Introduction to Biomaterials

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Lecture No. # 25

Electrostatic Spraying of UHMWPE-HA-CNT Biocomposite

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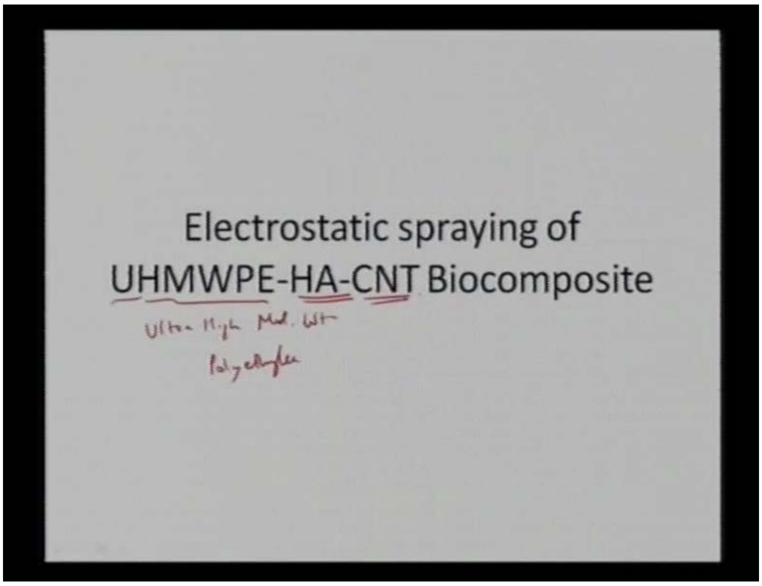

In this lecture, we learn about the electrostatic spraying of the Ultra High Molecular Weight Polyethylene. It is UHMWPE. It is Ultra High Molecular Weight Polyethylene, weight polyethylene, which has been reinforced with hydroxyapatite and carbon nanotube. So, where in this particular lecture we will learn about the coating technique of the electrostatic spray and utilizing this ultra-high molecular weight polyethylene which has been reinforced with hydroxyapatite and carbon nanotube to form a particular biocomposite.

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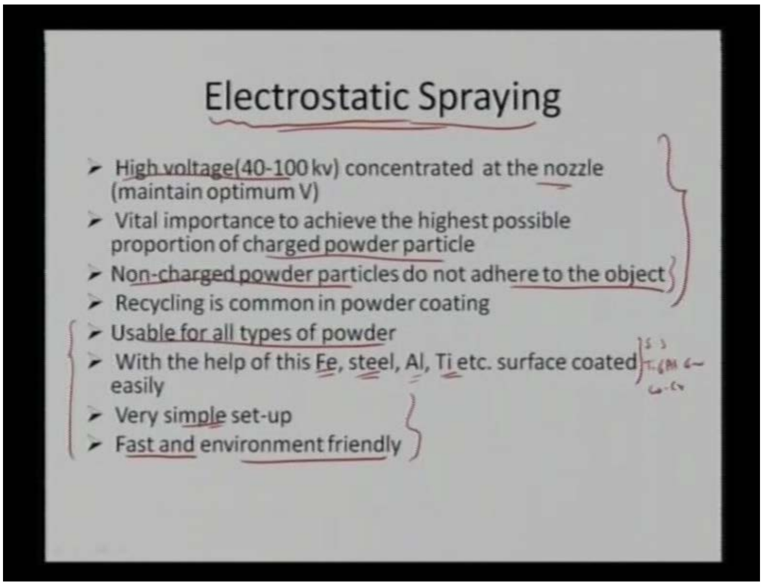

So, in this particular process, we will focus on what is electrostatic spray and how it has been utilized to create a biocomposite coating. In this electrostatics spray we apply very high voltage; which is in the order of 40 to 100 k v, which is concentrated at the nozzle. And, that has been obtained, maintained at optimum voltage. Here our important, the overall important criteria or the vital component of here is that, we can we can attain highly charged powder particles. So, the powder itself has to be much more insulating in nature, so that charge can be created on the particular powder particle, when when it is passing through the particular nozzle which is being maintained at certain high voltage. So, after that, what happens here is that non-charged powder particles, they do not adhere to the object because they can dissipate the charge very easily.

So, in this particular case, we need some powder particles which can get charged. And, that charge has been created by the voltage, which is which is again concentrated at the nozzle. And, once we can do that, we can again coat the..., we can let the powder adhere to the particular substrate. And, the powder which is going outside; which is not really setting on the substrate while the process is going on, then that extra powder can be recycled back to the powder Hopper. And, from there we can again, we can circulate the powder. What is the overall working in, how the how the overall functionality of this electrostatic spraying occurs; we will come back to it. It is more like a coating technique.

The way the way we utilize that for spraying; so, we have particular charge entity basically through the powder at a particular substrate, which is which is kept at a little lower or the ground potential to complete the overall circuit. And, the charge between the powder particles is utilized for the travel over those powder particles from the from an electrostatic gun through the substrate. And later on, we can do some sort of curing to keep those powder particles entire or so that they can get fused together.

And, again it can be... It is usable for all types of powders. And more than that, we can also utilize this particular powder, utilizing the electrostatic spraying to coat either iron, steel, aluminium, titanium, etcetera. And, as we know that there are certain common bio... for the implant material, we need to have particular implant material to be good enough in terms of strength. And hence, metallic materials come as the emerging candidates for them.

Further, we have stainless steel or titanium, 6 aluminium, 4 vanadium or cobalt chromium alloys. And we also saw that, some other elements such as certain other materials such as titanium, magnesium and many others. So, all those are nothing but metallic material. So, this process can be highly utilized in terms of coating all those metallic implant. And so, again it is a very simple set up and it is again very fast and environment friendly.

So, we see in this particular electrostatic spraying is that, we can maintain a high voltage into the nozzle. And, that particular voltage is utilized for creating a charge on a particular powder particle. And then, we let this powder particle flow through and get deposited on a substrate. And then, we can do some sort of a secondary treatment which can be a fuse, which can be which can be basically the melting of those powder particles to get cured on the particular substrate. And, the powder which is extra, which is kind of over spraying that can be recycled again in the later stage.

And, again the advantage of this particular process is that, we can easily coat a particular metallic implant using any type of a powder particle which can get charged. And, it is again a very simple set up and it is very fast, it is very rapid. It is very very simple process, very rapid process. And in the same time, it is environmental friendly because it is not creating any, generating any fuse. This is the overall set up of electrostatic spraying.

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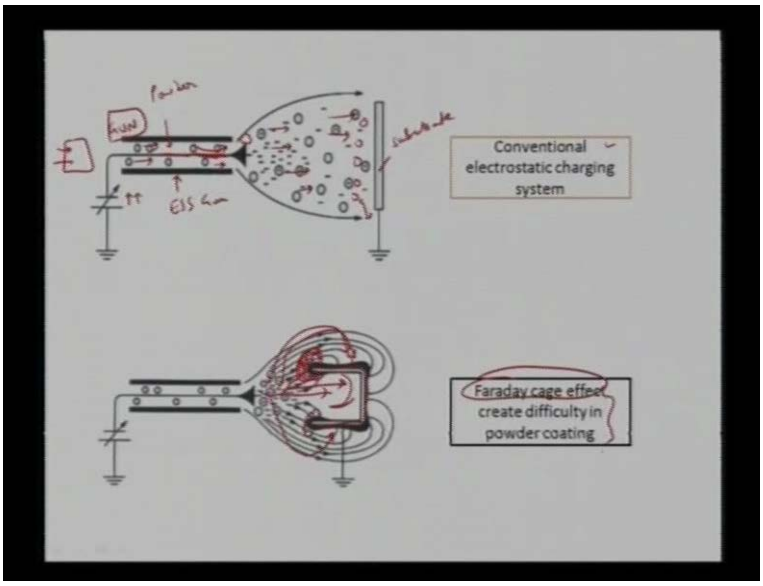

How does it really appear is that, particular we apply certain particular voltage. We have container which contains our powders. So, we have powdered particles out here. Then, we have this electrode which is charged, which is kept at a higher voltage. And then, we have a substrate on which you want to coat this particular powder particle. So, we have a particular particular electrode. As powders are passing through it, they get charged. So, once a charge is being created on the powder particle; so, right now it is at higher potential. And then, basically it progresses to the lower potential side. And, we can have some kinds of blowers which can allow the particles in that certain velocity or basically to flow from gun to the substrate. So, that is the that is the overall philosophy out here.

That we apply particular blower, it carries away the powder particles. And, once it is carrying over the part of powder particles, it will encounter electrode which is centrally located in the gun. And, that makes the powder particles to get charged. And the flow of air, which is being loaded from another end; it carries away the powder particles. And now, the powder particles are charged in nature. And, once they strike the substrate, they can transfer the charge back to the substrate. But, in that particular process what is happening is, all the powder particles are... they have similar charges. So, there is some sort of an electrostatic repulsion. And, that electrostatic repulsion is the cause of uniform dispersion of the powder particles. That is what happens in the conventional electrostatic charging system.

Again, so this is the overall, it is one of the very simple processes. And, we see here that we apply certain voltage out here. And then, that voltage is being carried over by the electrode which is facing the centre front portion of the... This is nothing but the electrostatic spraying gun. And, the blower is creating, is allowing the powder particles to flow. And, as soon as the flowing; it is getting charged because it comes and interacts with the electrode. And, once it is once it strikes a particular substrate, the overall repulsion between the powder particles because of the similar charges creates a very nicely dispersed powder particles setting on the substrate. And, once we have this powder particles setting on the substrate, it is just setting; it does not it is not form the coating or anything like that. It is just setting on the substrate.

So, in the process we do not have to damage it. We do not have to damage the overall orientation of this powder particles or the... we should not tap it; otherwise it will lose its overall integrity. And then, later on we can take the similar plate or the substrate and get it cured at much high temperature; which which is to be above the melting point of the particular polymer, which is being spread on to the substrate. So, we take all those deposited powder particles which are now very nice disperse. But, they are just hanging on mechanically. There is no metallurgical bounding or there is no fusion between the powder particles.

So, they are just setting mechanically on a particular substrate. And later on, they have to be taken to the oven and then cured. That is what is happening in the conventional electrostatic charging system. But, when there are certain crevices, and we say we had a particular implant particular substrate which is which has a certain cavity or some sort of a cage effect. So, in this case what happens? As soon as powder particles, they start depositing on the front portion of that and they have not charged, they are not the charged entities. And the second powder particle, instead of getting inside this particular cage, it will experience a repulsion from the already deposited powder particles.

So, it will try to tend, it will tend to find a new site for its deposition. And, it can find an easy path of travel on the surface of this particular substrate; not inside of it. So, in that particular sense, the powder particles which are now charged, they will try to go and set on the top surface, rather than the inside surface. And, if you want to coat the particular substrate from the inside as well, that becomes very very difficult. Initially, few powder particles can go inside that will be fine.

But, as soon as we express more and more charge which is depositing on the particular front portion of that particular substrate, it will be very difficult for the powder particles to squeeze through it and then get deposited inside as well to a larger extent. So, that that is called a Faraday cage effect and that can create difficulty in the coating of a particular powder.

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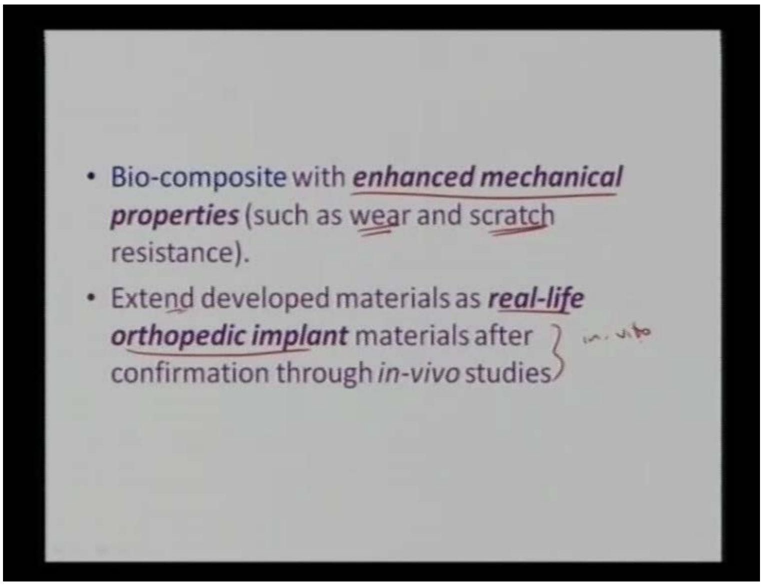

So, overall aim is to create a biocomposite, which need to have enhanced mechanical properties; because if you are creating a particular biocomposite, we need need to perform much superior to already existing coating materials. So, if it is a polymer, we definitely wanted to have a higher wear resistance as well as higher scratch resistance.

And, if we, if possible we can also, we would also want to extend this developed materials as a real-life orthopedic implants. So, we also need some sort of studies; in-vitro and in-vivo studies for the confirmation of the biocompatibility or cytocompatibility of this particular coatings.

And, as we have seen in the earlier lecture that surface is one of the very critical component of deciding the cytocompatibility; because any particular environment will come in contact with the surface first. So, that is the critical issue in terms of deciding the cytocompatibility. And, if this coatings, they have to be utilized as a superior mechanically; which are much more superior in terms of mechanical and tribological properties. They also have to retain the cytocompatibility is the same in the same type. So that, then only we can extend them to certain potential biomedical applications.

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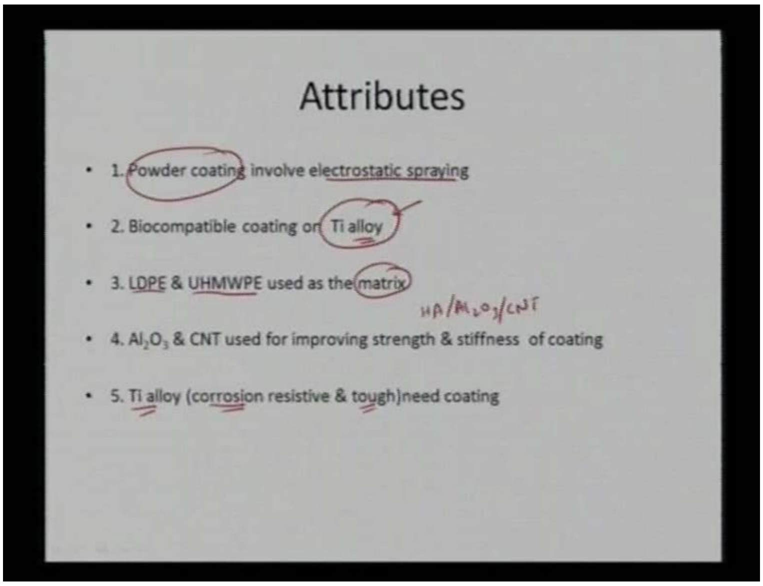

So, the certain attributes to it is, first of all we are utilizing this electrostatic spraying for the powder coating. Secondly, we know that they need some charge for some surface, so that they can dissipate the charge.

So, for that we need to have a metallic entity where the charges, it can be taken away. That is nothing but a metallic substrate. It can be titanium alloy; it can be stainless steel; it can be cobalt chromium alloys. The only required criteria is that the substrate has to be conducting in nature.

Once we have that, we can either utilize low density polyethylene or ultra high molecular weight polyethylene as the main component as the main component of the coating. So, we have a... we are going to deposit a coating which is rich in polyethylene. It can be a high molecular weight or it can be low density polyethylene. And, we can make that as a major constituent of the coating. And, because this coatings are very very softer in nature, we also want to increase a wear resistance or the tribological properties. So, for that, we can either introduce something called a hydroxyapatite, we can also induce some ceramic; it can be aluminium oxide or we can also incorporate carbon nanotube for improving the strength as well as stiffness.

So, once we have much superior mechanical properties, automatically we can expect that there are wear or the tribological properties will also enhance with the particular reinforcement. And, again we, in this particular… much better because of its superior corrosion resistance as well as its toughness.

So, once we can select a very appropriate biomaterial. We can always do some sort of a coating which can be of polyethylene, which is again still biocompatible material. And, we can enhance its strength by using certain reinforcements, which is hydroxyapatite or alumina or carbon nanotube. And, again there incorporation will depend or will vary depending on what kind of applications we are aiming at.

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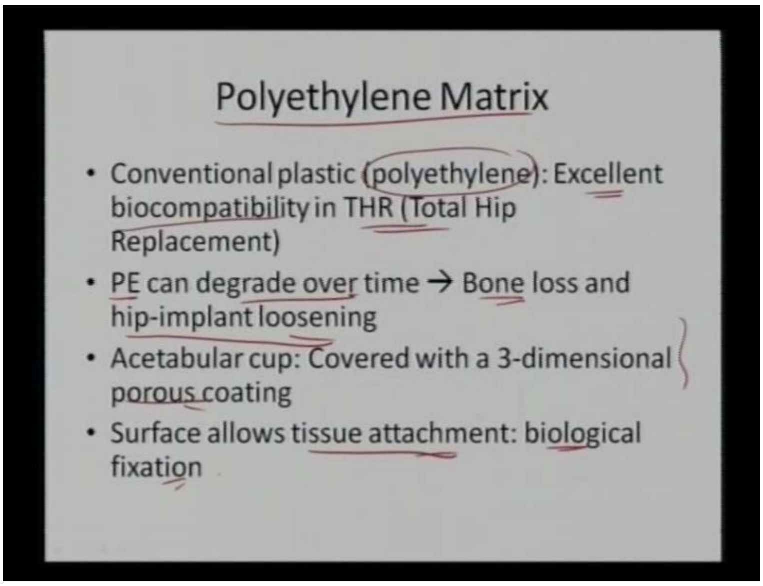

So, we know that for the polyethylene polyethylene matrix, conventionally the polyethylene has shown to be excellent or exceptional in terms of biocompatibility. So, just Total Hip Replacement. So, in THR surgeries polyethylene has shown to be exceptional material or the very excellent biocompatible material in terms of Total Hip Replacement. But, the problem with this is that polyethylene, it can degrade over time.

So, that might create some bone loss or the hip implant loosening; because once we are losing some material, it always create some gap or some spaces between the implant and the bone. So, for that, we want the polyethylene coating to survive much longer or for a very long time. Generally, we have a we have a ceramic... polymer liner. Then, it will always lead to much more degradation of the polymer coating. So, if you want to improve the wear resistance or the tribological properties of this polyethylene polyethylene, we need to always incorporate, using incorporate with certain ceramics as the reinforcement.

So, in this particular case we also want to, we want to create some sort of a porous coating, so that cells can really come and adhere. Or, depending upon the kind of applicability, we can also provide some lubrication in the particular porous coating. So, that is the deal with this particular polyethylene matrix. In the same time, polyethylene can also allow for a tissue attachment at the biological fixation. So, there is one more advantage. If the polyethylene is a it can allow biological fixation and it can allow tissues and tissues and cells to grow on to its surface.

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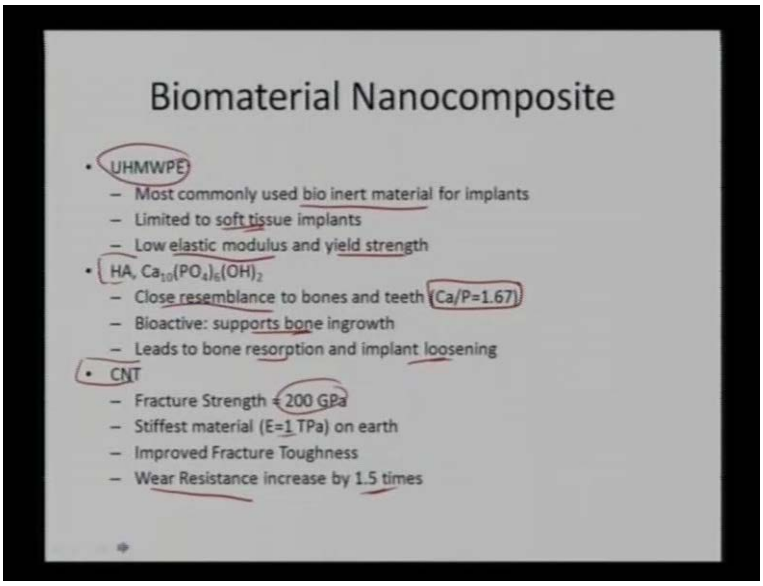

So, in this particular component we are utilizing ultra molecular polyethylene because it has shown to shown to be exceptionally a cytocompatible in Total Hip Replacements. And, it is a very commonly used bio inert material for implants. But, the problem with this polyethylene is, it is limited to only soft tissues. Because of its lower mechanical properties, it is limited to only soft tissues implants. And at the same time, it is very low elastic modulus and low yield strength. So, to improve those particular properties in terms of strength as well as wear or tribological properties, we may want to add some hydroxyapatite. Hydroxyapatite; it has shown to be exceptionally bioactive material. It has a close resemblance to bone and teeth; because its calcium to phosphate ratio is 1.67. And because of its bioactive nature, it also supports bone growth.

So, in certain cases when you want the bones to get reattached to the implant materials and to provide a strong reinforcement, hydroxyapatite come come over to a rescue. So, again it leads to the bone resorption and implant loosening. In case we get a very poor… or generation of some secondary phases which are amorphous in nature, that can also create certain proper some problems, in case the processing is not done properly. So, session has already been taken in terms of the overall processing of this bio ceramics or or even the bio glass materials.

Coming coming next, if you want to improve the fracture toughness or the strength of the polymeric materials, we also want to introduce some carbon nanotube as a reinforcement because its fracture strength is 200 gigapascal. It is its one of the stiffest material with young's modulus of 1 terapascal. It is approximately six to ten times as strong as steel, but at the same time, it is as light as four to six times lighter than that of lighter that that an a steel.

So, that is that is our attempt, provided exceptionally toughening properties. So, if you are able to reinforce it in polyethylene matrix, it can result in good fracture toughness. It will also induce improved strength; it will also improve wear resistance improvement by approximately 1.5 times.

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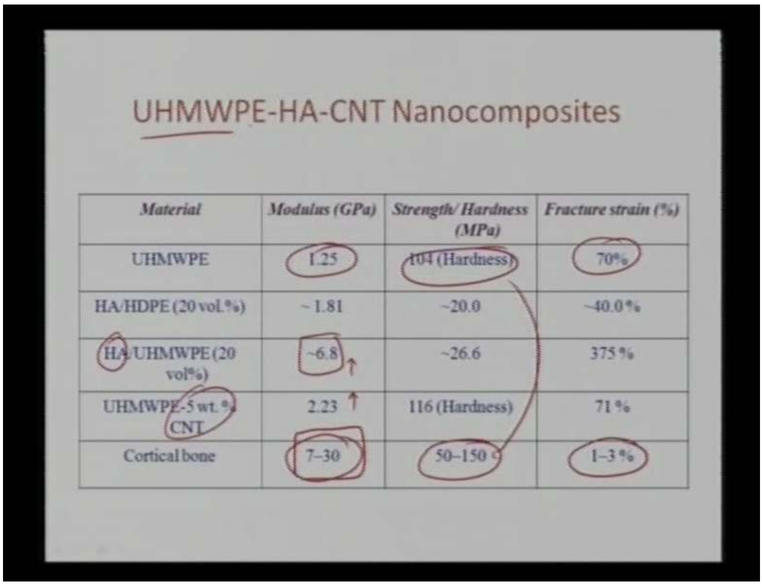
UHMWPE-HA-CNT Nanocomposites

Material	Modulus (GPa)	Strength/ Hardness (MPa)	Fracture strain (%)
UHMWPE	1.25	104 (Hardness)	70%
HA/HDPE (20 vol.%)	~1.81	~20.0	~40.0%
HA/UHMWPE (20 vol%)	~6.8	~26.6	375%
UHMWPE-5 wt.% CNT	2.23	116 (Hardness)	71%
Cortical bone	7–30	50–150	1–3%

So, we can see such things have been already reported with the incorporation of carbon nanotube. So, one more problem out here we see is that, our cortical bone; it has a elastic modulus of from 7 to 30 and strength is approximately 50 to 150 M P a. Its fracture strain is only 1 to 3 percent. So, if you want to match it with polyethylene, polyethylene has a modulus of around 1.25, its density is also very very similar to that of a cortical bone. It is approximately 1.25 at strength, hardness as approximately 104; which falls in range.

It has a very high fracture strain as we want to require, as we might require. And, if we can see, if we can start introducing some sort of a hydroxyapatite in terms of volume percent or we start into since some sort of a carbon nanotube. We are seeing improvement in the mechanical properties in terms of its modulus. And, that thing is now coming back into the regime of the modulus as that of a cortical bone.

So, what happens is low density like Ultra High Molecular Weight Polyethylene is, it can start matching the modulus of that of a bone, once if we start reinforced in certain ceramic. So, that is the advantage. It can provide… it is very very light. Polyethylene is very very light. So, it can soon reach the density of a bone approximately 1… per c c. And, whereas our hydroxyapatite or alumina itself they are much more, they have very high stiffness. So, what happens with them is, there is some sort of a bone resorption; because the body starts shrinking that, the overall load is being born by the ceramics such as hydroxyapatite or alumina, monolithic alumina means hydroxyapatite.

Once we only have that that is an implant to bone starts shrinking over high, they are not really did there. And because of the CNTs loosening, we can also see some absorption of the bone itself; because the overall load is being born by some other particles. So, that can be a problem. That is the reason our polymer matrix can come over to rescue. In that particular sense, that it has a lower modulus and it can match the elastic modulus as well as the strength as well as the… It can have a very superior fracture strain as well. That gives the overall importance to the ultra high molecular weight polyethylene, which has been reinforced with hydroxyapatite as well as carbon nanotube.

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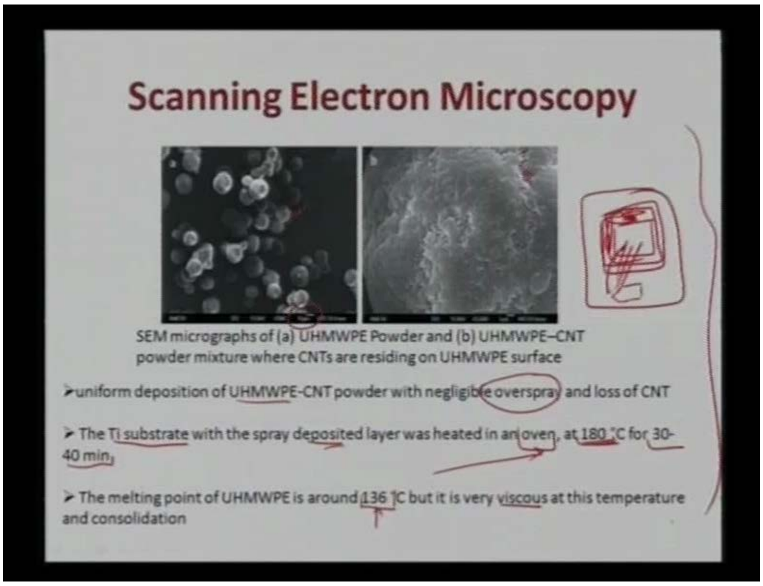

So, from the Scanning Electron Microscopy, we can see that how the powders are being generated. Like, we can see some powder particles which are approximately around 20 microns also. We can see the microns bar here. So, around 10 to 20 micro microns in diameter and then we can also start reinforcing them with some carbon nanotubes.

All those carbon nanotubes appear as small tubular structures, which we can see out here. And, that thing has to be also dispersed; because carbon nanotubes can provide much more strengthening; only once they are distributed throughout the… If they are… if they are isolated in some certain location, that particular regime can become much stronger. Also depending on if they are not strong, if they are not dispersed properly, one region will become very weak.

So, it will also lead to some sort of straining or some sort of a stress concentration at certain location. So, that might again be a problem. Again, people do not know how CNTs or the carbon nanotubes will react, once they are in the body environment. So, they are, they have been generated two schools of thoughts. On one hand, carbon nanotube; it is nano in nature, so it can penetrate to cell walls, it can create some damage or it can get agglomerated, it can basically get accumulated either at liver or brain or even heart or some other location. So, that can even create some problem.

And, even once anything is the nano form and if it goes to our lungs, it is very hard for to hard for us to take it out. So, it can be very very toxic; depending on how the CNTs are being now introduced into the introduce in to the matrix. But, on the other hand, our body is also made up of carbon. So, why carbon will be deleterious to our own body? So, there are two schools of thought which are being proposed by the researches. And, once we can trap all those CNTs in some matrix, then we do not allow any free CNTs or any loose CNTs to flow in our blood. Or, do not do not allow them to flow through and get accumulated certain parts of our organ of the body. So, we want to… once we trap those carbon nanotubes, we get much more strengthening in the polymer matrix. And, we can also achieve much more superior mechanical properties while retuning the cytocompatibility.

So, in this particular case we have utilized ultra high molecular weight polyethylene. And then, carbon nanotube powder, carbon nanotube is now being dispersed with the matrix via certain ball milling technique. And, once we have that, we can utilize the electrostatic spraying to basically coat the substrate material. And, the over spray; like once we are spraying it, some part of it can also go outside the particular substrate regime. So, once we have substrate like this and we start coating using a particular gun; once we are coating it, the powder particles must set on to it. But, some of it can also go outside the particles substrate where we are where we are spraying.

So, this extra powder particle, the extra regime of the powder, it can be again collected back. If you have a particular container, we can again collect this particular extra powder back and we can recycle it. So, we can minimize the over spray and we can again minimize the material loss. And, we can… and, in this particular case we are utilizing titanium substrate. So, once we have the particular coating which is deposited on the on to the titanium substrate, we take this deposited layer and then we heated in an oven for around 180 degrees centigrade depending on the melting point of the polymer. So, we want the polymer to melt on the substrate, so that it can get fused and it can melt and basically coat the titanium implant. And, depending on that, we can also have certain temperature as well as certain time; like in this case, the utilize time is 30 to 40 minutes.

So, we can decide the temperature and time depending on the particular polymer, which we are utilizing for the electrostatic spray. So, what we are doing? We are taking titanium substrate, we…electrostatic spraying, the Ultra ultra high molecular Weight Polyethylene which is not reinforced with carbon nanotube. And once we have that, we put it in an oven for a certain region of time and temperature, to basically cure the polymer and achieve a uniform coating on a titanium substrate. And, because in this particular case the melting part of polyethylene is around 136 degrees centigrade, but it is very viscous at this particular temperature, so in case when we want the polyethylene to flow, we need to obviously heat to, super-heated to much high temperature than 136 degrees centigrade. So, in this particular case we are heating it to around 180 degrees centigrade, so that now it is… enough to cover the overall surface of the titanium substrate. So, that is the overall deal with the deposition of CNT reinforced polyethylene using electrostatic spraying.

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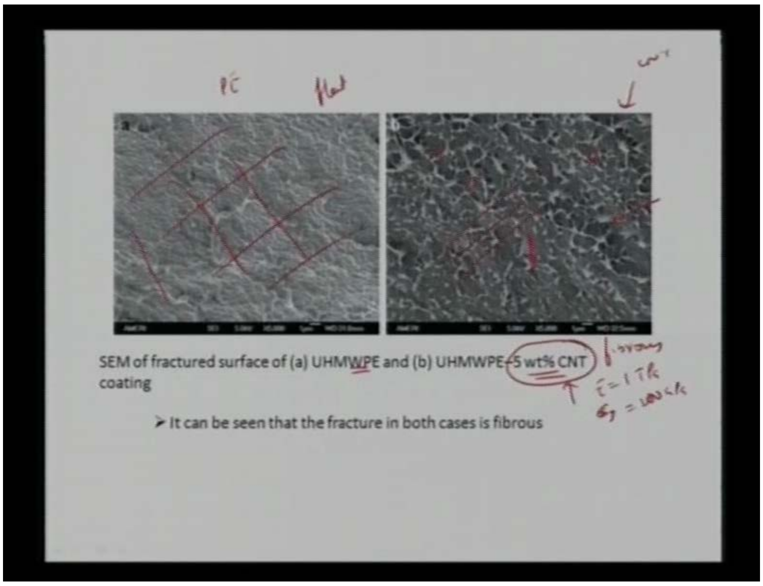

And, once we have the… and, once we fractured those samples; in this case one, we have only polyethylene. And second case, once we are reinforcing it with some carbon nanotube. So, what we can see here is, in this particular in this particular case, once we have only polyethylene; nothing else. No CNT, it is a flat morphology. But, once we have some carbon nanotube, we can see all those; very dimple kind of a… very fibrous kind of a fracture out here. So, this case it is very fibrous and in this case it is a very flat fracture.

This directly tells that my coating or my particular coating which is now reinforced with carbon nanotube is much more ductile. So, that is what is giving much more advantage that I can have a very adherent coating, very nice coating and that is also have much more higher fracture toughness. At the same time, it should it should show a very good mechanical properties; because what is happening here is, we want the surface to yield when we, when it is undergoing some stresses.

So, in that particular case we can see that with CN , I am getting much more fibrous coating which can be basically shear off or deform with particular applied load and it can sustain much longer time. So, that is the advantage with the addition of carbon nanotube; because carbon nanotube would have exceptional mechanical properties takes modulus of around 1 terapascal, fracture strength of around 200 gigapascal. So, that is the advantage of utilizing carbon nanotube as the reinforcement. At the same time, it is also assisting formation of a fibrous structure and which is much more, which can provide us much more stress stress absorption in many many cases.

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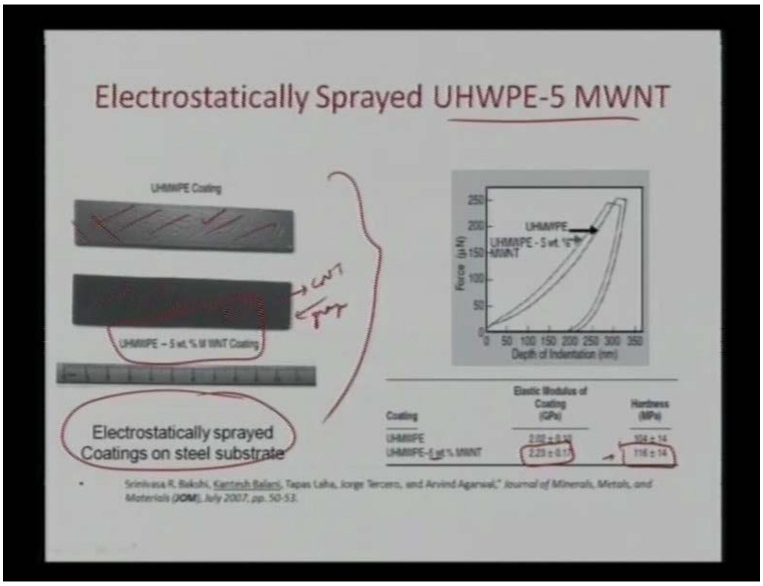

This is how the coatings look like. In this case, we utilize only the polyethylene with some carbon nanotube. So, in this case we have ultra high molecular weight polyethylene and we have around 5 weight percent of multi walled carbon nanotube. And, the coatings show very smooth surface finish as you see here. And, in this case because of CNT, we are seeing a little greyish coating.

And, this coatings are now electrostatically sprayed on the steel substrate. Then, in this case we have to utilize the steel substrate, not only the titanium substrate. But, we can see the overall feel of how the coatings are deposited using an electrostatic spraying. And correspondingly, as we have seen the fracture part was very very different.

So, in this particular case with reinforcement of the 5 weight percent multi walled carbon nanotubes, we are seeing increase in the elastic modulus by approximately 10 percent. That is again very substantial because we are using only 5weight percent of CNTs. And, that has enhanced the mechanical properties for the elastic modulus by around 10 percent. At the same time, we can also see improvement in the hardness. this is very very marginal.

But at the same time, we can see this is overall generating increase in terms of, general increase in either the hardness as well as the elastic modulus so marginally. But, we can see there is some sort of an influence of carbon nanotube reinforcement in the ultra high molecular weight polyethylene matrix.

So, that is what we can see that electrostatic spraying coatings; they are very very smooth. So, we can utilize them as such. So, they are very smooth they are very smooth surface. And, aesthetically also they look very good. So, we can utilize all these coatings as such as the… in the implant, while they are showing the improvement in the mechanical properties.

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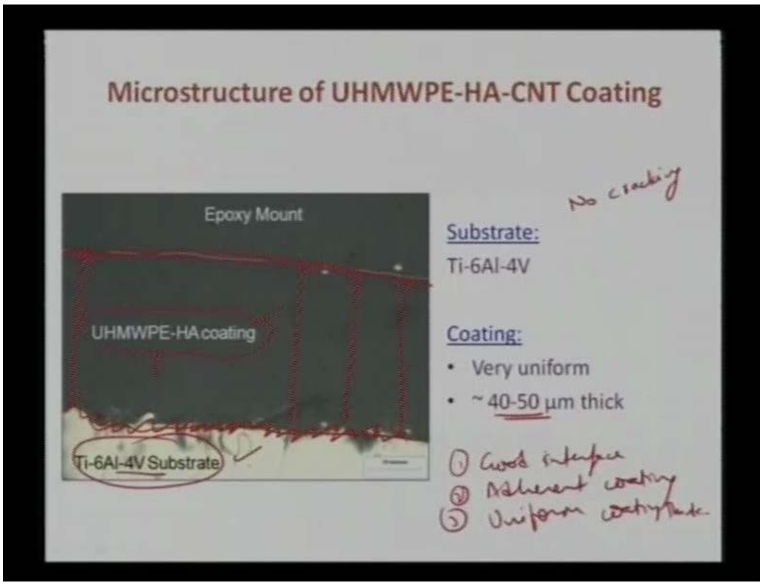

Now coming next, we can see that this is the second case. We have some ultra molecular polyethylene with hydroxyapatite coating. So, in this particular case we have titanium, 6 aluminium, 4 vanadium substrate. And over that, … spread this particular coating, which is ultra high molecular weight polyethylene. This is now reinforced with some hydroxyapatite. And, we can see one very nice observation that the coating is very very uniform. This particular coating, it is very very uniform. The interface is very very adherent. We can see out here, there is no cracking. You can see no cracking at the interface. So, we can see there is the interface is very very strong, which is between the substrate and the coating. And later on, this particular point was sectioned and mounted.

So, we have this Epoxy Mount which is basically distinguishing the… which is basically captured the coating as well as the substrate. So, we can see in this case, the coatings are very very uniform which is approximately 40 to 50 micrometres thick. But, the main point is it is very very uniform.

We can see this particular part that we can achieve the approximately a constant thickness. However, a smooth surface is utilizing the electrostatic spraying. That is, the basic advantage of electrostatic spraying is, I can achieve very uniform coatings on a metallic substrate. And mostly, all our implants are metallic in nature because they need to they need to render, enhance pressure toughness, enhance… and such basically that to take care of the wear and tear and work as a hot material or work hot material.

So, in that particular case, it is this particular process can highly be utilized for electrostatic spraying of certain polymer coating. So, that part we can see here that we can achieve a very nice uniform coating on a metallic substrate, which is titanium, 6 aluminium, 4 vanadium substrate. I can achieve good interface. So, I have very good interface without any cracking. Coating is highly adherent adherent coating.

And, third thing is, I am achieving a very uniform coating thickness. So, these are three very three very nice components which we can really see here that, I have a very good interface. Coating is highly adherent; it is not peeling off and I have a uniform coating thickness. So, in that particular manner, I can really see how much coating I really require out here. But, one problem with this electrostatic spraying is, I cannot achieve very high coating thickness, which can exceed say 200-300 microns or so because my substrate need to be highly conducting.

Once I achieve a certain thickness of this powder, later on it is very hard for me to develop, keep developing powders on a charged surface. Because I have a powder, powder once we melted because insulating and powder themselves have some charge. So, it will not allow charge to keep accumulating with the electrostatic spraying. So, I keep the substrate, I deposit certain thickness of powders. It is not limitless, the process is not limitless. I can achieve only very fine coatings which can be limited up to say around 150 to 200 microns and not more. That is the disadvantage of the process. But, it becomes advantage for this particular as a biocompatible coating. …we can achieve very fine adherent and uniform coating on a particular metallic substrate.

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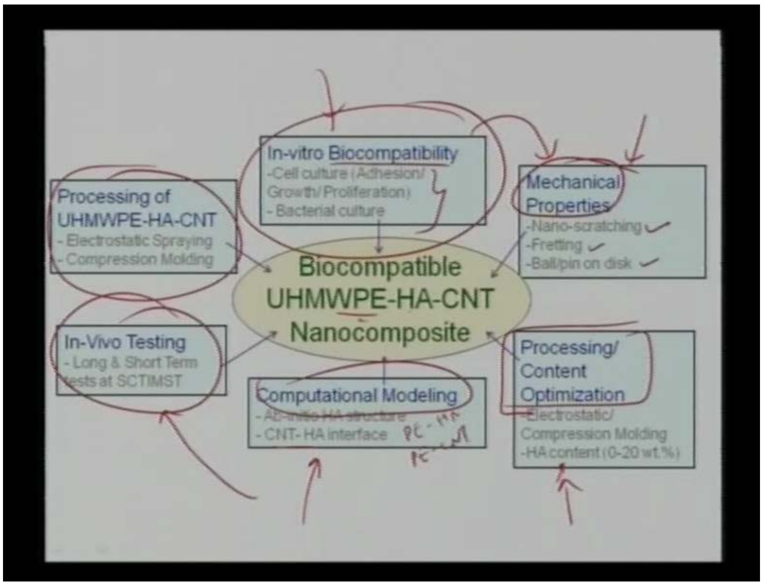

Seeing overall overall feel of… is , that in first step is the processing of this ultra molecular weight polyethylene; which is now reinforced with the hydroxyapatite and carbon nanotube. And then, once we synthesis this coatings, we need to have some sort of a biocompatible test; In-vitro biocompatibility. That can come from either cell culture or bacterial cultural studies. Once you have done that, we will we will know what are the potential materials and which, for which we can achieve, expect much more enhancement in the mechanical properties.

So, for that we can either do Nano-scratching, we can do fretting, we can also do ball or pin on disk. And, once we attain that, once we can see how we are getting enhancement of the mechanical properties, we can come to the optimization. We can come to the process optimization by electrostatic spraying in terms of hydroxyapatite contain in terms of any other reinforcement work we require.

And, some other components which might be essential is, what might be happening with the either CNT Hap interface or the polyethylene Hap interface or the polyethylene CNT interface. So, there can be certain components which can be answered via some computational modelling. At the same time, once we have conformed from in-vitro, from mechanical properties, from the optimization of the composition. We would also want to know what is happening in-vivo in terms of both long term and the short term test. So, that part also is, that part also might become very very critical in terms of evincing the overall biocompatibility of polyethylene, which is now reinforced with hydroxyapatite and carbon nanotube.

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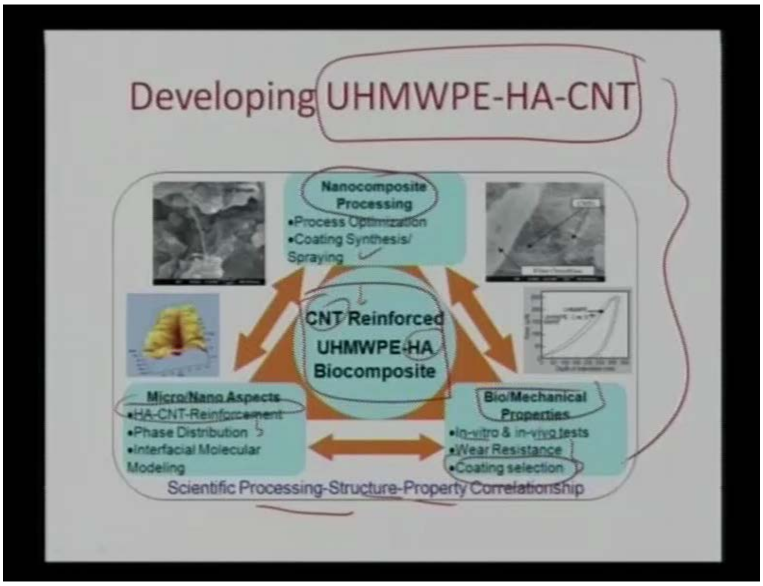

So, this particular case we can see overall pyramid of this CNT reinforced ultra high molecular weight polyethylene with hydroxyapatite. So, there are certain criterias to it. First thing is the nano composite processing. So, we have to optimize the process and then synthesize the particular coating or do the spraying part.

Then, second part is the mechanical properties. So, we we want to know what is happening in-vitro and in-vivo and also design; what is happening with to the wear or the tribology of this particular coating. And then, so we can collect, finally select the coating. And further, we can also want to, we would also want to know what is the overall effect of the composition in terms of how the reinforcement is being given by either hydroxyapatite or carbon nanotube; how those species are distributed so microstructurally; also we need to basically reinforce what we really want trying to look at; in terms of the distribution, how the phases are not being distributed… both hydroxyapatite as well as carbon nanotube in the polyethylene matrix. Then at the same time, what is happening between the interfaces of all those? it can be hydroxyapatite and carbon nanotube. It can be polyethylene, it can be polyethylene plus hydroxyapatite; it can be polyethylene plus carbon nanotube. So, there are certain areas we would want to look at the overall interfacial compatibility.

So, this comes overall pyramid of processing; how do we process it using electrostatic spraying and we able to optimize the composition or the first, the process, then the composition. And then, once they optimize the composition, we want to look at the mechanical properties. So, what is happening at the interfaces, how the phases are not being distributed and then coming on to the in-vitro and in-vivo testing; so that, we can choose them as a potential biomaterial. That is the overall strategy of developing ultra high molecular polyethylene, which is not reinforced with hydroxyapatite and carbon nanotube.

So, we can also see electrostatic spraying can allow us to do this particular type of processing and being able and we can, how we can select in terms of the process, how do we optimize the process in terms of its duration or the time, what is overall composition of hydroxyapatite will be utilizing in n polyethylene matrix.

What is the composition of CNT will be utilizing in reinforcing the polyethylene, Then what is the enhancement and mechanism properties we are attaining by this particular reinforcement, then how the things will behave at the at the interface and how it will eventually lead to the overall cytocompatibility both in-vitro as well as in-vivo to finally come up with the potential by material; which is now reinforced with both hydroxyapatite as well as carbon nanotube. This is the overall scientific processing structured property for co-relationship which becomes essential. So, that is the overall deal with the development of ultra high molecular weight polyethylene with hydroxyapatite and carbon nanotube.

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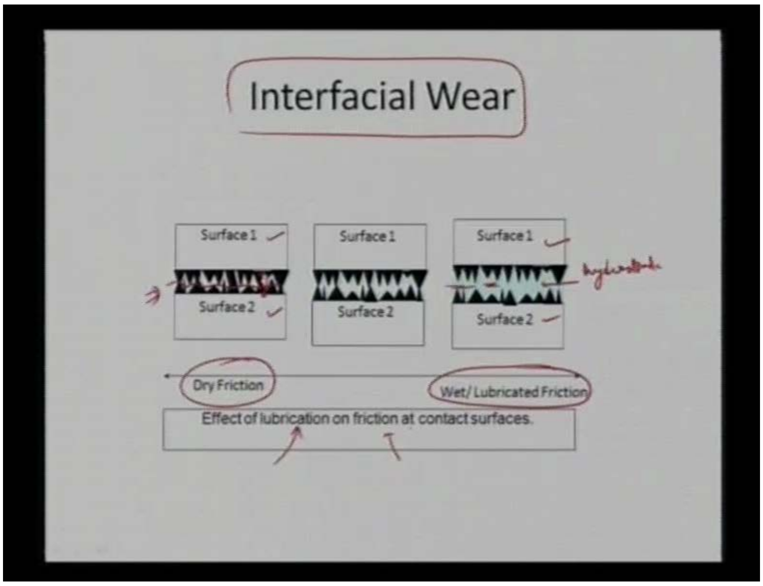

And most importantly, interfacial wear is also one of the very critical components. So, the first we have surface 1 and surface 2. How do they interact, how the how is overall roughness, how is the overall chemistry, how is the overall lubrication lubrication between the two surfaces will result, how my material will now be lost once I have two operating surfaces.

So, I can have a dry friction. Once, I do not have any particular fluid or secondly I can also wet or lubricated friction. So, in this particular case, I have some hydrostatic film which can form between the two surfaces. And, once I have some thin forming between those two, it is now only the film which can easily shear off. And, once it is now shearing off, I will achieve very low coefficient of friction; because of surfaces it will flow smoothly over one another. Whereas in case of dry friction, I do not have any sort of lubrication. That is how the porosity also comes into picture that once I have my surface very dry, it always well as some… and grooves because any surface is not flat, atomically flat.

So, that that is how it will lead to some sort of contact between the asperities. Once the asperities are in terms of… they have length of microns to nanometres. It will always lead to some sort of a friction between those two surfaces. And, once I have certain friction, it will interlock all those asperities and with the particular movement. It will start breaking of all those asperities.

So, eventually I would want to introduce some sort of a lubricant to avoid this friction. And so that, the surfaces can flow very smoothly over one another. In this particular essences now, when I can see I have much more easier shape. So, I can introduce some carbon nanotube or I can introduce some ceramic particles, so my wear basically goes down to a very large extent. So, once I have carbon nanotubes or hydroxyapatite, hydroxyapatite is much is a ceramic in nature.

So, the abrasion on, once I have a hydroxyapatite reinforcement it will always be, always much more superior to that of a polythene analog. Again, it also depends on the interfaces, if I have a very poor interface between hydroxyapatite and polyethylene, then hydroxyapatite can also come out and it can also start hitting away my polyethylene. So, I need to a very strong interface between polyethylene and hydroxyapatite.

CNT is on the other hand, they are much more graphitic and graphite is also used as a lubricant. So, depending on how the interfaces between CNT and hydroxyapatite and polyethylene, I can somehow control my wear or the tribological properties. So, at the same time I can also provide some sort of lubrication at the contact surfaces to decide the overall wear of a particular interface.

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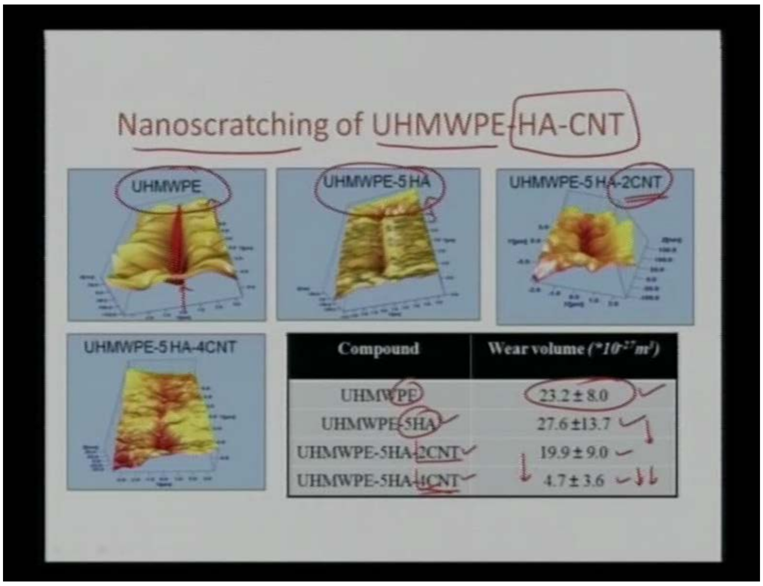

So, we can see how the composition itself can be much more influential in terms of dictating the overall wear between the 2 between the two compositions. In this case, we will see that we have done nano scratching of a Ultra Molecular Weight Polyethylene which is now reinforced with hydroxyapatite and carbon nanotube.

So, in this first first case, we only have polyethylene. Second case, we have reinforcement of some hydroxyapatite. So, what we can see here is that, I have a nanotube, then what I am seeing here is the wear volume; which is now calculated by the amount of or the volume of material being displaced by the inert depth both in polyethylene as well as in the… which is now being reinforced with the hydroxyapatite. We can see I have certain wear volume in polyethylene. But, once I am reinforcing some ceramic, I am getting much higher wear volume. That is my contradictory. Because once I am reinforcing my polyethylene with certain ceramic, I will expect the wear volume to go down.

But, what is happening here is that the interface between hydroxyapatite and polyethylene may not be that good. What is happening is hydroxyapatite probably loosening away and that again is acting as the scratching media for the polyethylene; that is the reason I am seeing much more or much higher wear volume once I am reinforcing with hydroxyapatite.

But, once I start introducing some carbon nanotube in terms like 2 weight percent and 4 weight percent, I am seeing much reduction in the wear volume. This is happening because carbon nanotube, they have very superior mechanical properties, also they also serves as a lubricant. They have exceptionally wear, superior wear properties, tribological properties, mechanical properties. At the same time, they have much more lubricating properties.

So, once I have introducing more carbon nanotubes out here, I am seeing overall deduction in the wear volume. It means I am achieving a superior wear resistance in the CNT reinforced hydroxyapatite, which is now again reinforced in the polyethylene matrix. So, once I am increasing the CNT content, I am seeing further decrease in the wear volume. It means I am achieving much more superior tribological properties, once I have CNT reinforced or … CNT reinforced, maintain the polyethylene and hydroxyapatite material.

That is that that is what we can see that once you have poor interface between hydroxyapatite and polyethylene. I am seeing much enhancement in the wear volume or my wear resistance is now dropping off. But, once I start a reinforcing with carbon nanotube I am seeing much more enhancement in the wear resistance. That is what is happening out here. So, I my wear volume is basically going down with increasing the CNT content. And, that is what happening is with the Nano-scratching out here in the particular phase.

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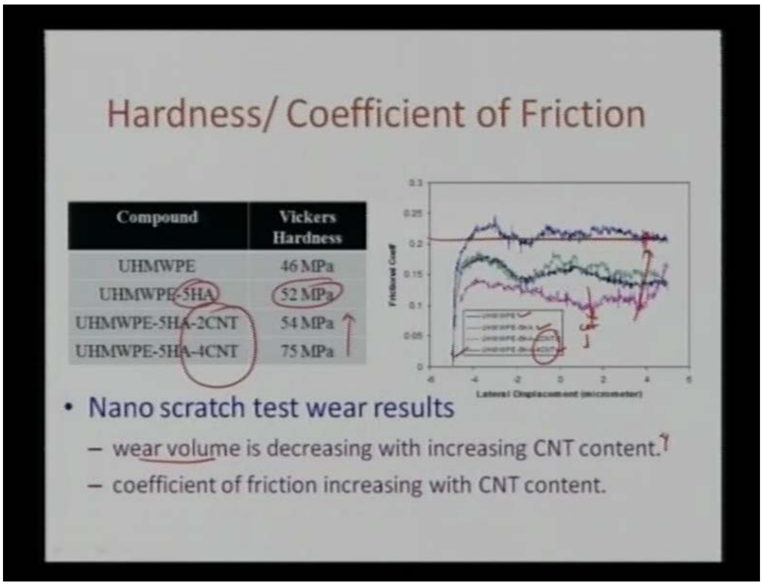

At the same time I can see with the increase increase in the hydroxyapatite, I am seeing increase in the Vickers hardness. That, what can be expected because hydroxyapatite is ceramic. Once I have adding some ceramic, obviously my hardness should go up. And further, increase in the carbon nanotube, I am seeing much little marginal increase in the hardness as well. So, we can see here is that the wear volume is decreasing with increasing CNT content. So, obviously my CNT is now improving the wear resistance. Once I am saying that CNT is a lubricant, I should expect that my coefficient of friction should go down.

But, we are seeing exactly opposite. In this particular case, we are seeing coefficient of friction is not going up with the CNT content. So, with CNT content, I am seeing my increase in the in the coefficient of friction. And first of all, I had polyethylene; it was showing me some coefficient of friction. Once I am adding hydroxyapatite, I am seeing decrease in the coefficient of friction. That is happening because at Nano level, once I am doing the Nano-scratching, there is very poor interface between hydroxyapatite polyethylene.

So, as soon as I am putting my nano tube, it is very easy for the for the nano tube to flow away the material on the side. So, there is very less of a lateral force in comparison to the normal force. So, that is the reason I am seeing much reduction in the coefficient of friction for the 5 percent hydroxyapatite. Whereas, in case of… once I am adding some carbon nanotube to it, what is happening here is, now CNT is introducing much more strength to the polyethylene matrix. They are very superior mechanical properties. So… finds very difficult to displace the material.

So, at Nano level things are very very different. And, it it finds harder to displace the materials. So, lateral force goes much higher. That is the reason we can see increase in the coefficient of friction, once we have more CNT content. So, it is in agreement with the observed wear resistance or the wear volume loss, which are observed in the observed in the Nano-scratch testing.

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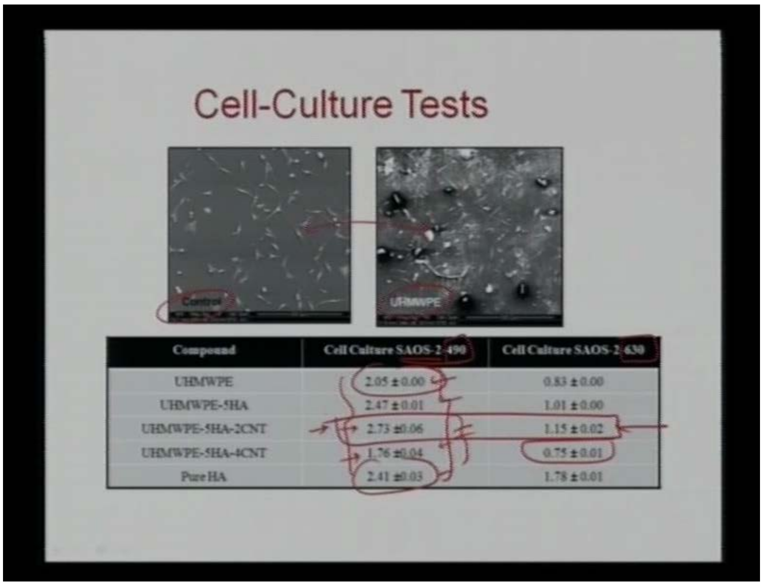

And finally, it everything boils down to the… how the cells or how the cytocompatibility of those particular material behaviour. So, if once to take a control and once we take a polyethylene, we can see the number of cells how they basically grow. In this case, we we have to SAOS to 2 to 490, SAOS to cell line, which is a mouse fibre osteoblast, mouse mouse fibroblast at a wavelength of 490 nanometre and at a 630 nanometre. And, we can see the the quantification rises that we are seeing approximately similar cytocompatibility.

So, I can see that the overall count of the cells is through the through a particular contribution technique. It is coming out to be U V spectrophotometer. We can see that the particular counts are approximately similar. They are not deteriorate deteriorating to a stronger extent. If I had a pure Hap or I had a polyethylene, I am seeing my CNT is approximately the same. Though I can see certain decrease in the cytocompatibility, but not to the very large extent.

But,… 2 weight percent CNT, they show me much more superior properties as compared to the 4 weight percent CNT. So, overall we can say that we can achieve some marginal improvement of the mechanical mechanical properties without deteriorating the cytocompatibility of this particular composite.

So, eventually we can say that electrostatic spraying can be utilized because it is particular process when which we utilize a blower to take the powder particles away, get them charged with the electrode. Once it is now charged with the electrode, it cannot disperse very uniformly on a on a particular substrate because of electrostatic repulsion between them. Once we have that particular entity, we can take it and we can cure it and curing can be done at temperature which is higher than the melting point. So, I can… so we can achieve little fluid fluid fluidity in the particular polymer material; so that, it can spread out and it can coat the particular substrate nicely. And, as we see that the surface was very adherent, it can cover the crevices very very uniformly.

It is adherent, it is not peeling off easily and also it has a uniform thickness. That gives the advantage of the electrostatic spraying. And, that was the from the processing part. And now coming to the material part, we can utilize polyethylene very easily out here and we can also incorporate some reinforcement which can be ceramic reinforcement of hydroxyapatite. Or, it can again be carbon nanotube to provide some strengthening to it.

We can utilize some ceramic reinforcement. It is aluminium oxide to incorporate much more wear resistance or the tribological resistance. And, as we see it also depends on the interfacial interaction, in the interfacial component of the matrix as well as the reinforcement. If the reinforcement itself is not compatible with the matrix, it might just go out and it cannot serve as the agent to again scratch of the polyethylene surface; because hydroxyapatite, it is it does not have a good interfacial bonding with the polyethylene, it can come out and create a three body wear.

But, once we also introduce some carbon nanotube into the material; carbon nanotube can also act as a strong reinforcement. And, it can provide much more strengthening, much more fracture toughness, much more superior hardness. It also have superior wear wear and tribological resistance.

So, that is the overall deal with it; also playing with the composition part and how you can utilize them in terms of electrostatic spraying and depositing them onto a body implant body implant surface. So, that that is what basically I summarize the lecture again that electrostatic spraying, we are utilizing electrostatic gun which can carry the powder, which can form a very nice coating on a particular body implant material. But, the substrate has to be much more conducting in nature. That is the overall limitation to it. At the same time, we can achieve very uniform coating. But, we cannot achieve very thick coatings using electrostatic spraying.

And in this particular case, we are limited only to the certain polymers which can be easily deposited and which can be easily cured to give a uniform coating. And, the coating size is also, thickness is also limited.

So, that is the drawback of this particular process. But, again it is advantageous to biocoatings or bio bioimplant coatings because those are very fine. And, that is what we really seek for achieving very good interfacial properties.

So, that is what it will assist assist us in terms of achieving. And, once we have a uniform very uniform and adherent coating, which is on the substrate very uniform, we can also expect the similar bio cytocompatible response from the surface; because surface is one which comes in direct contact with the blood or any any particular biological environment. That is the advantage of that.

And then, we can see that using, altering all this compositions we can attain the required tribological properties, required bio cytocompatible properties using the electrostatic spray. So, I will end my lecture here. Thanks a lot.