matrix composite, as far as polymer matrix composite is concerned it enhances the toughness property as well as wear resistance property people have added nano materials which are conducting inside it. So, this has led to conducting polymers.

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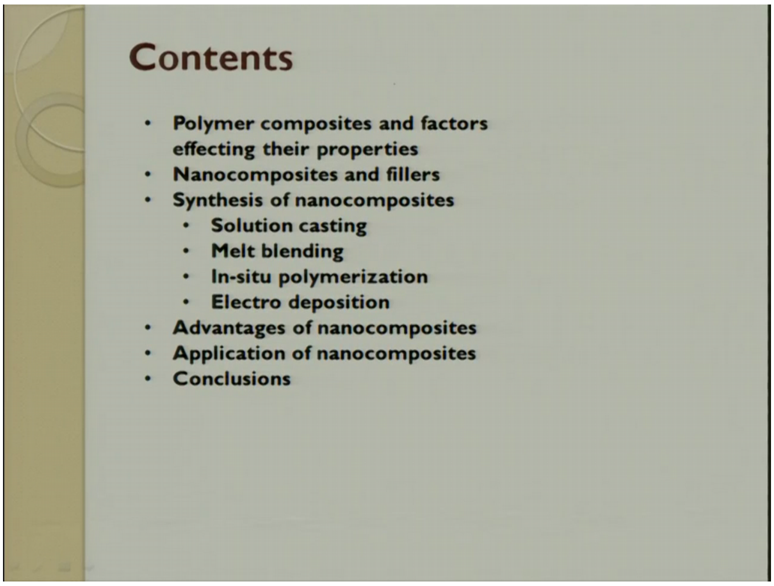

Contents

- Polymer composites and factors effecting their properties
- Nanocomposites and fillers
- Synthesis of nanocomposites
    - Solution casting
    - Melt blending
    - In-situ polymerization
    - Electro deposition
- Advantages of nanocomposites
- Application of nanocomposites
- Conclusions

So, in this lecture we will have the following content. So, it will be polymer composites and the factors affecting their property, nano composites and there fillers, synthesis of nano composite I have put in 4 processing routes, then advantage of nano composites applications and finally, we will have conclusions.

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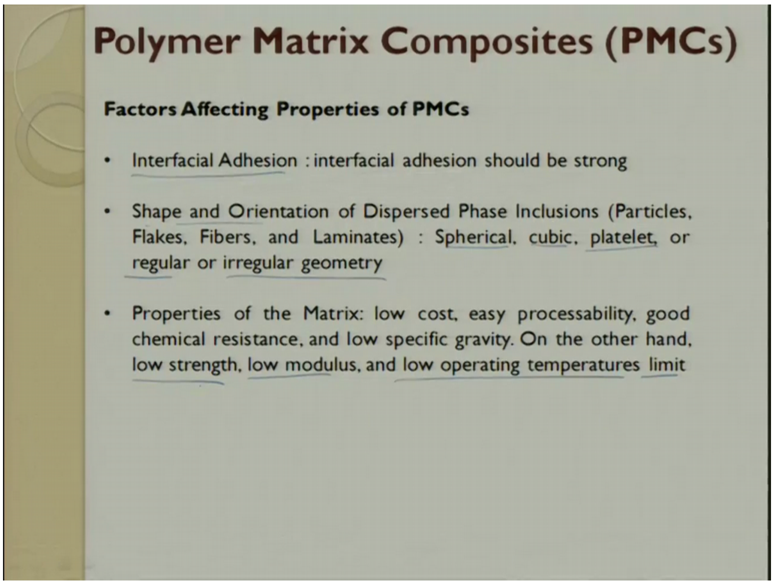

Polymer Matrix Composites (PMCs)

Factors Affecting Properties of PMCs

- Interfacial Adhesion : interfacial adhesion should be strong
- Shape and Orientation of Dispersed Phase Inclusions (Particles, Flakes, Fibers, and Laminates) : Spherical, cubic, platelet, or regular or irregular geometry
- Properties of the Matrix: low cost, easy processability, good chemical resistance, and low specific gravity. On the other hand, low strength, low modulus, and low operating temperatures limit

So, factors affecting the properties of a polymer matrix composite is more towards interfacial adhesion. So, interfacial adhesion has to be very strong, let it be a fibre let it be a particulate or let it be nano materials. So, the interfacial factor; that means, to adhesion factor should be very strong, the shape and the orientation plays a very important role of the dispersed phase for example, when we talk about fibre we talk about orientation of the fibre 0 degrees, 45 degrees, 90 degrees and the orientation which is made so that we get a required output.

So, when we talk about shape and orientation of particulates the spherical nature of the sphericity cubic platelet size; that means, to say we are talking about the aspect ratio it can be regular or it can be irregular geometries, can be thought of the shape and the orientation of the dispersed phase inclusion place a very very important role. The last one is going to be the property of the matrix show the property of the matrix is also plays a important roles because it has to give enough of space for a particulate to go sit there properly to meet out the requirements.

So, here when the properties of the matrix we put costing easy process ability for example, all thermo sets are easy to process, thermoplastic are difficult to process. Good chemical resistance low specific gravity all those things are properties of the matrix which are very important factor while deciding polymer matrix nano composites for required application.

On the other hand low strength, low modulus and low operating temperature limits the usage of a particular polymer. So, based upon the requirement we look into all those properties and decide a polymer whether it has to be a thermo set, whether it has to be a thermoplast or it has to be an elastomer.

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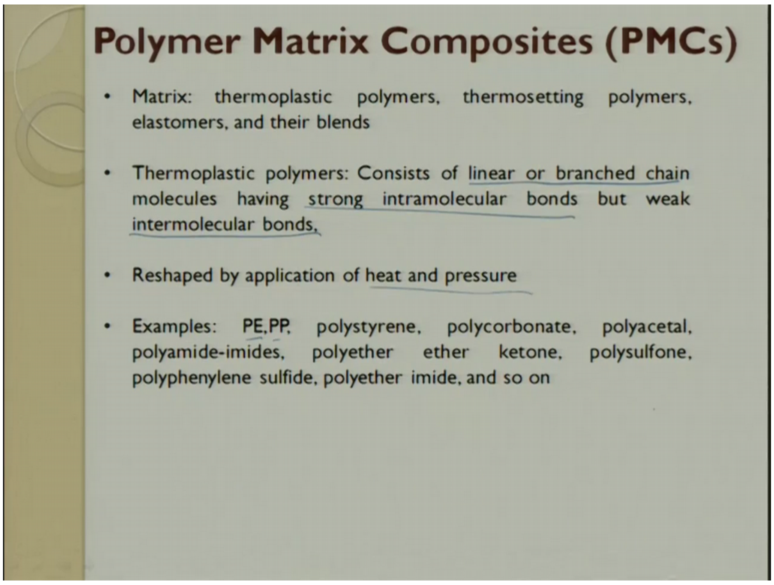

Polymer Matrix Composites (PMCs)

- Matrix: thermoplastic polymers, thermosetting polymers, elastomers, and their blends
- Thermoplastic polymers: Consists of linear or branched chain molecules having strong intramolecular bonds but weak intermolecular bonds.
- Reshaped by application of heat and pressure
- Examples: PE,PP, polystyrene, polycorbonate, polyacetal, polyamide-imides, polyether ether ketone, polysulfone, polyphenylene sulfide, polyether imide, and so on

When we talk about matrix so you have thermoplastic polymers, you have thermosetting polymers, you have elastomers and their blends today we have matrices where and which a thermo set is mixed with thermoplastic, a thermo set is mixed with elastomer to meet out requirements. So, when we talk about thermoplastic polymers, thermoplastic polymers consists of a linear or a branched chain molecule having strong intra molecular bond, but weak intermolecular bond, intra and inter please have a note of it. So, intra is within the same and inter is between 2 different particles, reshaped by application of heat and pressure is a very common feature of thermoplastic polymers, the example for thermoplastic polymers we have seen enough. So, I have just put down the list it is PE, PP polystyrene polycarbonate and then so on and so forth.

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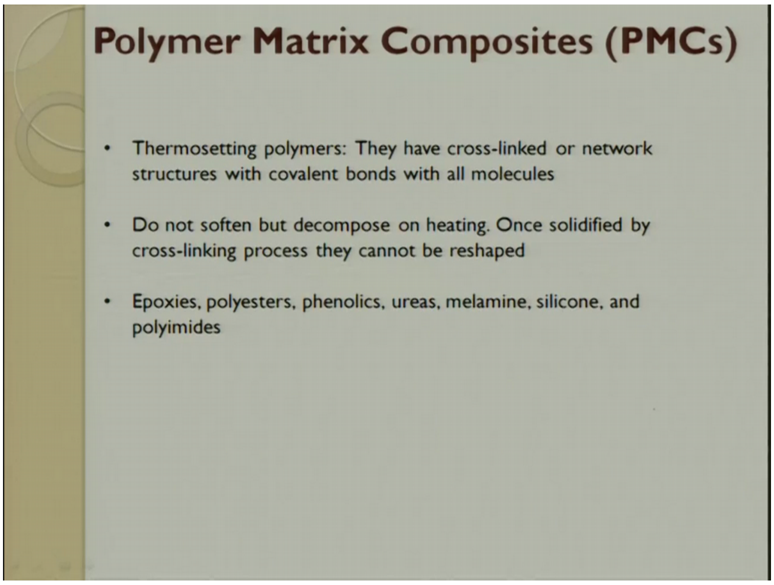

Polymer Matrix Composites (PMCs)

- Thermosetting polymers: They have cross-linked or network structures with covalent bonds with all molecules
- Do not soften but decompose on heating. Once solidified by cross-linking process they cannot be reshaped
- Epoxies, polyesters, phenolics, ureas, melamine, silicone, and polyimides

When you look into thermo set polymer they have cross linked or network structure with covalent bond with all molecules, they do not soften, but they directly decompose with heat, once solidified the cross link process they cannot be reshaped. So, the examples are polyester, epoxy, phenolic, furious and silicon are some of the examples of thermoset polymer, when we talk about the composite.

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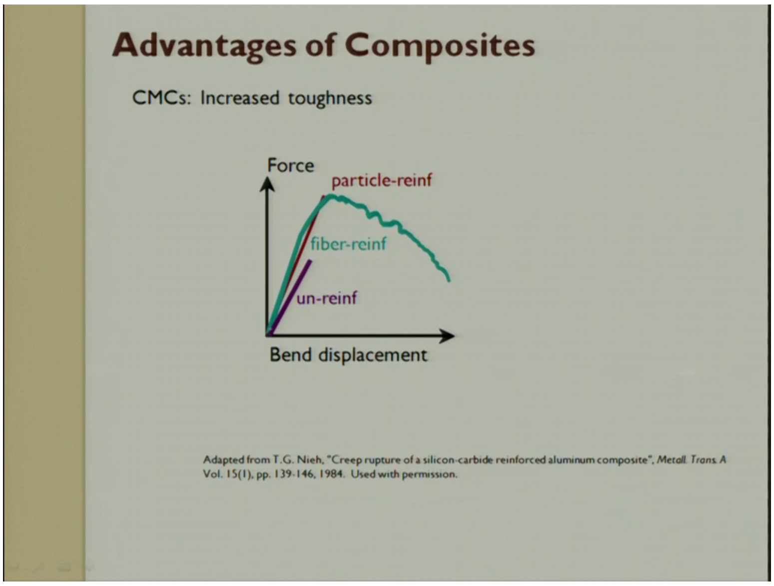

Advantages of Composites

CMCs: Increased toughness

Adapted from T.G. Nieh, "Creep rupture of a silicon-carbide reinforced aluminum composite", *Metall. Trans. A* Vol. 15(1), pp. 139-146, 1984. Used with permission.

So, you can see that you have un reinforced polymer which is the bend displacement, we have we had looking into force versus bend displacement and then the next one is we are looking at fibre reinforced composite and then the last one what we are seeing is particulate reinforced composites. In particulate reinforced composites you see there is a gradual fall of the force.

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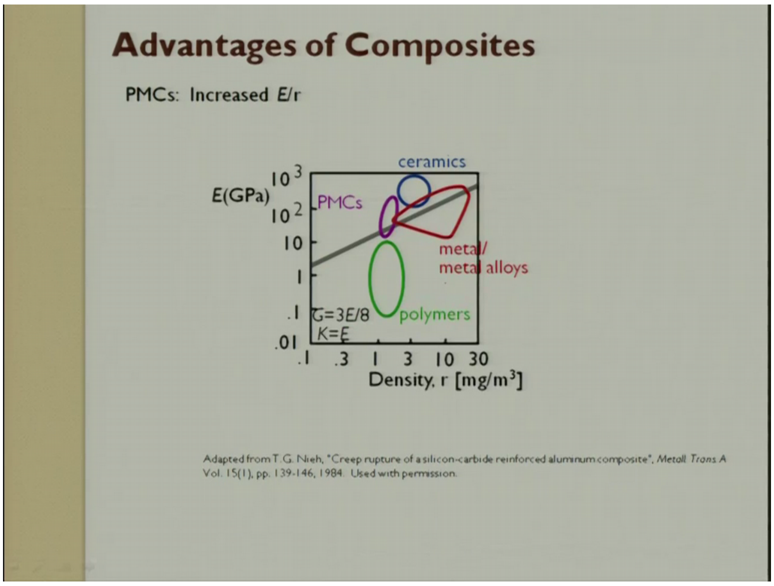

Advantages of Composites

PMCs: Increased *E*/r

Adapted from T.G. Nieh, "Creep rupture of a silicon-carbide reinforced aluminum composite", *Metall. Trans. A* Vol. 15(1), pp. 139-146, 1984. Used with permission.

So, what are the advantage of polymer matrix composite? It has a very high e by r ratio. So, a r is the density or it can be considered as row, you can make it as row its row e by row is very important. So, you can see polymers fall in this region polymer matrix composites fall in this region ceramics much, ceramics much higher and metal alloys fall in this region. So, this makes polymer matrix composite more prominent for applications where weight is an important factor.

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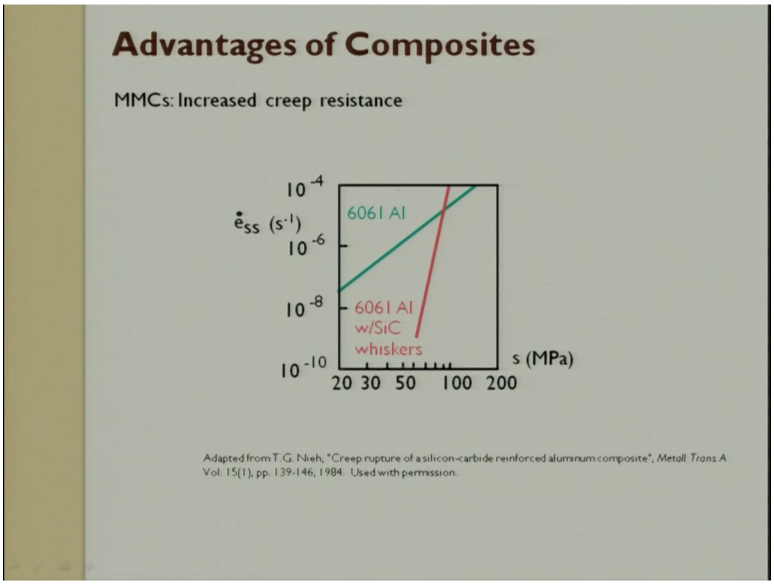

Advantages of Composites

MMCs: Increased creep resistance

Adapted from T.G. Nieh, "Creep rupture of a silicon-carbide reinforced aluminum composite", *Metall. Trans A* Vol. 15(1), pp. 139-146, 1984. Used with permission.

So, if you see metal matrix composite, in metal matrix composite it increases creep resistance. So, you can see a whisker reinforced this is the alumina whisker reinforced s i c you can see the creep resistance behaviour this is a typical aluminum alloy, 6061 response.

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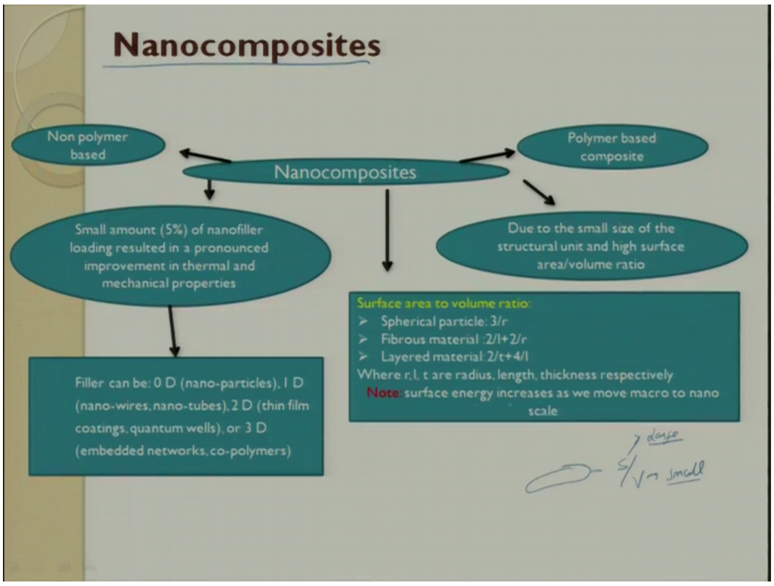

Nanocomposites

Nanocomposites

Non polymer based

Polymer based composite

Small amount (5%) of nanofiller loading resulted in a pronounced improvement in thermal and mechanical properties

Due to the small size of the structural unit and high surface area/volume ratio

Filler can be: 0 D (nano-particles), 1 D (nano-wires, nano-tubes), 2 D (thin film coatings, quantum wells), or 3 D (embedded networks, co-polymers)

Surface area to volume ratio:
- Spherical particle: 3/r
- Fibrous material :2/l+2/r
- Layered material: 2/t+4/l

Where r, l, t are radius, length, thickness respectively

Note: surface energy increases as we move macro to nano scale

S/V → large
→ small

So, when you look at nano composite these are the classifications, the nano composite it can be polymer based composite due to small size of the nano particles of the structural unit and high surface area to volume ratio this we are talking about the nano. So, nano materials will have a very large surface area, but a very small volume. So, s by v so s is large and volume is small. So, here what happens is we do not talk about gravitational force we talk about, we talk about van der Waals bond, we talked about surface tension all this small surface phenomena’s get into action and they try to dictate the process.

So, gravity is no more important when we talk about nano, density is no more important when we talk about nano, we talk more in terms of surface to volume ratio because the signs changes. So, due to small size of the structural units and high surface to volume ratio these nano composites are finding, this nano particles included in nano composites are finding large utilisation. So, when we talk about shape, these are various shapes which are given, spherical particles will have 3 by r the fibres particle will have 2 by l plus 2 by r, the layered matrix will have 2 by t plus 4 by l.

So, here r l and t represents the radius, length and the thickness respectively, note the surface energy increases as we move macro to nano. So, if you go to macro the surface area becomes, if you assume the surface area is the same, but volume increases. So, now, you see the gravitational force starts playing important role. So, when you go towards nano the surface energy the s by v ratio plays a very very important role, when you talk about here it is non polymer based and a small amount of 5 percent of nano filler loading resulting in a pronoun improvement in the thermal and mechanical properties. So, when we are talking about fibre reinforcement we talk about 30 percent, 40 percent and when you do automatically talk about 60 percent and 70 percent, but when you work on this nano composite adding 5 percent nano fillers into the matrix itself brings in a drastic improvement in thermal and mechanical properties.

The filler can be 0 d; that means, to say a nano particle can be 1 d which can be a nano wire or a nano tube can be 2 d thin film coating on quantum wells or 3 d which is embedded network or copolymers these are some of the fillers which are possible by nano materials which are getting integrated into the composite ok.

So, what is the processing difficulty with this nano composite, nano particles have large amount of surface charges. So, moment you have large amount of surface charges they quickly go get agglomerated, moment it gets agglomerated then the functional property is not uniformly distributed all across the matrix. So, you will have chunks of nano particles loaded at few spots and some area it will be exclusively polymers. So, here in order to break the agglomeration we always try to functionally coat the nano particle. So, that we play with the charges, they always stay little far away and then they do not agglomerate, this is a huge challenge.

See for example, when you have 2 huge challenges one is agglomeration, 2 the density nano particles are always very light. So, when you try to disperse it in a polymer matrix they will always try to come to the top and they will try to stand there and get frozen. So, in order to have a uniform distribution we have to think of novel mechanisms where and which these particles enter into the polymer and get dispersed then it gets cured. So, these 2 are the major challenges.

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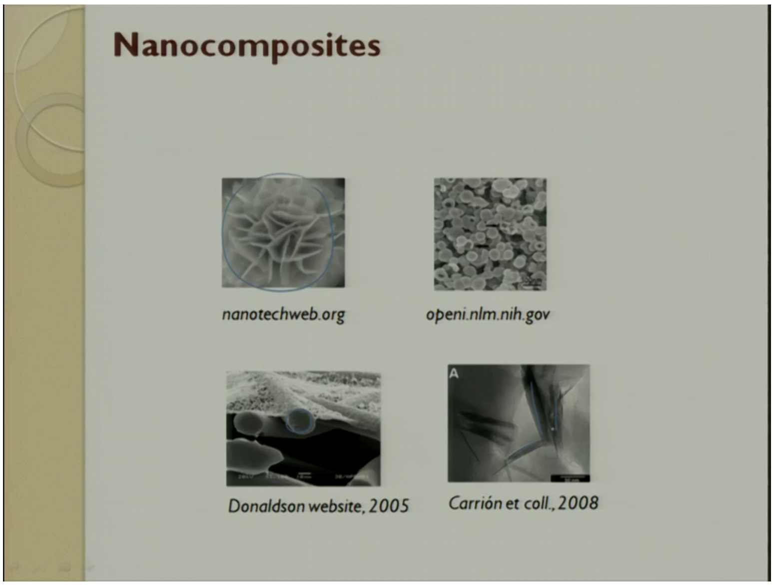

Nanocomposites

nanotechweb.org

openi.nlm.nih.gov

Donaldson website, 2005

Carrión et coll., 2008

So, this is what is a nano this is a cauliflower structure which is there of nano particles, these are small nano particles which are dispersed in a polymer and here you can see fibre, nano fibres which are dispersed in a polymer and this is a CNT which is dispersed in a in a polymer CNT is carbon nano tubes and you can have single wall, multi wall. So, you can get it done.

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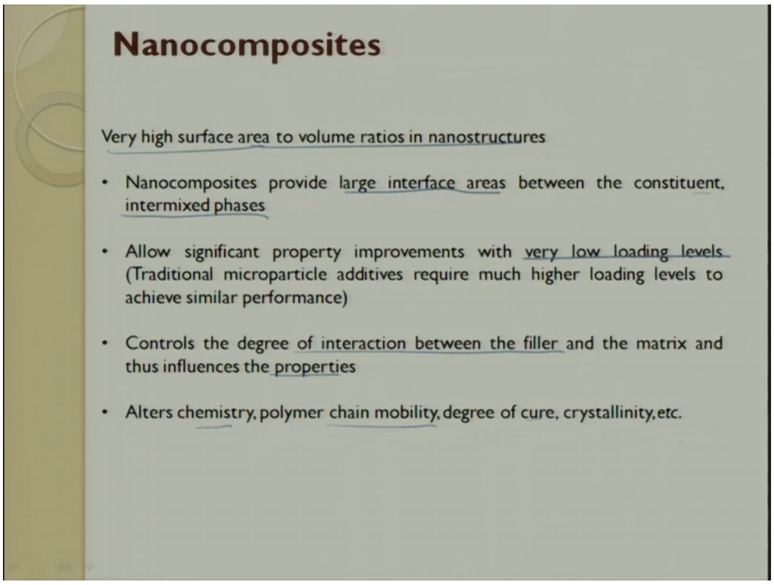

Nanocomposites

Very high surface area to volume ratios in nanostructures

- Nanocomposites provide large interface areas between the constituent, intermixed phases
- Allow significant property improvements with very low loading levels (Traditional microparticle additives require much higher loading levels to achieve similar performance)
- Controls the degree of interaction between the filler and the matrix and thus influences the properties
- Alters chemistry, polymer chain mobility, degree of cure, crystallinity, etc.

So, in nano composites very high surface area to volume ratio in nano structures are there, the nano composites provides a very large interface area between the constituent and the intermixed phase. So, the interfacial area is more, moment the interfacial area is more when the crack grows it gets arrested very fast, it allows significant property improvement with a very low loading at very low loading levels because the density is low, second you will have more amount of particles individual particles present when you try to wait.

So, you will see lot amount of particles present even at a very low loading. So, traditionally micro particles additives require a much higher loading levels as compared to that of nano particles; this controls the degree of interaction between the filler and the matrix thus influencing the property. It alters the chemistry the polymer chain mobility degree of cure and the crystallinity etcetera all these things are changed because of adding this nano particles inside a polymer. So, that is nothing, but the nano composite what we make.

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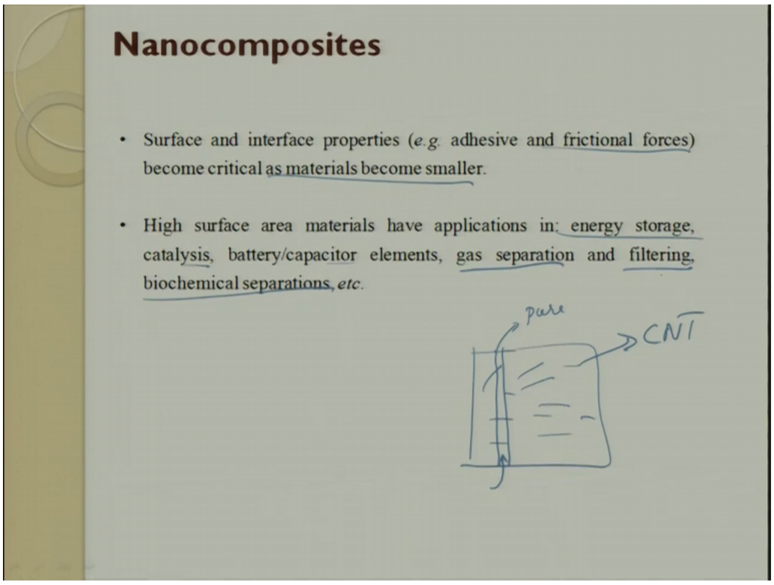

Nanocomposites

- Surface and interface properties (*e.g.* adhesive and frictional forces) become critical as materials become smaller.
- High surface area materials have applications in: energy storage, catalysis, battery/capacitor elements, gas separation and filtering, biochemical separations, *etc*.

The surface and the interfational properties example adhesion and friction forces becomes very critical as the material is very small, I have told discuss this point high surface area materials have application in energy storage, catalysis battery and capacitor elements, gas separation, filtering biochemical separations etcetera these are the areas where today nano composite polymer matrix nano composite are used exhaustively. So, for energy storage catalysis reaction in chemistry what we do battery and capacitor elements for storing charges, today we talked about super capacitors where and which within very short period of time it stores and discharges very slowly.

Then gas separation people are talking about for water filtration they will, they are trying to have a polymer matrix composite made and they have functionalised CNT and then they have dispersed it inside a polymer matrix these are CNTs which are functionalized so they are dispersed in a matrix. Now what they do is they try to make small holes and through these holes they try to pass gases and these gases are used for separation of and then these functionalized CNT might attract the grass elements all along the way and it releases whatever is in the pure form. So, water filtering is also done in a very similar way to get the required output.

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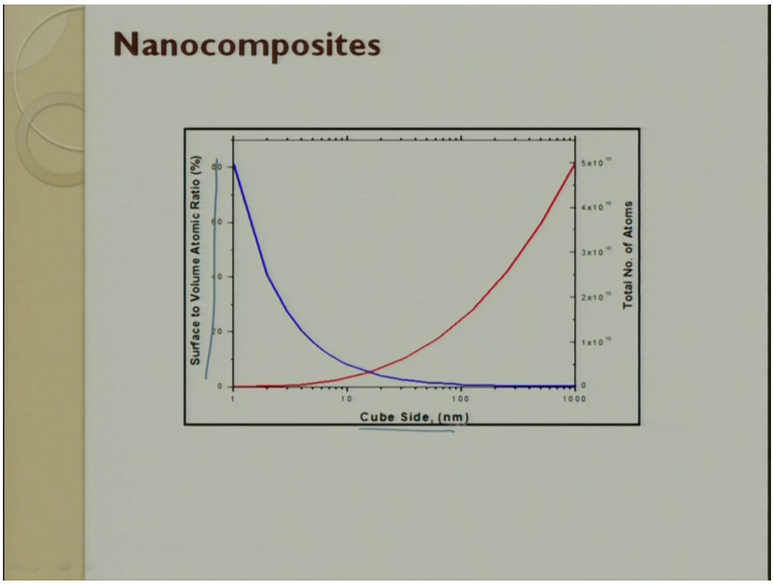

Nanocomposites

So, if you look at it the surface volume atomic ratio to cubic side. So, you can see that there is a decrease in the trend and there is a increase in the trend. So, this trend is move towards total number of atoms present and this is surface to volume atom ratio percentage you can see it decreases with respect to cube size which is all in nanometres.

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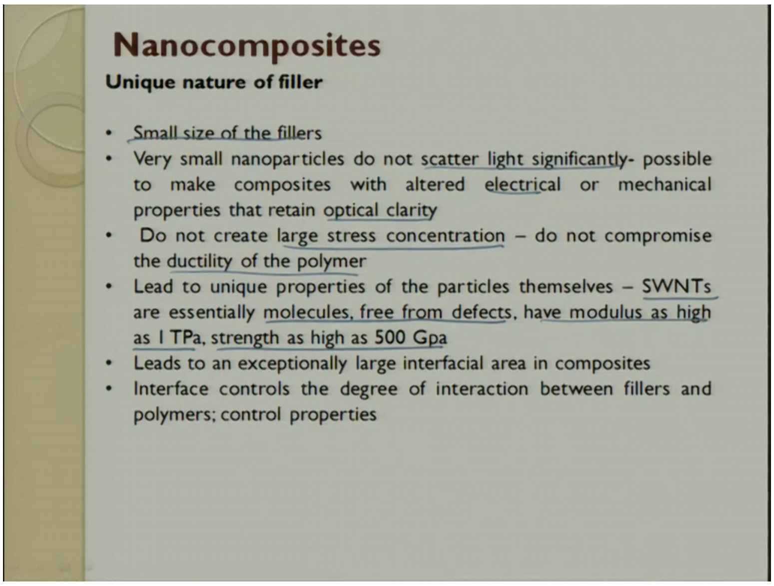

Nanocomposites

Unique nature of filler

- Small size of the fillers
- Very small nanoparticles do not scatter light significantly- possible to make composites with altered electrical or mechanical properties that retain optical clarity
- Do not create large stress concentration – do not compromise the ductility of the polymer
- Lead to unique properties of the particles themselves – SWNTs are essentially molecules, free from defects, have modulus as high as I TPa, strength as high as 500 Gpa
- Leads to an exceptionally large interfacial area in composites
- Interface controls the degree of interaction between fillers and polymers; control properties

What is the unique nature of the filler which we use it is small in size very small nano particles do not scatter light significantly possibly to make the composite with an alt which alters electrical and mechanical properties that retains optical clarity. So, what we are trying to tell is we are trying to say electrical property and mechanical property can be can be changed by retaining the optical clarity; that means, to say you will have a transparent material. So, transparent polymer which is very which will be used for vision application, but it will also try to become electrically and mechanically stronger.

Do not create large stress concentration. So, do not compromise on the ductility of the polymer. So, the sizes are very small. So, to a large extent that ductility sacrifices not there. So, leads to a unique property of the particle by them self it is single valve nano tubes are essentially molecules free from defects having modulus as high as 1 tera Pascal, the strength as high as 500 giga Pascal, which is very difficult to get in a single material which is got in single valve nano tubes. It leads to exceptional large interface area in the composite the interface controls the degree of interaction between the filler polymer and the control properties.

These are some of the unique properties which we get by using this nano in nano particles while making composites.

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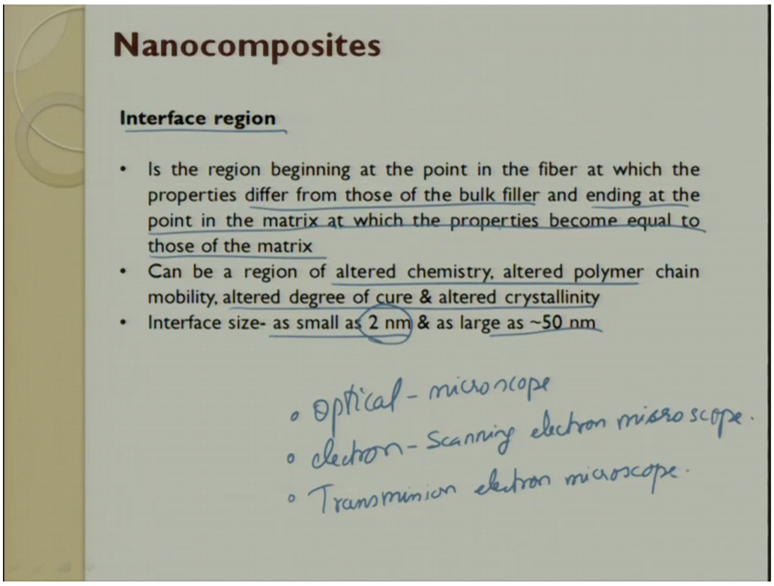

Nanocomposites

Interface region

- Is the region beginning at the point in the fiber at which the properties differ from those of the bulk filler and ending at the point in the matrix at which the properties become equal to those of the matrix
- Can be a region of altered chemistry, altered polymer chain mobility, altered degree of cure & altered crystallinity
- Interface size- as small as 2 nm & as large as ~50 nm

- optical - microscope
- electron - Scanning electron microscope.
- Transmission electron microscope.

In the interfational regions t his is a region beginning at a point in the fibre at which the property is differ from those of the bulk filler and ends at the point in a matrix at which the property becomes equal to those of the matrix. So, this is very important. So, the property differs from those of the bulk filler and ends at the point in a matrix at which the property equal becomes equal to that of the matrix.

So, you will have a very smooth interfacial changes that is what we trying to say, it can be a region that alters chemistry, polymer chain, mobility and alters degree of cure and crystalinity. The interfacial size can vary from 2 nanometre can go up to 50 nanometre, the biggest challenge for us is to visualise this 2 nanometre it cannot be done by optical, it cannot be majority of the time it can also be not done by electron. So, we always go for, we always go for transmission electron.

So, here I mean to say scanning electron and this is optical microscope, scanning electron microscope, and transmission electron microscope. So, if you want to see the agglomeration and other things. So, it is very difficult to do in scanning electron so we always go for transmission electron microscope. So, here we try to see very small particles and then we also try to look at that twist anality how is it we get to see the distribution.

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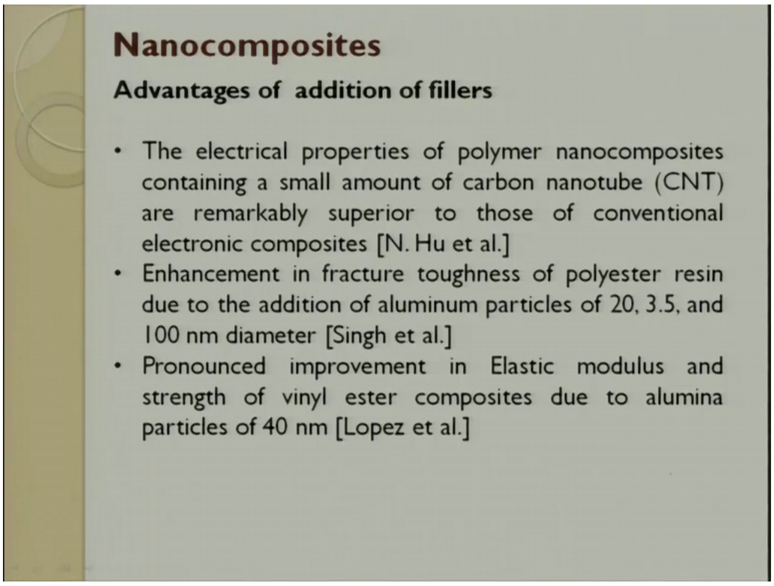

Nanocomposites

Advantages of addition of fillers

- The electrical properties of polymer nanocomposites containing a small amount of carbon nanotube (CNT) are remarkably superior to those of conventional electronic composites [N. Hu et al.]
- Enhancement in fracture toughness of polyester resin due to the addition of aluminum particles of 20, 3.5, and 100 nm diameter [Singh et al.]
- Pronounced improvement in Elastic modulus and strength of vinyl ester composites due to alumina particles of 40 nm [Lopez et al.]

So, the advantage electrical property can be changed by adding CNT, the mechanical property can be changed because you have lot amount of toughness and the elastic modulus and the strength of the vinly ester component can be changed by adding alumina particles of 40 nanometre size this also can be done. So, mechanical electrical properties can be changed by adding these fillers.

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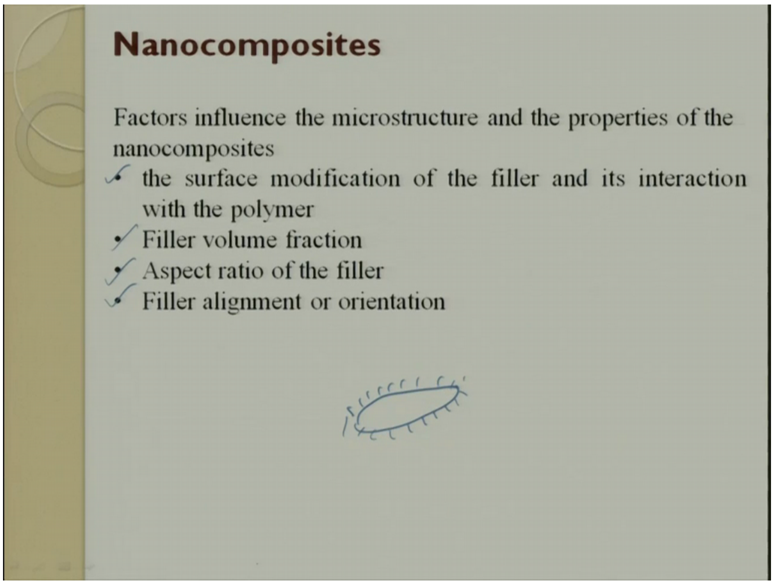

Nanocomposites

Factors influence the microstructure and the properties of the nanocomposites

- ✓ the surface modification of the filler and its interaction with the polymer
- ✓ Filler volume fraction
- ✓ Aspect ratio of the filler
- ✓ Filler alignment or orientation

So, the in the factors influence the microstructure and the properties of a nano composite the surface modification of the filler and its interaction with a polymer, the filler volume fraction, the aspect ratio of the filler and the filler alignment whether it is oriented in one direction or it is it is randomly distributed. These are factors which tries to influence the nano composite properties, the surface modification of the filler that is what I said fictionalization of the so if this is a.

So, here you will add some charged particle and these charged particles try to change the interaction with a polymer, the number of particles present is the volume fraction aspect ratio. So, here s by v aspect ratio is very very important, the filler alignment it can be random element or it can be oriented in one direction.

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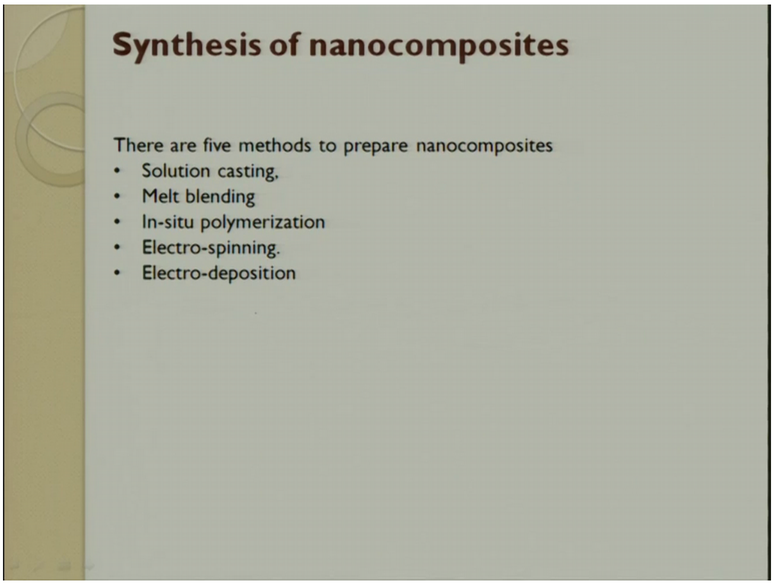

Synthesis of nanocomposites

There are five methods to prepare nanocomposites

- Solution casting.
- Melt blending
- In-situ polymerization
- Electro-spinning.
- Electro-deposition

So, what are the most common synthesis route for nano composite, these are the 4 or 5 very common preparation route for nano composite solution casting, melts blending in situ polymerization, electro spinning and electro deposition, in situ polymerization when you do polymerization the particles gets generated of its own. So, these are nano in shape. So, it gets dispersed.

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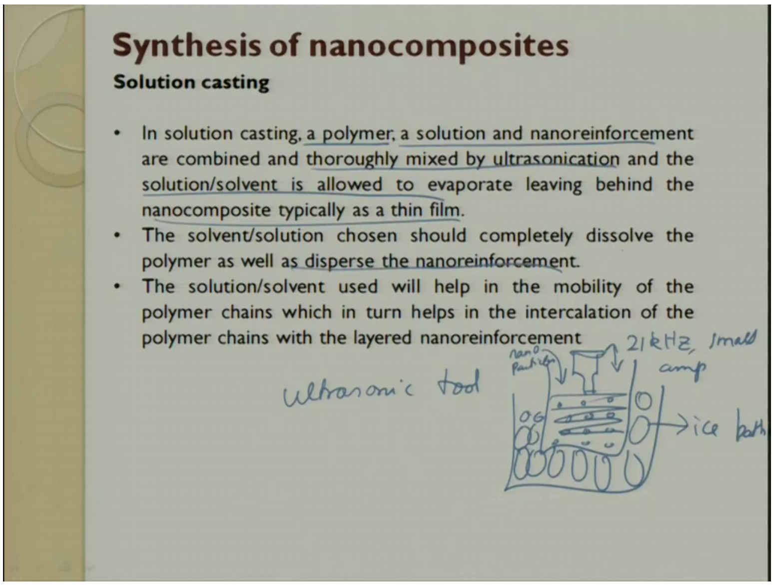

Synthesis of nanocomposites

Solution casting

- In solution casting, a polymer, a solution and nanoreinforcement are combined and thoroughly mixed by ultrasonication and the solution/solvent is allowed to evaporate leaving behind the nanocomposite typically as a thin film.
- The solvent/solution chosen should completely dissolve the polymer as well as disperse the nanoreinforcement.
- The solution/solvent used will help in the mobility of the polymer chains which in turn helps in the intercalation of the polymer chains with the layered nanoreinforcement

In solution casting a polymer a solution and a nano reinforcement are combined thoroughly mixed by ultrasonification. So, what is ultrasonification? We use a ultrasonic, we use ultrasonic agitator, ultrasonic tool where and which we fill the polymer. So, that tool is there. So, it tries to vibrate in 21 kilohertz with a small amplitude and creates lot of cavities. So, these cavity bubbles keep moving towards the top and dispersing. So, where at this we will try to disperse the nano particles and there are several tricks for example, when you do epoxy the temperature might go very high. So, we put it in a ice bath. So, this is an ice bath we put. So, in order to maintain the temperature of the polymer we put it in a ice bath right.

So, it can be done, people use to disperse polyester epoxy resin and all the liquid resins can be dispersed for example, elastomers you can also choose elastomers and dispersed nano particles like this. So, here ultrasonification is very important because that creates cavitation when this cavitation bubble burst then there is a space for a nanoparticle to get inside and it gets properly mix all around. So, thoroughly mixed by an ultrasonification and the solution or solvent is allowed to evaporate leaving behind the nano particles typically as a thin film right.

So, ultrasonification and the solutions are solvent is allowed to evaporate leaving along the things. So, all these nano particles will form a thin film or it can be uniformly dispersed, now you pour it inside a die you get a nano composite. The solvent or the solution chosen should completely dissolve and the polymer as well as disperse the nano particles, the solution solvent used with the help in the mobility of the polymer chain which in turn helps in inter calcination of the polymer chain with the layered nano reinforcement leads to a nano composite.

So, you can do like this or you can try to have polymer which is blend in a solvent, nano particles blend in a solvent both the solvents mix together evaporated form a thin film get a nano composite. So, this is what it is. So, this is called as solution casting.

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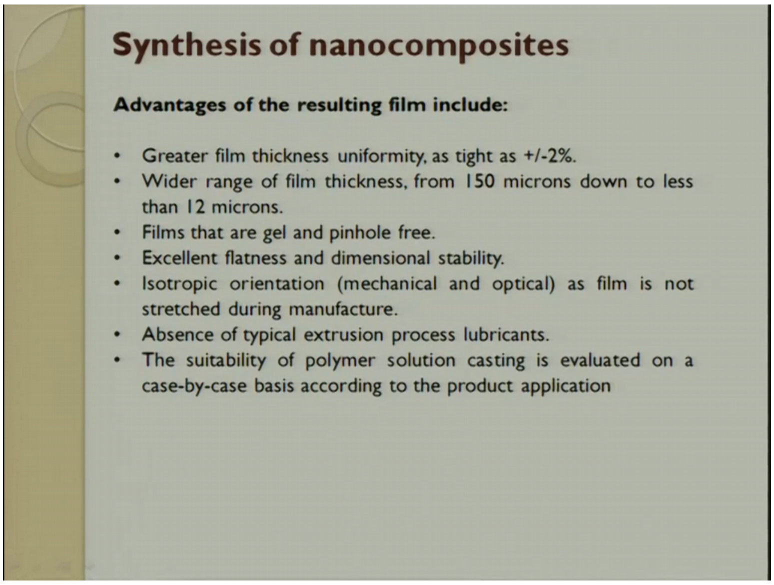

Synthesis of nanocomposites

Advantages of the resulting film include:

- Greater film thickness uniformity, as tight as +/-2%.
- Wider range of film thickness, from 150 microns down to less than 12 microns.
- Films that are gel and pinhole free.
- Excellent flatness and dimensional stability.
- Isotropic orientation (mechanical and optical) as film is not stretched during manufacture.
- Absence of typical extrusion process lubricants.
- The suitability of polymer solution casting is evaluated on a case-by-case basis according to the product application

So, the major advantage is going to be the great the greater the film thickness uniformity will be there, wide range of films can be made the film that are gel and a pin hole free. The excellent flatness and dimension stabilities can be got isotropic property orientation as film is not stretched during manufacturing you get a very good isotropic orientation, then absence of extrusion process lubricants and then it is suitable the suitability of the polymer solution casting is evaluated case by case cases according to the product formation.

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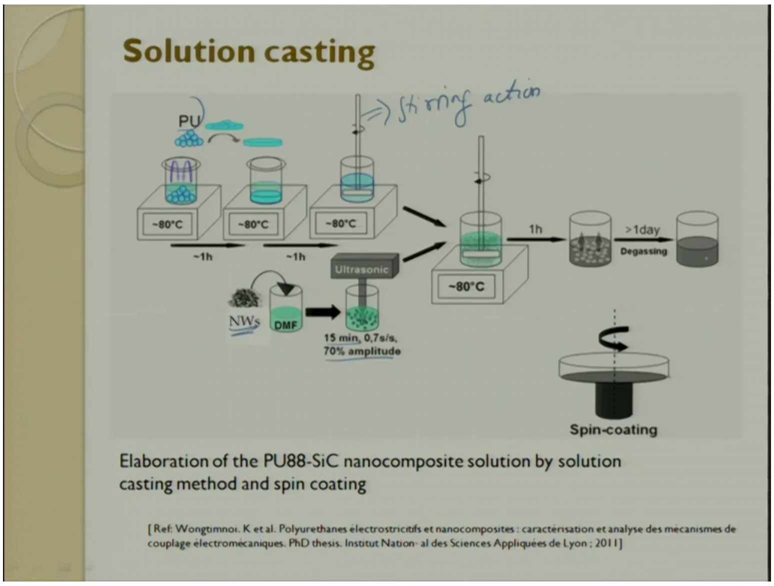

Solution casting

Elaboration of the PU88-SiC nanocomposite solution by solution casting method and spin coating

[Ref: Wongtimnoi. K et al. Polyurethanes électrostrictifs et nanocomposites : caractérisation et analyse des mécanismes de couplage électromécaniques. PhD thesis. Institut Nation- al des Sciences Appliquées de Lyon ; 2011]

So, this is what is a solution casting u c p u it is getting formed. So, you heat it to a certain temperature, measure the stir the particle the new nano sonicated then you add all the nano particles into it then you stir it and then you heat it. So, you allow all the solvents to evaporate or you leave it as a polymer. So, it gets uniformly dispersed then finally, you do degassing and then from the degassing you try to pour it on a spin coating and then its forms a small thin uniform layer you can either do it in the spin coating machine or if you want you can even go ahead casting it. So, this is what it is so here p u then it is mixed with a solvent so you mix it here then it is stirred.

So, uniform dispersion this is a stirring action, stirring action is uniform dispersion of solvent and polymer or polymer inside everything then you try to take the nano valve whatever CNT or nano material and then disperse it in a in a liquid. So, this liquid is again dispersed is inside the polymer. So, it sonicated for 15 minutes and you say 70 percent amplitude they have set. So, 70 percent of maybe 10 microns are 50 microns they do it and then they try to vibrated it then pour this solvent, this solvent then you allow it to cure de gas it get it and then this can be casted or it can be spin coated. So, that you get a thin film of whatever polymer you want.

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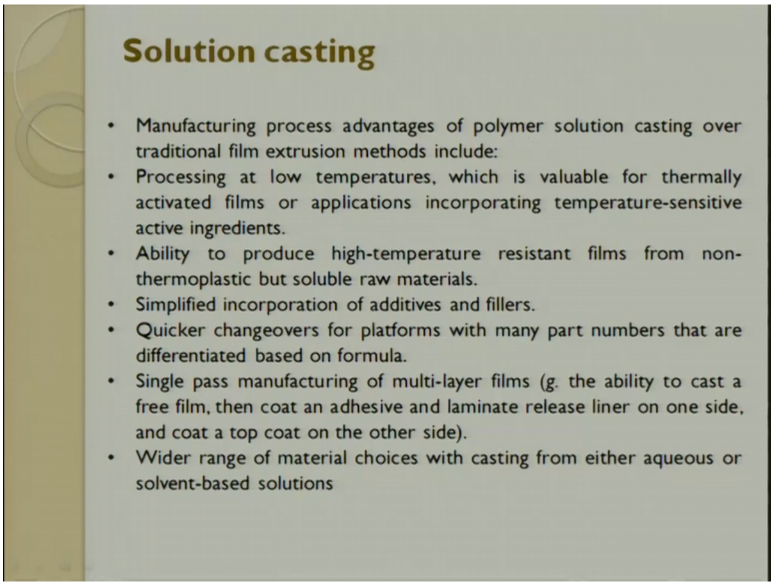

Solution casting

- Manufacturing process advantages of polymer solution casting over traditional film extrusion methods include:
- Processing at low temperatures, which is valuable for thermally activated films or applications incorporating temperature-sensitive active ingredients.
- Ability to produce high-temperature resistant films from non-thermoplastic but soluble raw materials.
- Simplified incorporation of additives and fillers.
- Quicker changeovers for platforms with many part numbers that are differentiated based on formula.
- Single pass manufacturing of multi-layer films (g. the ability to cast a free film, then coat an adhesive and laminate release liner on one side, and coat a top coat on the other side).
- Wider range of material choices with casting from either aqueous or solvent-based solutions

The manufacturing process advantage of polymer solution casting over the traditional film extrusion method is included, the process the processing happens at low temperature it is valuable for thermally activated films or application incorporating temperature sensitive active ingredients. The ability to produce high temperature resistant films from non thermoplastic, but soluble raw materials can be done simplified incorporation of additives and fillers can be done in this quicker change over for platforms which may, which many part numbers that are differentiated based on the formulas can be done here single pass manufacturing of multilayer films can be done. So, you can also make functionally graded materials also can be done, every spin coat layer can have varying volume fractions and you can have a functionally graded material, wided range of material choice with casting from either acquiescent or solvent based solutions can be done.

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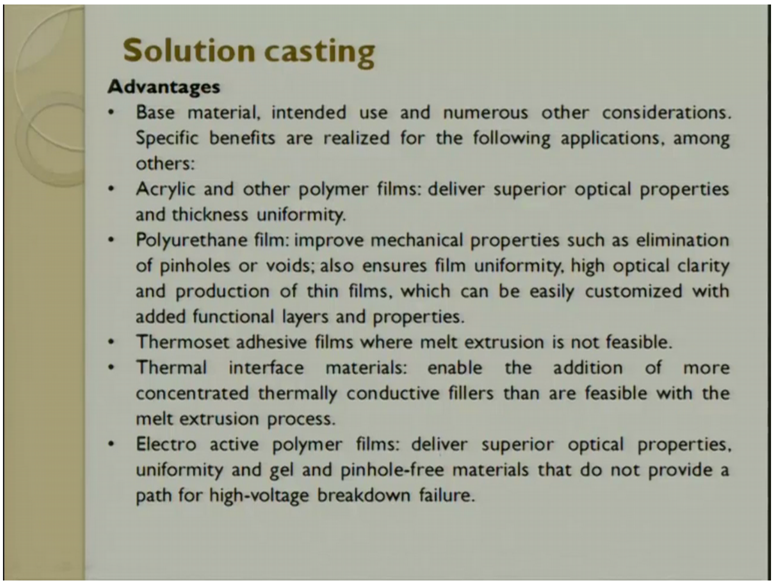

Solution casting

Advantages

- Base material, intended use and numerous other considerations. Specific benefits are realized for the following applications, among others:
- Acrylic and other polymer films: deliver superior optical properties and thickness uniformity.
- Polyurethane film: improve mechanical properties such as elimination of pinholes or voids; also ensures film uniformity, high optical clarity and production of thin films, which can be easily customized with added functional layers and properties.
- Thermoset adhesive films where melt extrusion is not feasible.
- Thermal interface materials: enable the addition of more concentrated thermally conductive fillers than are feasible with the melt extrusion process.
- Electro active polymer films: deliver superior optical properties, uniformity and gel and pinhole-free materials that do not provide a path for high-voltage breakdown failure.

The basic material intended to use and numerous other considerations are specific benefits are realised for the following applications is acrylic and the other polymer films deliver superior optical properties and thicker and thickness uniform. When you talk about polyurethane film improves mechanical properties such as elimination of pin holes or voids also ensures film uniformity high optical clarity and production of thin films which can be easily customised with added functional layer and properties. The thermoset additive films where melt extrusion is not feasible we try to do it the thermal interfacial material addition of more concentration thermally conductive fillers than the feasible of the melt extrusion process can be done here, electro active polymer films can also be made by this process.

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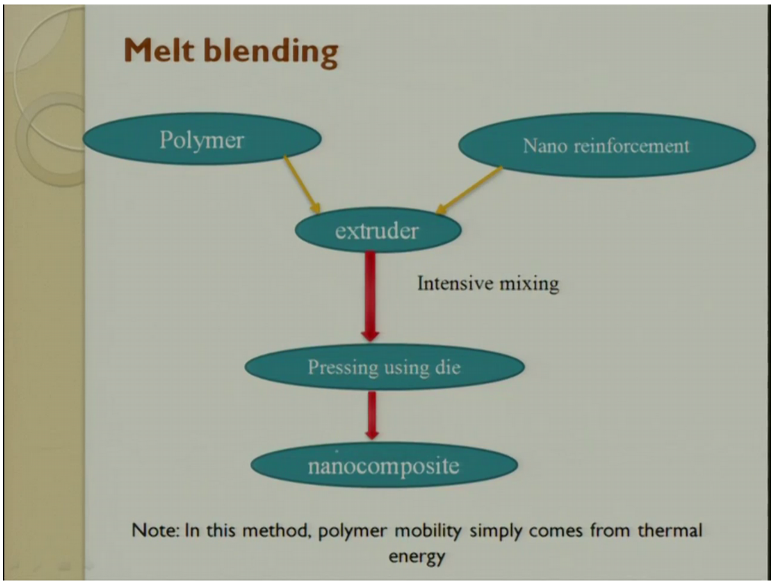

Melt blending

Polymer

Nano reinforcement

extruder

Intensive mixing

Pressing using die

nanocomposite

Note: In this method, polymer mobility simply comes from thermal energy

So, the melts blending is the other process we take a polymer, we take a nano material it is extruded it is intensive mixing is happened then it is pressing using a die and then you get a nano composite in this method the polymer mobility simply comes out from the thermal energy.

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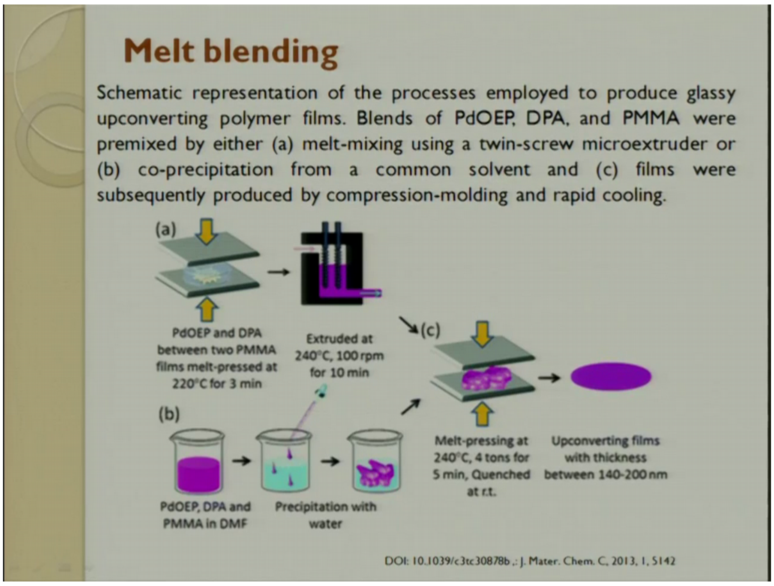

Melt blending

Schematic representation of the processes employed to produce glassy upconverting polymer films. Blends of PdOEP, DPA, and PMMA were premixed by either (a) melt-mixing using a twin-screw microextruder or (b) co-precipitation from a common solvent and (c) films were subsequently produced by compression-molding and rapid cooling.

DOI: 10.1039/c3tc30878b ,: J. Mater. Chem. C, 2013, 1, 5142

So, this is melts blending process schematic diagram. So, here you try to take the polymer and then what you do is you try to extrude it at 240 degree Celsius 100 r p m you try to do this and then you try to mix it up, you put it in a compression mould and then you try to pressing at 240 degrees for 5 minutes and what you get is a thin film which is done by melt blending.

So, this is a thermo plastic polymer which is taken it is extruded and then you try to get it, there are twin screw extruder which are used where and which you can even dispersed solid nano particles and then you try to dispersive it to get it is extruded. It is like an injection moulding machine, twin screw extruders injection moulding you directly injected into a die to get the required part.

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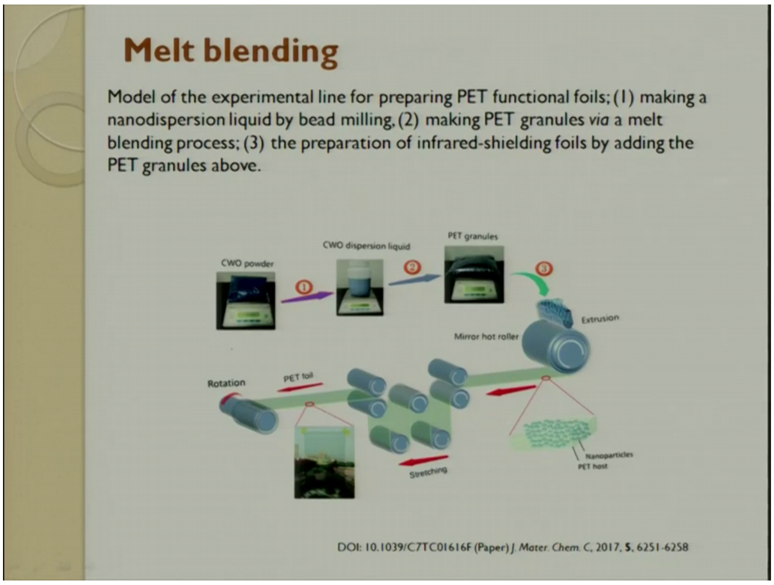

Melt blending

Model of the experimental line for preparing PET functional foils; (1) making a nanodispersion liquid by bead milling, (2) making PET granules *via* a melt blending process; (3) the preparation of infrared-shielding foils by adding the PET granules above.

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So, this is a model of the experimental line for preparing PET functional foils making a nano dispersion liquid by blend milling. So, here we make PET granulars wire melt blending process and the preparation of the infrared shielding foil by adding a PET granular above. So, here you can see that. So, we make a powder dispersion in a liquid granules are made these granules are rolled and then when you roll we try to add this here we add nano particles, granules nano particles is added you roll and then you stretch it and then you get PET foils and then this foils are rolled up into this. So, that it can be sold at commercial applications.

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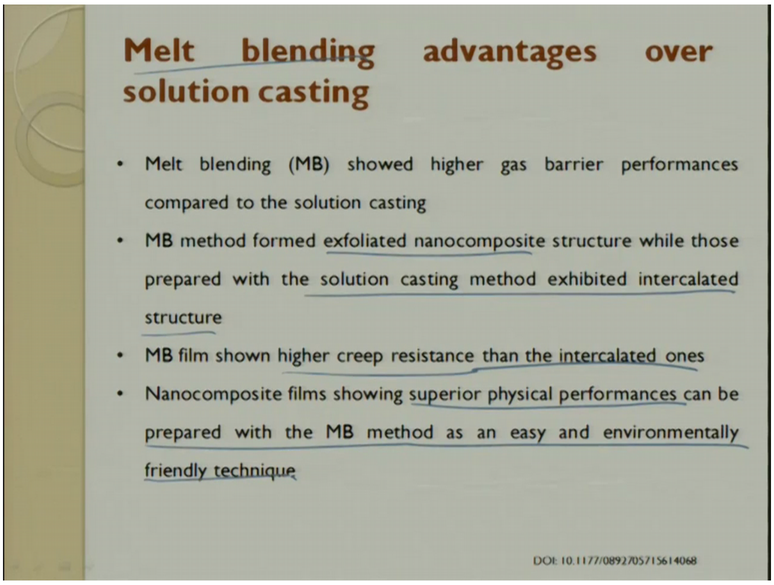

Melt blending advantages over solution casting

- Melt blending (MB) showed higher gas barrier performances compared to the solution casting
- MB method formed exfoliated nanocomposite structure while those prepared with the solution casting method exhibited intercalated structure
- MB film shown higher creep resistance than the intercalated ones
- Nanocomposite films showing superior physical performances can be prepared with the MB method as an easy and environmentally friendly technique

DOI: 10.1177/0892705715614068

So, what is the advantage here, naturally the advantages going to be it is going to have higher strain and the number of defects are going to be less in melt blending. So, shows a higher gas barrier performance compared to that of solution casting, the here formed exfoliated nanostructure while those prepared with the solution exhibits inter calcinated structures only. So, here it is much more stronger than the solution casting, the melt blending film shows higher creep resistance than the inter calcinated once. T he nano composite films show superior physical properties and can be prepared with m b method are easy and environmental friendly techniques can be used. So, melt blending method is always beneficial than the solution casting method.

The next topic of discussion is going to be in situ polymerization. So, in situ means I think it is getting developed while the process is going on by adding 2 independent elements you add together and then it mixes it tries to generate a polymer nano composite.

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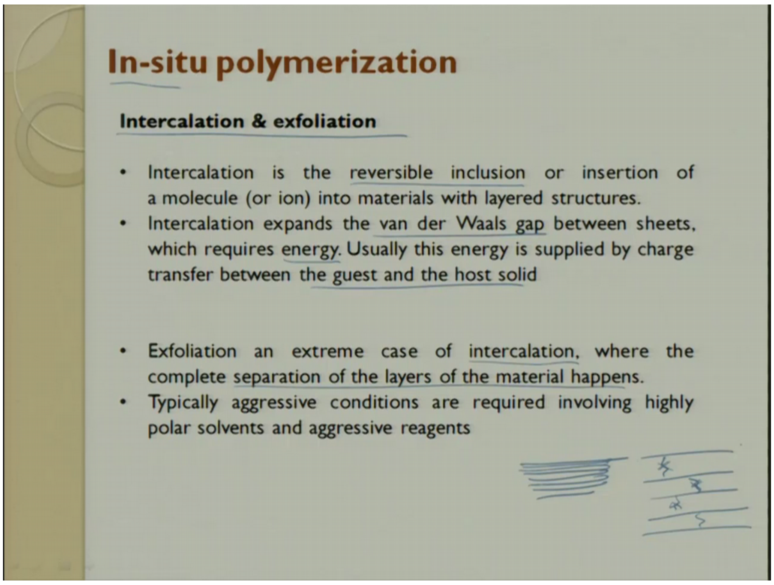

In-situ polymerization

Intercalation & exfoliation

- Intercalation is the reversible inclusion or insertion of a molecule (or ion) into materials with layered structures.
- Intercalation expands the van der Waals gap between sheets, which requires energy. Usually this energy is supplied by charge transfer between the guest and the host solid

- Exfoliation an extreme case of intercalation, where the complete separation of the layers of the material happens.
- Typically aggressive conditions are required involving highly polar solvents and aggressive reagents

So, in situ polymerization as you all know lot of mass together to form a polymer. So, in situ polymerization in this there are 2 important discussions to be carried out this is with regard to the nano material which is getting reinforced inside the polymer material. There are 2 process one is called as inter calcination the other one is called as exfoliation, as you know in nano composites they are charged there if lot of charge around the nano composite it is going to create agglomeration. So, I have to separate these nano particles. So, basically I try to do functionalization and in the same thing a nano particle can have multiple layers and each layer it will be a nanometre. So, I want to separate these layers one from each other such that the agglomeration does not happen, for this what we go ahead is we do this inter calcination and exfoliation.

Inter calcination is the reversible process like reversible inclusion or insertion of molecule or ion into the material with layered structure. So, this is very clear inter calcination and extra exfoliation can happen only with layered nano particles or layered nano materials. So, what I try to do here is I tried to separate these layers for example; I have several layers of some materials stack to each other. So, what I do is I tried to put spacer in between. So, what has happened I have now separated the layers so that is what is happening in inter calcination. So, I tried to add a material such that this material is getting included into the nano layers and it separates out nano layers, the inter calcination expands the van der Waals gap. So, as I told you in nano materials all the van der Waals forces surface tension all these things play a very very important role, the van der Waals gap between the sheets which is which requires energy what we do is we try to push in this material this ion or a molecule inside such that it separates out usually this energy is supplied by charge transfer between the guest and the host solid.

So, guest these are these are the guest these are the host solids I try to have separations such that you can now get layers of nano structure. Exfoliation is nothing, but an extreme case of inter calcination, in inter calculation if you still see that there is an attachment between the layers now I get layer by layer by layer material. So, all these layers are in nanometre dimension, one of the dimensions are in nanometre. So, exfoliation an extreme case of inter calcination where the complete separation of the layer of the material happens. So, how do you do it, after you put this inside still there will be sticking. So, I aggressively try to break the bond. So, the typical aggressive conditions are required to remove the highly polar solvent and the aggressive reagents they react and then this fellow gets disintegrated such that I get layer by layer by layer now each layer is of nano material dimension.

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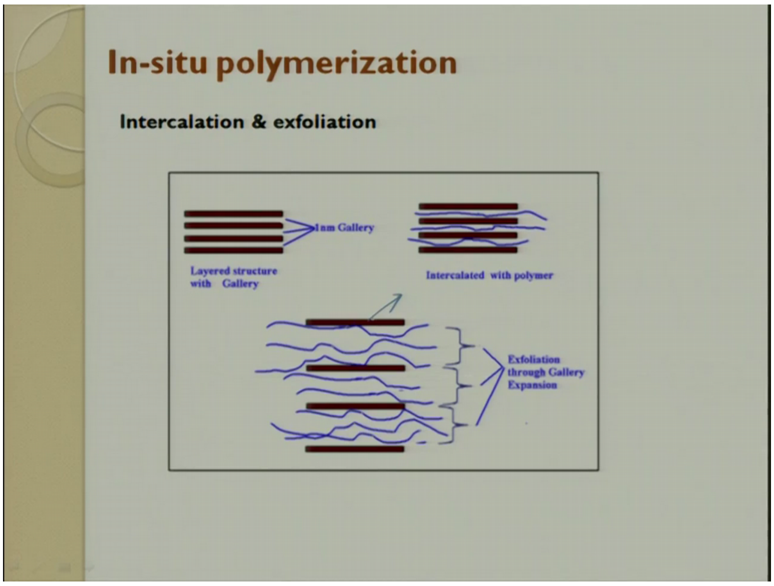

In-situ polymerization

Intercalation & exfoliation

So, what I explained you is given in clear picture here. So, these are the layers. So, it is layered structure with gallery. So, now, in this layer it is all attached to each other just for schematic representation we have given the spacing, now what I do is inter calcination something flows in between and it tries to separate out a distance right. In exfoliation what happens this distance is further enhanced and we separate out layer by layer by layer.

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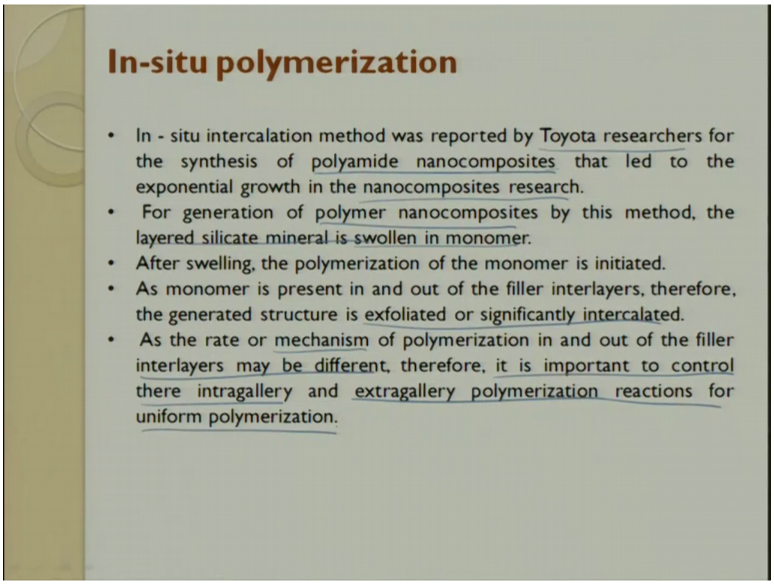

In-situ polymerization

- In - situ intercalation method was reported by Toyota researchers for the synthesis of polyamide nanocomposites that led to the exponential growth in the nanocomposites research.
- For generation of polymer nanocomposites by this method, the layered silicate mineral is swollen in monomer.
- After swelling, the polymerization of the monomer is initiated.
- As monomer is present in and out of the filler interlayers, therefore, the generated structure is exfoliated or significantly intercalated.
- As the rate or mechanism of polymerization in and out of the filler interlayers may be different, therefore, it is important to control there intragallery and extragallery polymerization reactions for uniform polymerization.

So, in situ polymerization method was first reported by Toyota researches from the synthesis of a polyamide nano composite that led to the exponential growth in the nano composite research, for generation of polymer nano composite by this method a layered silicates mineral is swollen in a monomer. So, what have you done? The layered silicate is insert or its it is dissolved or it is put inside a liquid. So, this liquid will try to swell or it will try to separate out. So, after swelling the polymerization of the monomer is initiated. So, now, it is swelled.

So, once moved apart there is enough space for polymer whatever it is to happen as monomers is present in and out of the of the filler interlayer the generated structure is exfoliated or significantly inter calcinated removed a layer out and the polymerization happens. Rate or the mechanism of polymerization in and out of the filler interlayer maybe different therefore, it is important to control the inter gallery or the extra gallery polymerization reaction for getting uniform reaction. So, what I am trying to say is I am trying to say this is separated by a monomer and after this, this is added to or in this what happens you try to have a reaction to form in situ polymerization of generating polyamide nano composite.

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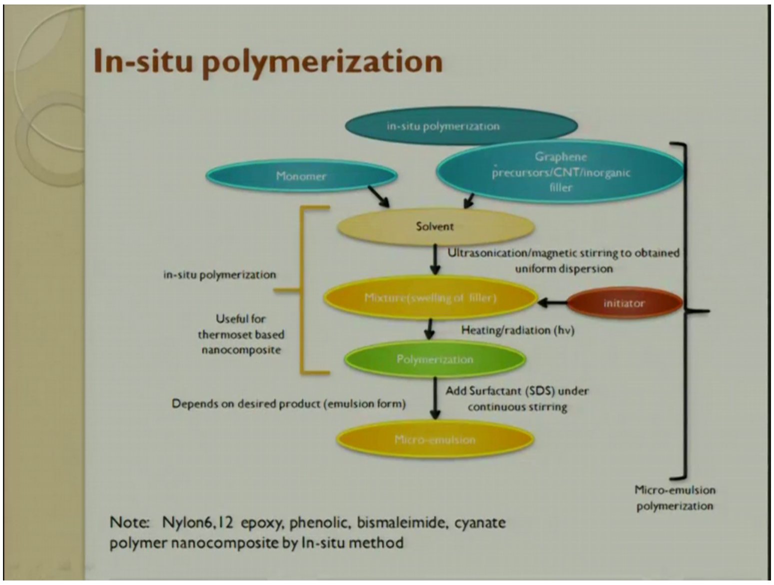

In-situ polymerization

Note: Nylon6,12 epoxy, phenolic, bismaleimide, cyanate polymer nanocomposite by In-situ method

If you look at the schematic diagram so you can see in situ polymerization I add a monomer, I add grapheme, CNT or inorganic filler whatever it is which has a layered structure. So, then it is put together in a solvent, now in a solvent what we do is you have to somehow push the layer in between. So, if you have to push the layer in between you have to aggressively create a space and push inside. So, this can be done by ultrasonification, in ultrasonification process what we do is we try to vibrate, we vibrate the solvent at 21 kilo hertz, it creates cavity small small bubbles these cavities are broken or it is blast and then when it is blast it creates so much of pressure there.

So, it is easy for a material to go inside or it can get inside some material without any problem. So, that is why we always go for ultrasonification, ultrasonification is always used for homogenising the reinforcement in a viscous material we go for ultrasonification, if the viscosity is slightly low then we also go for magnetic stirring. So, this 2 is done only to get uniform dispersal then afterwards the mixing, the mixture that is the swelling of the happens and then we add initiators these initiators are added for initiating the polymerization then I have to accelerate my polymerization. So, I tried to give heat rather than giving a heat by a laser and other things which is for a spot we always try to give for radiations. So, this radiation can be uv can be infrared such that the polymerization happens.

The in situ polymerization is this. So, here what we do is we are trying to work on thermoset polymer matrix composite. So, you have a solvent, mixture is there polymerization can happen after this polymerization surfactant s d s under continuous stirring happens and then you form micro emulsions. So, by this way we try to form this is micro emulsion polymerization by this way we try to form in situ polymerization, since thermosets are liquid in nature this process is very easy, to a large extent it is easy to get uniform homogenisation of the reinforcement in a polymer.

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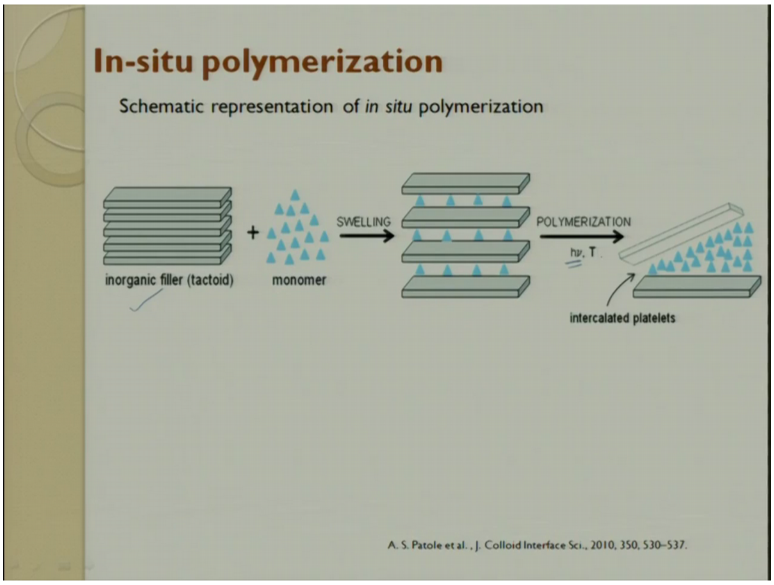

In-situ polymerization

Schematic representation of *in situ* polymerization

A. S. Patole et al., J. Colloid Interface Sci., 2010, 350, 530–537.

So, the schematic diagram I have just put here. So, inorganic filler is used and then we add polymer to it we allow it to swell. So, it is swelled. So, this monomer goes inside. So, polymerization happens I apply heat, heat in the form of light I apply. So, inter calcination of the platelets happens and then this is a polymer which is formed the monomer is converted into a polymer and that is how you get a polymer nano composite in the in situ polymerization process, now I think it should be very clear for you.

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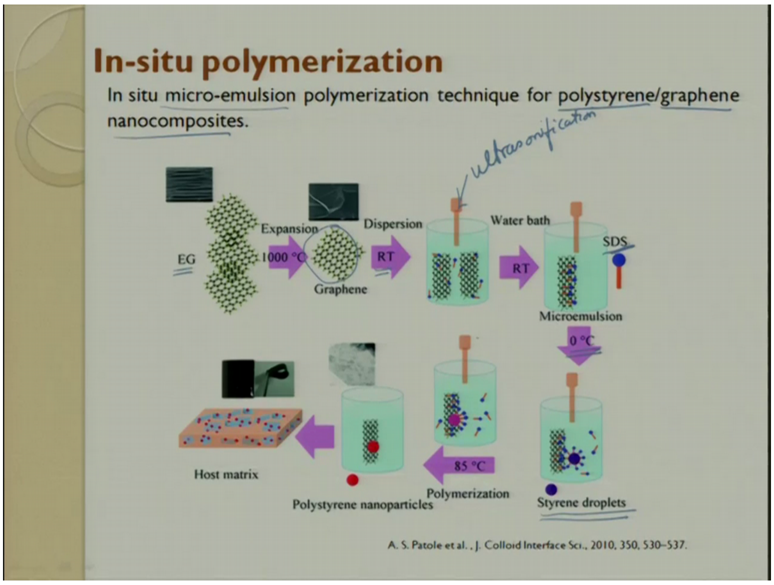

In-situ polymerization

In situ micro-emulsion polymerization technique for polystyrene/graphene nanocomposites.

A. S. Patole et al., J. Colloid Interface Sci., 2010, 350, 530–537.

So, I have put one more example. So, in this example you can see the in situ micro emulsion, what is this micro emulsion? This micro emulsion what we were talking about micro emulsion polymerization right the same thing we are trying to take in situ micro emulsion polymerization technique for polystyrene and graphene, what is graphene? Graphene is another form of a carbon. So, we are trying to graphene is trying to pushed is being pushed into polystyrene. So, maybe they wanted to have a conducting property so they do it or they would like to have a better fracture toughness property they are doing it. So, there are several applications.

So, e g is taken so graphene is taken and then these graphene are expanded and moment it is expanded they are expanded by applying very high temperature by this what we have is we try to take a single layer of grapheme, now the single layer of graphene at room temperature is dispersed in a water bath. So, what are you doing you want to add something into the graphene layer or if you want to delete something into the graphene layer you can get it done. So, when you want to add it is called as functionalization, when you want to remove certain things which you do not want. So, then also we try to do this water, water is something which is easy to handle and it is low viscous. So, it is it can be easily mixed with graphene. So, when you want to mix with graphene we always use a process called as ultrasonification, ultrasonification process.

So, in this process we try to add some functional agents then at room temperature the s d s what are s d s, s d s are nothing, but surfactants you see that s d s at surfactants under the continuous stirring. So, this surfactants are added again it is getting functionalized.

So, now, you see uniformly it is all dispersed then at 0 degree celsius what we do is we try to add styrene droplets polystyrene what you want is polystyrene supposed styrene droplets, styrene droplets are added then at 85 degrees Celsius you again sonicate you see that this polystyrene particles are formed and this s d s is also added.

So, they try to mix each other properly and try to get whatever is the output. So, now, these are polystyrenes which are there, polystyrene are made and then we try to pore it inside a die or extrude it in a strip whatever it is we try to get the polymer nano composite that is polystyrene grapheme impregnated polymer nano composite for various applications, you can see the red dots are polymers polystyrene and the functional parts also mixed. So, you get the graphene is also mixed. So, you get a host matrix and then you get the final output.

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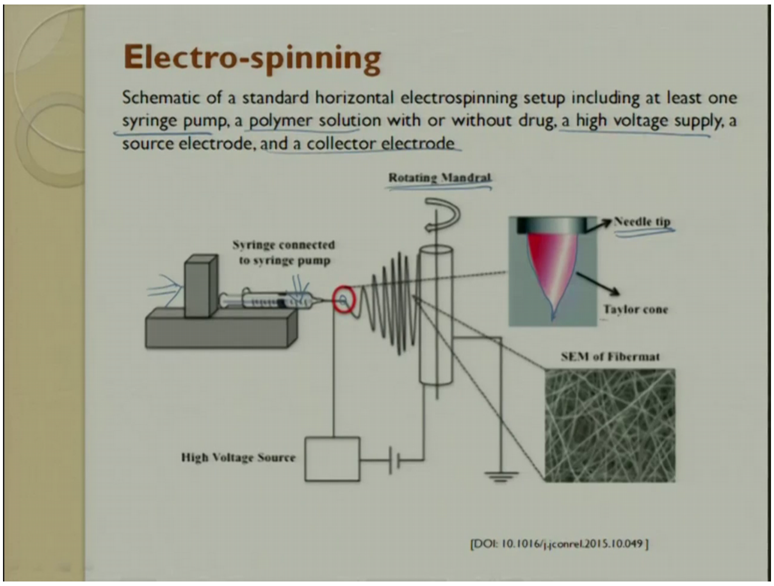

Electro-spinning

Schematic of a standard horizontal electrospinning setup including at least one syringe pump, a polymer solution with or without drug, a high voltage supply, a source electrode, and a collector electrode

[DOI: 10.1016/j.jconrel.2015.10.049]

The next interesting processes electro spinning, what is electro spinning? electro spinning what we do is we try to generate nano fibres, how do we generate nano fibres we try to take the liquid what you want to convert it into a fibre. So, in this syringe what we do is we apply pressure here and slowly the liquid which is here is through this syringe is try to flow out and simultaneously what I do is I try to create an ambience where and which there is a very high potential. So, when the liquid comes out and when there is a very high potential done its try to generate nano fibres, these nano fibres are stuck on or are grown on top of a rotating mandrel or a flat mandrel. So, what is happening is it gets uniformly rotated.

So, all around the mandrel you will have now nano fibres which are getting impregnate or which are getting formed, which just in gets stuck physical sticking happens. So, this is what is electro spinning process it is it is a very interesting process, now lot of things are getting electro spin and then they get try to get the output for example, today they make fibres. These fibres are used for water treatment they have they functionalized these fibres with the with such a, with the such an element or with the such a functionalizing agent it tries to attract arsenic and it completely absorbs arsenic and you get a to a large extent you tried to remove arsenic from the drinking water.

So, for this we use this man of fibres and their fibres are dispersed in a polymer. So, it is nothing, but a polymer matrix nano fibre reinforced nano composite is there. So, this is having lot of roll today. So, here in the schematic standard horizontal you can have this horizontal or you can have this vertical standard horizontal electro spinning setup is shown a for at least a syringe pump. So, this is a syringe pump. So, through this syringe you have a pump which gives the pressure. So, that it tries to eject out very small quantity of a polymer solution.

So, this is at a very high voltage is applied at the electrode sources and then it is and a collector shows a very high potential is applied and then you try to generate this nano fibres, out of this syringe out of the syringe you will have needle tip you can see there is a Taylor cone which is formed and this Taylor cone is will help in making nano fibres. So, the entire process goes in making this Taylor cone and this Taylor cone confirmation is a big challenge, moment it is formed then the fibre is a continuous process it produces lot of things.

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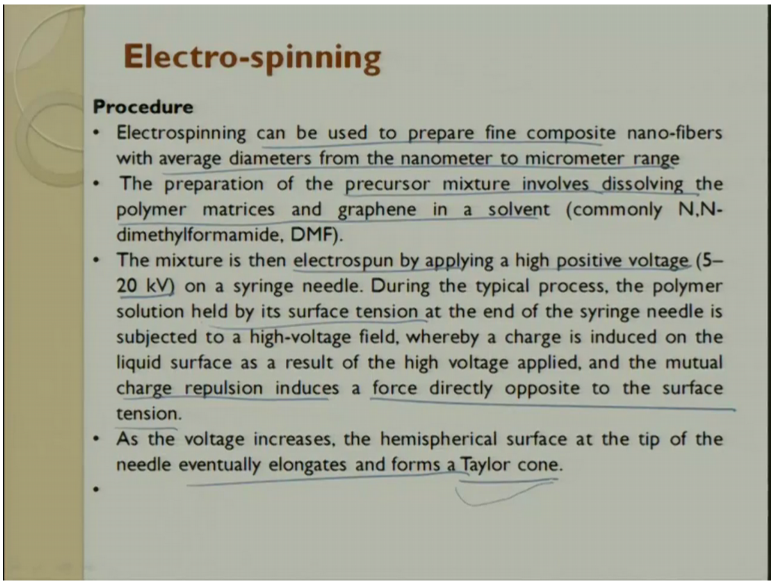

Electro-spinning

Procedure

- Electrospinning can be used to prepare fine composite nano-fibers with average diameters from the nanometer to micrometer range
- The preparation of the precursor mixture involves dissolving the polymer matrices and graphene in a solvent (commonly N,N-dimethylformamide, DMF).
- The mixture is then electrospun by applying a high positive voltage (5–20 kV) on a syringe needle. During the typical process, the polymer solution held by its surface tension at the end of the syringe needle is subjected to a high-voltage field, whereby a charge is induced on the liquid surface as a result of the high voltage applied, and the mutual charge repulsion induces a force directly opposite to the surface tension.
- As the voltage increases, the hemispherical surface at the tip of the needle eventually elongates and forms a Taylor cone.

So, in electro spinning electro spinning can be used to prepare fine composite nano fibres with a diameter from nanometre to micrometre range you can have the diameter and length can be long, the preparation of the precursor mixture involves dissolving the polymer matrix and the graphene in the solvent. So, we mix it and then put it in the electro spin the mixture is then elerctrospun. So, what are we trying to do? We are trying to mix polymer, we are trying to mix graphene and then we are trying to eject it out. So, the mixture is then electro spun by applying a very high voltage of 5 to 20 kilo volt on the syringe needle.

During the typical process the polymer solution held by its surface tension please note, during the typical process the polymer solution held by its surface tension at the end of the syringe needle is subjected to a very high voltage field where by a charge is induced on the liquid surface as a result of high voltage applied and the mutual charge repulsion induces of force directly opposing to the surface tension. So, something pulls out and there is a resistance something pulls out and then you try to form a Taylor cone.

So, here where by a charge is induced on the liquid surface, what liquid comes out what liquid comes out there is a there is a force which is given. So, this will try to restrict the flow as a result of the high voltage applied and mutual liquid charge repulsion induces a force directly opposite to the surface tension and such high voltages increases forms a hemispherical surface at the tip of the needle which is eventually elongated and forms a Taylor cone, there is a lot of science which goes for the formation of this Taylor cone.

So, this is very important process and here we try to mix it with a polymer and try to get it required output.

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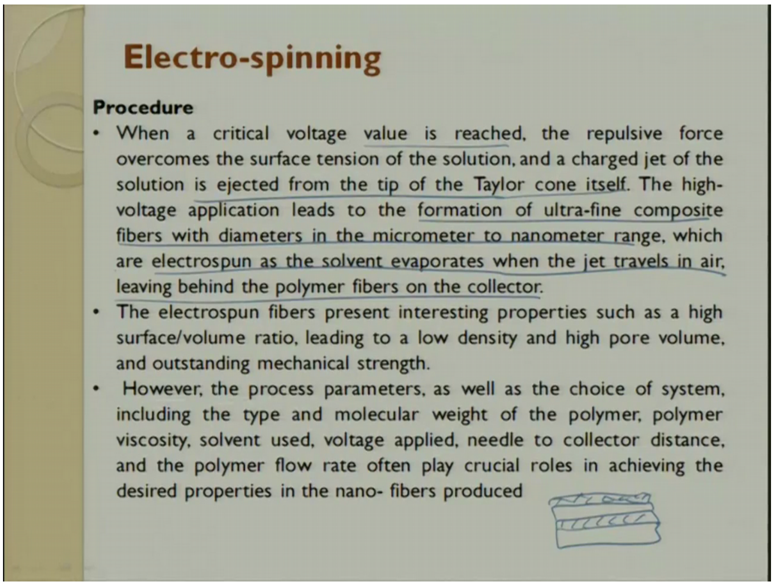

Electro-spinning

Procedure

- When a critical voltage value is reached, the repulsive force overcomes the surface tension of the solution, and a charged jet of the solution is ejected from the tip of the Taylor cone itself. The high-voltage application leads to the formation of ultra-fine composite fibers with diameters in the micrometer to nanometer range, which are electrospun as the solvent evaporates when the jet travels in air, leaving behind the polymer fibers on the collector.
- The electrospun fibers present interesting properties such as a high surface/volume ratio, leading to a low density and high pore volume, and outstanding mechanical strength.
- However, the process parameters, as well as the choice of system, including the type and molecular weight of the polymer, polymer viscosity, solvent used, voltage applied, needle to collector distance, and the polymer flow rate often play crucial roles in achieving the desired properties in the nano- fibers produced

When a critical voltage is voltage value is reached the repulsive forces overcomes the surface tension of the solution and the charge jet of the solution is eject out the tip of the tip of the Taylor cone itself. The high voltage application leads to the formation of ultra fine composite fibres with diameter micrometre range to nanometre range, while which are electrospun as a solvent evaporates when the jet is travel through air and then a behind a polymer fibre on the collector is done.

So, you can have a polymer fibre fit it can be beautifully done you can have a polymer fibre on a, polymer fibre matrix and then you can spun everything and then you can all have one more polymer layer then you can you can spin. So, what you have as you have functionally graded materials or you can also have functionally controlled or tweak materials. So, the voltage applied leads to the formation of ultra fine composite fibres with a diameter in a micrometre or nanometre range and then when it is spun if there are solvents because the solvents are generally used for flowing. So, the solvent evaporates while it comes into the free air contact and leaves behind a polymer fibre on the collector.

The electro spun fibre presents an interesting property has high surface volume to volume ratio leading to low density high pore volume and outstanding mechanical strength can be brought in when you do electro spinning process and generate a polymer nano composite. However, the process parameters as well as the choice of the system includes the type and the molecular weight of the polymer the polymer viscosity, solvent used, voltage applied, needle of the collector distance and the polymer flow rate often plays a crucial role in achieving the desired properties in the nano fibre composite procedure.

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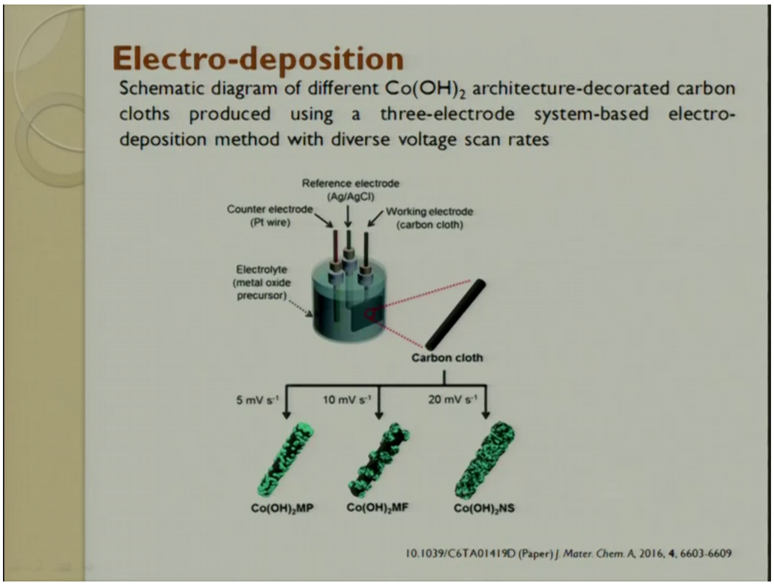

Electro-deposition

Schematic diagram of different $Co(OH)_2$ architecture-decorated carbon cloths produced using a three-electrode system-based electro-deposition method with diverse voltage scan rates

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So, this is another process which is electro deposition. So, in electro deposition, deposition means I tried to deposit nano materials on top of polymer and try to make a composite out of it. So, the electro deposition the schematic diagram of a different CO OH twice architecture de corrected carbon cloth produced using a 3 electrode system based electro deposition method with diverse voltage scanning rates can be done.

So, you have an electrolyte which is having a metal oxide precursor, you have a platinum a platinum is a neutral one. So, you have a platinum electrode wire which is there then we have a reference which is a silver wire a g slash a g a g silver chloride and then you have a working electrode which is a carbon cloth right. So, then this is a carbon cloth. So, if you try to scan it with different different voltages you try to get different different nano particles which is getting embedded on a polymer matrix or on a cloth which can be used for applications.

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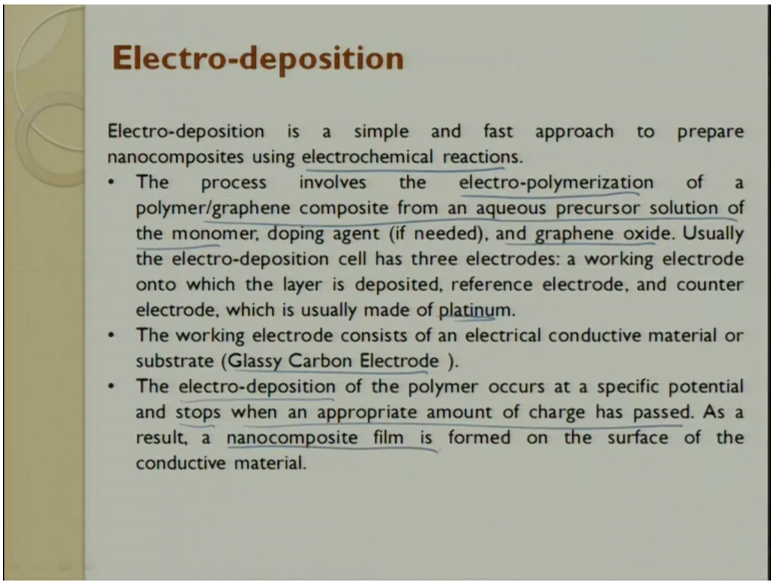

Electro-deposition

Electro-deposition is a simple and fast approach to prepare nanocomposites using electrochemical reactions.

- The process involves the electro-polymerization of a polymer/graphene composite from an aqueous precursor solution of the monomer, doping agent (if needed), and graphene oxide. Usually the electro-deposition cell has three electrodes: a working electrode onto which the layer is deposited, reference electrode, and counter electrode, which is usually made of platinum.
- The working electrode consists of an electrical conductive material or substrate (Glassy Carbon Electrode).
- The electro-deposition of the polymer occurs at a specific potential and stops when an appropriate amount of charge has passed. As a result, a nanocomposite film is formed on the surface of the conductive material.

So, electro deposition is a simple and a fast approaching to prepare nano composites using electrochemical reaction, this process involves electro polymerization of a polymer slash a graphene composite from an aqueous precursor solution of a monomer doping agent and a graphene oxide. So, you need to do electro polymerization and electro polymerization, polymerization process in presence of electrical energy it is called as electro polymerization of what of a polymer slash a polymer or a graphene mixed polymer graphene composites. So, this 2 is mixed from a aqueous precursor solution of a monomer doping agent and graphene oxide all these things are mixed together.

Usually the electro deposition cell has 3 electrodes one is called as a working electrode one is called as a reference electrode one is called as the counter electrode. Counter electrode is generally polymer and the working electrode on which the layer is to be deposited the reference electron is a g c l whatever is there.

So, the working electrode consists of an electrically conducting material or a substance which is nothing, but glassy carbon electrode, the electroce deposition of the polymer occurs at a specific potential and stops when an appropriate amount of charge has passed. So, you can also control the process as a result a nano composite film is formed on the surface on the of the conducting material and if you stack all these things you can try to make a thick layer of nano composites.

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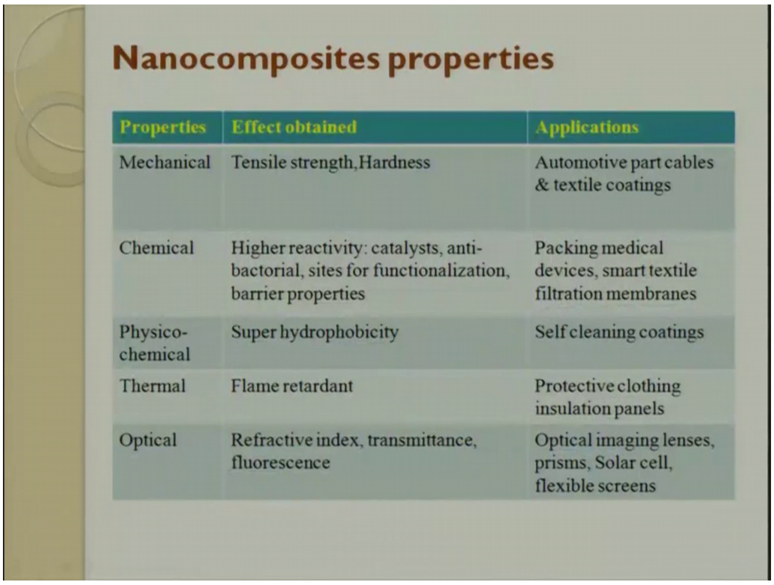

Nanocomposites properties

Properties	Effect obtained	Applications
Mechanical	Tensile strength, Hardness	Automotive part cables & textile coatings
Chemical	Higher reactivity: catalysts, anti-bacterial, sites for functionalization, barrier properties	Packing medical devices, smart textile filtration membranes
Physico-chemical	Super hydrophobicity	Self cleaning coatings
Thermal	Flame retardant	Protective clothing insulation panels
Optical	Refractive index, transmittance, fluorescence	Optical imaging lenses, prisms, Solar cell, flexible screens

So, if you look into the properties mechanical property the effect obtained is tensile enhancement and hardness finds its application in automotive industry and textile industry. The chemical highly reactive catalysis and anti bacterial size for functionalization, barrier properties, packing material, medical devices and smart textiles are coming up today. Smart textiles are textiles wear and which it tries to change the colour then filtration membrane is also coming up, physico and chemical super hydrophobicity is thought about, self cleaning coatings are coming up today. So, if you want to make a shirt and if there is a stain it gets cleaned of its own; that means, to say basically does not allow the particles to enter inside then thermal flame retardant is there. So, it is used as a protective coating insulating panels optical. So, refractive index and transmittance fluorescence it is there. So, it is used for optical imaging lenses.

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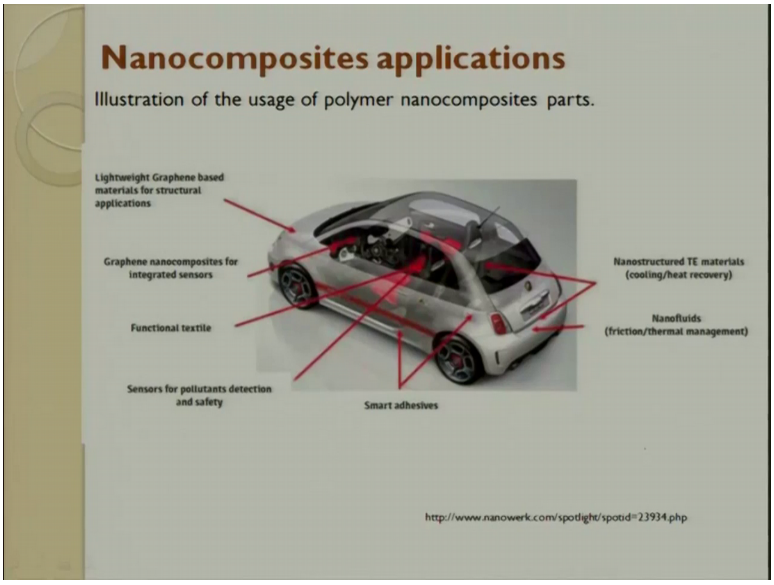

Nanocomposites applications

Illustration of the usage of polymer nanocomposites parts.

Lightweight Graphene based materials for structural applications

Graphene nanocomposites for integrated sensors

Functional textile

Sensors for pollutants detection and safety

Smart adhesives

Nanostructured TE materials (cooling/heat recovery)

Nanofluids (friction/thermal management)

http://www.nanowerk.com/spotlight/spotid=23934.php

So, if you look at a car these are nowadays several parts of a car is now replaced by nano composite, lightweight graphene based materials are used for structural applications in the engine. Graphene nano fibres are used for integrated sensors than functional textiles are used for detecting the sensors for pollution detection and safety is also there, smart adhesions are coming up today. So, where and which it can expand and contract depending upon the temperature and then you have nano fluids which are coming up for maintaining the thermal temperature friction and thermal management which is done by nano fluids and nanostructure thermal emmitive materials which are used for thermal energy materials which are used for cooling and heat recovery are being considered. So, that these are some of the applications where polymer nano composites are exhaustively used in automobile.

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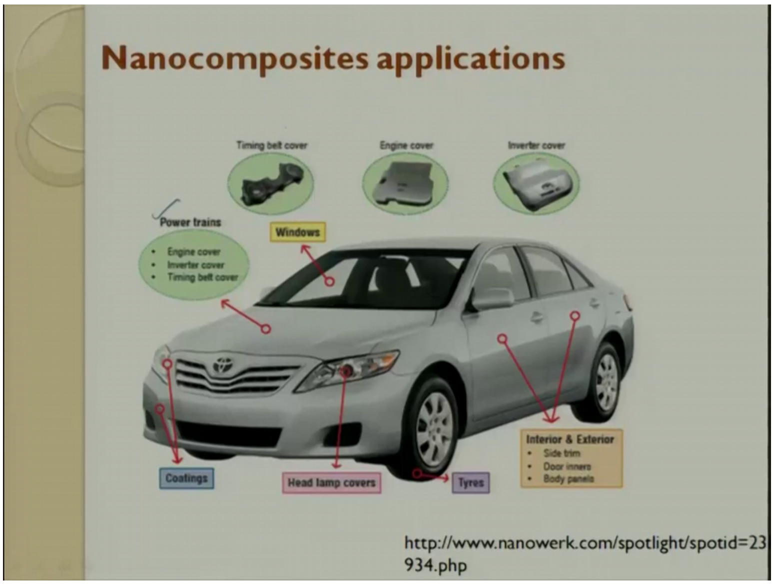

Nanocomposites applications

http://www.nanowerk.com/spotlight/spotid=23934.php

So, some more examples power train, timer belts, engine cover, inverter cover, coatings, headlamps, tires and then interiors all these things are made out of nano composites and they are finding it applications.

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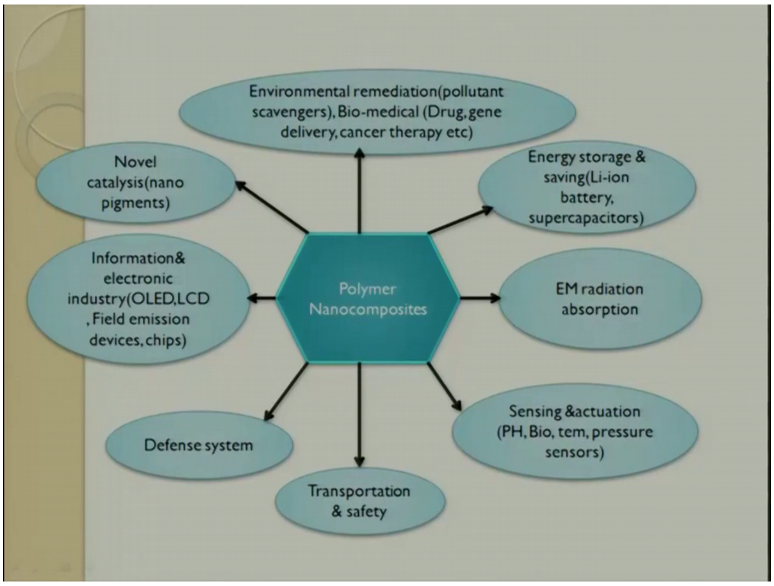

Environmental remediation(pollutant scavengers), Bio-medical (Drug, gene delivery, cancer therapy etc)

Novel catalysis(nano pigments)

Energy storage & saving(Li-ion battery, supercapacitors)

Information& electronic industry(OLED,LCD ,Field emission devices, chips)

Polymer Nanocomposites

EM radiation absorption

Defense system

Sensing &actuation (PH, Bio, tem, pressure sensors)

Transportation & safety

So, polymer nano composites are finding out for environmental remedial measures, energy storage, electromagnetic shielding sensing and activation transportation and safety defence systems information and electronic industry are using it o LED a LCD are using polymer nano composite and novel catalysis are done for nano pigments are also coming up, these are the areas where polymer matrix nano composites are used in a very big way.

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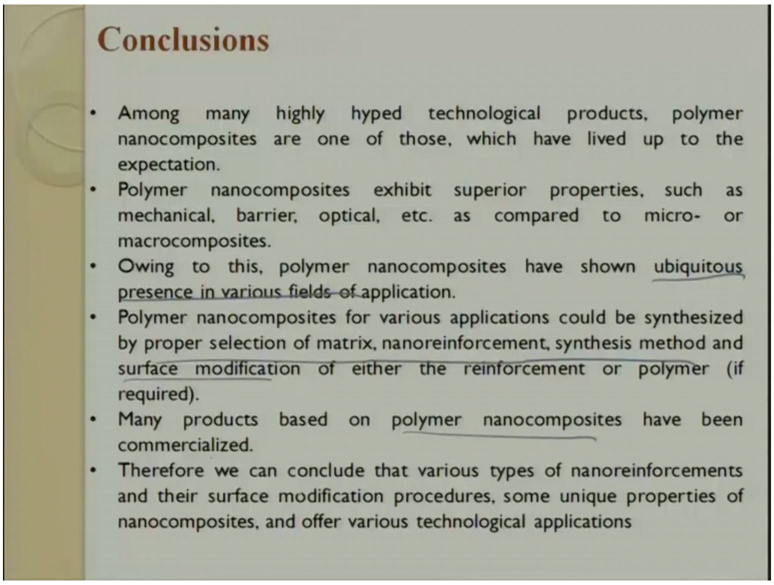

Conclusions

- Among many highly hyped technological products, polymer nanocomposites are one of those, which have lived up to the expectation.
- Polymer nanocomposites exhibit superior properties, such as mechanical, barrier, optical, etc. as compared to micro- or macrocomposites.
- Owing to this, polymer nanocomposites have shown ubiquitous presence in various fields of application.
- Polymer nanocomposites for various applications could be synthesized by proper selection of matrix, nanoreinforcement, synthesis method and surface modification of either the reinforcement or polymer (if required).
- Many products based on polymer nanocomposites have been commercialized.
- Therefore we can conclude that various types of nanoreinforcements and their surface modification procedures, some unique properties of nanocomposites, and offer various technological applications

In conclusion many high highly hyped technology products polymer nano composites are coming up into the market, polymer nano composites exhibits superior property in mechanical thermal barrier optical etcetera moving to the polymer nano composites how a presence omnipresence in various fields of applications seen. Polymer nano composites finds various applications could be synthesized by proper selection of matrix, nano reinforcement synthetic method and the process surface modification is also very important many products based on term polymer nano composites have been commercialized today therefore, we can conclude that various types of nano composites and their surface modification procedure some unique properties of nano composite and its offer for various technology applications can be achieved.

Thank you very much.