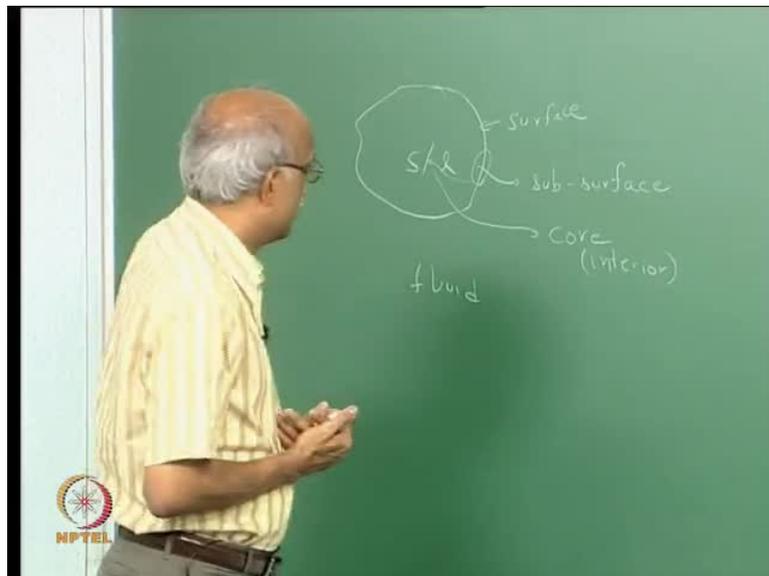


Particle Characterization
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Module No. # 04
Lecture No. # 13
Structural Characterization

Welcome to the thirteenth lecture in our NPTEL course on particle characterization. So far, in this, in this course, we have covered particle characterization in one very important aspect, that is morphological characterization. So, we have discussed shape and size characterization, in the, the previous lectures. Today, we are going to move on, to talk about structural characterization of particles and also, the interfacial characterization of particles. The reason that we need to take these two together, in a sense, is because, when you look at a particle as a whole, you can actually, divide its volume or its structure into three different regions.

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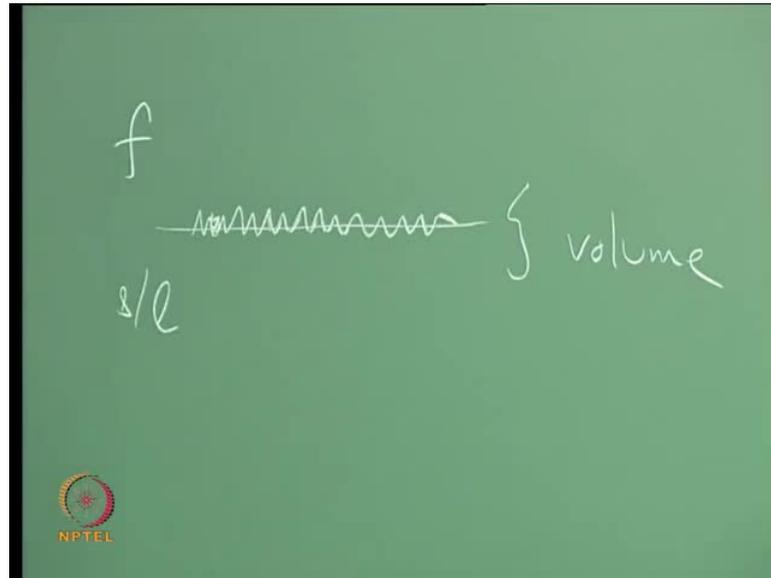
So, this is a particle that is suspended in a fluid, and let us say, this is, could be a solid particle or it could be a liquid droplet. The part of the surface, or part of the particle that is visible to us, is the exterior boundary. And, that is the interface between, essentially,

two bulk forms of matter; you have the solid or liquid particle that is sitting there and it is suspended in a fluid, either a gas or a liquid; and these two represent, essentially, two bulk systems that are adjacent to each other. And, the surface of a particle represents the interface, or the line of discontinuity between these two continuous phases. So, the outer most profile of the particle is, we, what we call the surface. The region just beneath the surface, so, this area, that is adjacent to the surface, but, just below the exterior surface is known as the sub-surface region. And, as you keep moving towards the center of the particle, you will eventually, reach its core or interior of the particle.

So, in terms of the structure of the particle, these are very distinct regions and we really need to appreciate the similarities and the differences between them. Now, go back to the surface. As I said, it represents essentially, the contact point between the discrete particle that represents one phase and the fluid, which it is suspended in, which, which represents the other phase. Now, clearly, there is a huge difference in properties of this particle phase and the surrounding fluid phase; density is different; everything is different; energy is different; surface tension is different; hardness is different; composition is different. So, there is a, a huge step difference, that happens at the interface between the particle and the fluid that it is suspended in. However, that assumes that, the surface itself is a two dimensional area.

Now, when you say surface, what you think of is, basically, two-dimensions, right. But, if you look at the external surface of a particle more closely, what you will find is that, it is really not a two-dimensional area, but actually, a three-dimensional volume. The reason for that is, the exterior surface of a particle typically, tends to be quite rough; unless it has gone through some special processing to, you know, improve its surface finish by orders of magnitude, you are going to see surface roughness asperities, that are of the order of microns, or at least in nanometers.

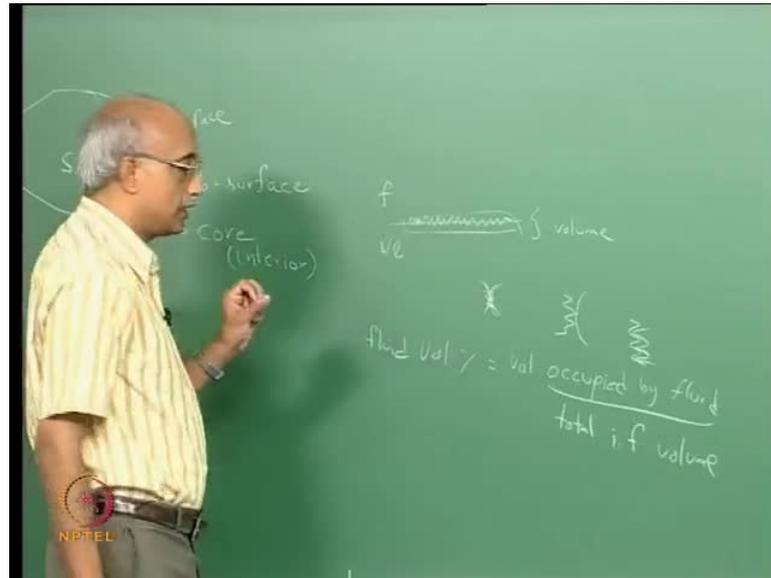
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So, the surface itself, it is not a clean line or plane of discontinuity between the fluid phase and the solid or liquid phase. Instead, you see a roughness profile on the surface of the particle. So, what that means is, this interface is now, actually a volume, because it has three dimensions to it. So, for example, if you have, let us say, a liquid, that is in contact with the particle, the way that it actually encounters and interfaces with the particle, is going to be different, depending on the actual location on the surface, where the contact or the interaction happens. So, for example, if the liquid contacts this point, it is actually, going to try and fill up this asperity, right; whereas, if it contacts it on a smoother area, it is going to spread itself differently.

So, even surface wetting by the fluid will be very different in its, in its nature, depending on, whether it is a smooth profile or a rough profile. So, the key point, one of the first key points to remember is that, even though we say particle surface, and imply that, it is a two-dimensional surface, in reality, the particle presents a three-dimensional interface to the fluid that is surrounding that particular particle. And similarly, when you have two particles that are close to each other, which are adhering to each other, the interaction between two solid particles will again, reflect the three dimensionality of the particles.

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So, depending on the relative roughness of the two particles, you may see, more or less interlocking. For example, if the roughness asperities align with each other, you can actually get an increased surface adhesion force. On the other hand, if you have a smooth particle, coming in contact with particles that is relatively rougher, the contact area can actually be, significantly reduced. And therefore, the inter particle adhesion forces will also be reduced. So, I mean, think of it, this way. If you have one particle that has a profile like this and relatively, the other particle has a profile like this; then, the contact areas are very isolated, right.

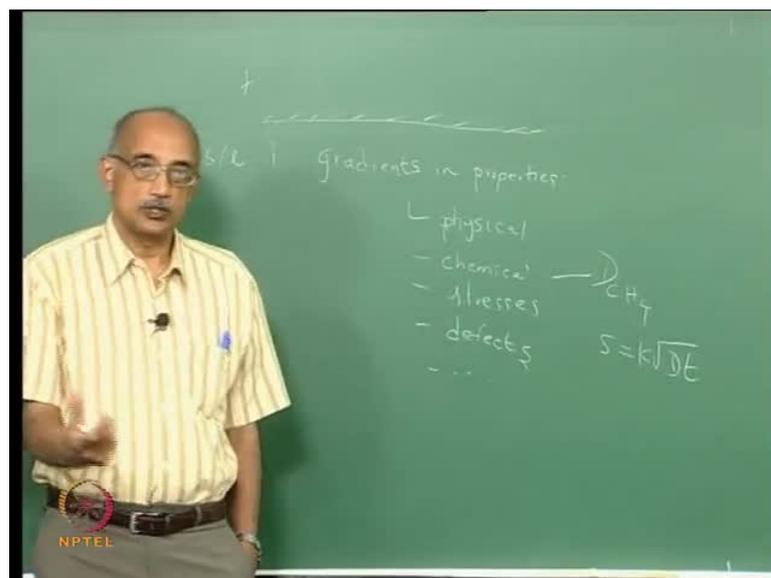
They are making contact only at these locations. So, since adhesion forces, essentially, depend on the area of contact between the surfaces, this will represent a case of very low adhesion force. On the other hand, if you have two rough surfaces, and they happen to align themselves, so that, you know, the roughness kind of fits in, which they will, I mean, surfaces have a natural tendency to accommodate each other. The adhesion force, in this case, may actually be, significantly higher, compared to the adhesion force on this side. So, that is why, it is important, to appreciate the three-dimensionality of the surface that you are considering. Now, if I look at the properties of the surface, they are going to be, actually, a mix of the property of the solid or liquid particle and of the contacting fluid, because, it is a, it is a volume fraction phenomena; you know, because, it is a volumetric interface, if I just take a slice of this surface and estimate the volume

percentage of the fluid on the surface, which would be, essentially, the volume that is occupied by fluid, to the total interfacial volume.

So, this is your fluid volume percentage. This parameter, actually, has a huge influence on the properties of the surface itself. The higher this volume percentage, the more the properties of the surface are going to reflect the properties of the fluid. I mean, in the extreme case, if the entire surface is inundated with the fluid, then, the particle surface will essentially behave just like the fluid, right. Or, in the other extreme case, if the particle is such that, it repels the fluid, that is where it suspended in, so that, the fluid is not able to wet the particle, the, the particle is not able to adsorb the fluid or absorb the fluid, then, this volume percentage is going to approach zero. In that case, the properties of the particle surface are going to be, essentially, the same as the particle material itself.

So, the inter, interfacial characteristics are very, very important in determining what properties, the particle surface is going to have, relative to the fluid that it is in contact with. But, it will be a sharp gradient, because, you are essentially, transitioning from a fluid to a solid or liquid phase. This subsurface region, on the other hand, provides a much more complex picture, because, here, what you will see is, the more gradual gradient of properties, compared to the surface of the particle.

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So, if this represents the surface, so, this is your solid or liquid particle; and then, this is your fluid, and let us represent this as a, a line of discontinuity between the particle and

its surroundings. What we call the subsurface, is basically, the region that is just below the surface, and extending some distance into the particle phase itself. Now, what we are going to see, between here and here, you will see gradients in properties. So, what are the properties in which you will see gradients? Physical properties, chemical properties, such as composition, stresses, defects, etcetera; I mean, virtually, any parametric that you use to characterize a surface, will show a gradient, as you penetrate further into the particle; and that, immaterial how fine the particle is, you will see this type of gradient behavior, even for a nano-particle.

Certainly, as the particle size increases, the gradients themselves will be extended over a longer distance; however, the magnitude of the gradient may still be, just as large in a nano-particle, compared to a micron-sized or a millimeter-sized particle. In terms of chemical properties, what do we mean by that? For example, composition. Why would the composition of the surface be different from the composition of the subsurface? Well, one obvious reason is, the surface is exposed to the fluid. So, for example, if it is in an oxidizing atmosphere, the surface may have an enrichment of oxide; whereas, depending on how many diffusion paths are provided, the oxidization may never be able to diffuse into the bulk of the particle and cause sub-surface oxidation. So, the sub-surface may still be, for example, metal; the surface may be a metal oxide.

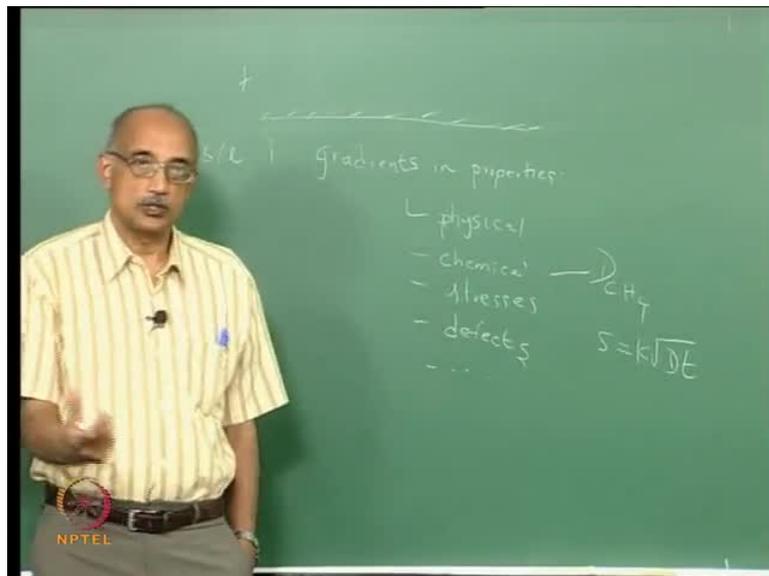
That is a simple example. Oxidation is a process that happens naturally, right. But, you can also think about manufacturing process, where we are deliberately introducing a reactive gas to achieve a certain purpose. For example, when you have steels that have low carbon content, and you want to increase the carbon content, there is a process called carbonization that is used, which essentially takes carbon molecules and lets them diffuse into the steel surface, in order to enrich the, the carbon in the steel alloy. Now, that is an example of, again, a chemical or compositional gradient, which will then exist from the surface to the sub-surface. And, the reason for that is that, the, the process by which you are introducing the carbon into the metal, into the alloy, is through a diffusion process.

So, typically, you would take a carbon containing species and let it diffuse into the metal. For example, it could be something as simple as carbon dioxide; or, it to be some organic carbon, like methane and so on. So, what would happen is, this species will diffuse with some diffusivity. So, let us say that, you are using methane to achieve this carbonization. The CH_4 will essentially, first, encounter the surface of the alloy, and it will leave

behind carbon, and therefore, increase the carbon content. But then, by controlling the amount of diffusion of this carbon containing species into the matrix of the material, we can control the depth to which this carbonization happens; because, the distance that this species will travel within a certain time, can actually be calculated. And, in fact, the diffusion distance S is roughly given by a constant, multiplied by square root of D times t , where D is the diffusivity of the species and t is the time over which the diffusion is occurring.

So, simply by controlling this parameter, the time parameter, you can control the depth, to which diffusion happens, and thereby, you can control the depth to which, for example, in this case, carbonization happens. Another example would be nitridation. Again, you want to add nitrogen to a, to an alloy material. This is typically done, by pumping nitrogen gas over the alloy under pressurized conditions, in order to improve diffusion, diffusion rates and diffusion coefficients.

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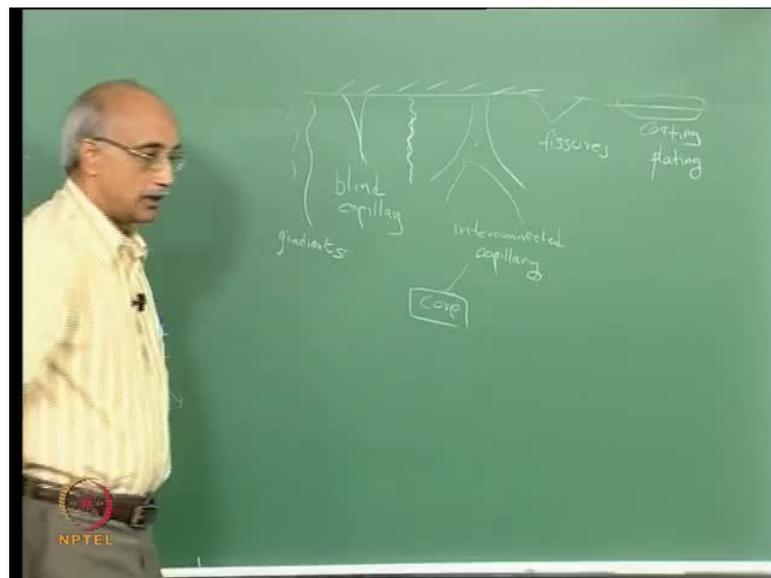
And, you will again see this type of behavior. It is basically, a square root dependence; you take the diffusivity of the species, multiply it by the time and take the, the square root; that basically, gives you the time dependence of the depth of the penetration by this, by this reactive gas. So, essentially, you can not only introduce a chemical gradient, you can actually control it, when you are doing it, essentially, as part of a manufacturing process. So, an example of this would be, let us say, you have aluminum metal and you

expose it to a, an oxidizing atmosphere; you are going to form, you know, brown layer, right.

The aluminum will turn brown; it is basically, aluminum oxide, which has formed on the surface. However, the aluminum core itself, still remains as aluminum, with just a surface layer of aluminum oxide; but, if you now let the penetration continue, let us say that, you have a very porous aluminum particle, and this oxygen can diffuse into the interior of the particle; then, the composition of the entire particle will slowly change, and, and the particle itself will eventually, be converted from an aluminum particle to an aluminum oxide particle, through the surface and the subsurface regions.

Now, will the core of the particle also be converted? That is very unlikely to happen. When you are using, in other words, you cannot convert metal, aluminum metal to ceramic alumina, simply by exposing it to oxygen; that is basically, what it means. However, you can change its external surface to aluminum oxide, and you can change as much of the subsurface as you want, to aluminum oxide, by providing a diffusion path, and by controlling the concentration of the diffusing material, the pressure that you are applying, the temperature at which you are applying, and most importantly, the time for which you are exposing that material to the diffusing species.

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Now, if you look at the sub-surface in more detail, under a microscope, you will see some interesting things. So, again, if this is your surface, and then, this is your sub-

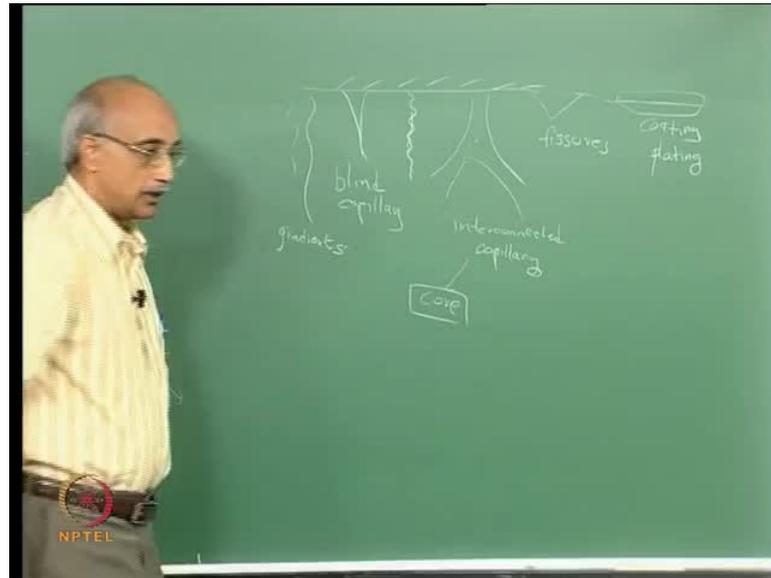
surface layer, one thing you will always see is, voids or porosities in the surface, which allow material to seep into the subsurface. It is very rare, that you find a surface that is so integral, that is so perfect, that nothing can diffuse beneath; I mean, diffusion can happen, even through molecular dimensions. So, as long as you have a 10 angstrom opening, vapors will get through.

So, it is virtually impossible, to entirely prevent diffusion of vapors through the surface into the sub-surface region. The way that, in particular, liquids get through, is slightly different. Vapors, as I said, can penetrate, no matter what you do, unless you have a single crystal, which has absolutely no openings of any kind. But, most materials are not like that. They are, they are either metals or alloys or composite materials, where there is sufficient openings, basically, in the, in the, in the way the material is put together, to allow for diffusion of species. But, liquids will not be able to penetrate into a, a solid surface, or another liquid surface that easily. In particular, when you have a liquid that is interacting with the solid surface, in order for this, the liquid to wet beneath the surface, you need some capillary action.

So, there are two types of capillaries that exist; one is the blind capillary, and the other type is the open or interconnected capillary. So, here, the material or the particle (()) the the liquid in, through a capillary action, that is driven by surface tension and viscosity based processes. The capillary itself, can end at a dead end somewhere, and that is called a blind capillary. So, depending on the length of the capillary, that tells you how far into the particle the liquid can penetrate; or the particle could be, could consist of several interconnected capillaries. Now, when this happens, the propagation of the liquid through the particle will be much more extensive and it can get transported, not only at its local area of entry, but throughout the surface.

And, there is a possibility that, it, this can actually extend all the way to the core of the particle. So, depending on what you are trying to achieve, you can, either try, and minimize these capillaries, or try and maximize the capillaries, depending on how extensive an interaction you are looking for, between the surrounding fluid and the particle that is suspended in this fluid. Now, the other kind of thing that you will see in the subsurface, are the, the grain boundaries and the phase boundaries. So, if you have a multi-grain structure, you may see a line of separation between the grains.

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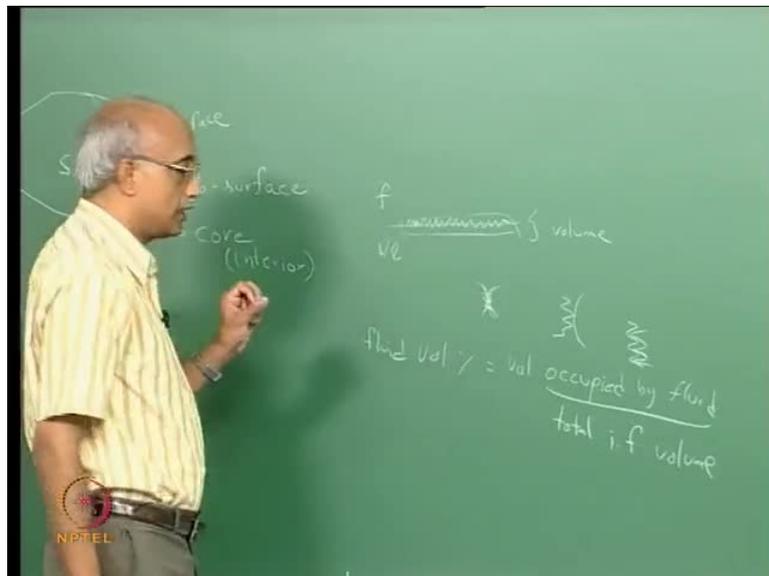
So, as you increase your magnification, or you start using an atomic force microscope, you can actually, start seeing, where these grains are laid down. So, essentially, you can start seeing the, the way that the material has been packed into its form, right. And again, that the, the boundaries can be between different grains, for example, in a crystalline material. It can be between different phases in a, for example, in an alloy, or a mixture compound; and they represent again, lines of discontinuity between one distinct entity and another distinct entity, in the, in the matrix of the particle. The other thing that you will normally see is, what are known as fissures. A fissure is essentially, where the surface has broken off. So, it is like a chip in the surface.

Now, it is a type of surface defect, unless the fissure is caused intentionally. But, for the most part, a fissure is not something that you put in, as a design. It is something that happens, because of damage over time. The fissure, again, can be of various types, but usually, they are closed structures, and usually, they would not penetrate very far into the material. So, they are confined to, probably, a few nanometers at the, at the most, a few microns, of the surface region. And, the other feature that you would see is, if there is a coating on top of the material, let us say that, this is your surface, and then, you put down a coating on top of it. This coating or plating, can actually penetrate into the sub-surface also. It is very difficult to do any kind of surface treatment; whether it is painting, or coating, or plating or passivation, anodization, all of these are supposed to be surface processes.

But in reality, again, it is almost impossible to control them in such a way that, they only act on the surface; there is some penetration always, to the subsurface region. So, a coating is supposed to just go on top of the surface; but, what we typically find is that, there is a, a fragment of it, that is beneath the surface, in the sub-surface region. So, if you are, if you do a metallographic analysis of the material, of the particle, you do a cross section, and actually look at the particle and its structure, by depth, as you go from the outer surface to the center, or the nucleus of the particle, you will see all these things.

You know, on the surface, you will see, essentially, the surface characteristics; and, if you have a very sensitive way of detecting, you will see the three dimensional morphology of the surface. But, the amount of detail that you see, will increase, when you go to the sub-surface region, because of the presence of all these different things that can happen. And, at the same time, you are, you are seeing all these gradients, right. So, if you are using a s e m e d x type of analyzer, you can actually see a, a gradient in the composition of the material. If you are doing a, a measurement of, for example, if you are using an X R D for your characterization, you will, you will see a gradient in the crystalline structure of the material.

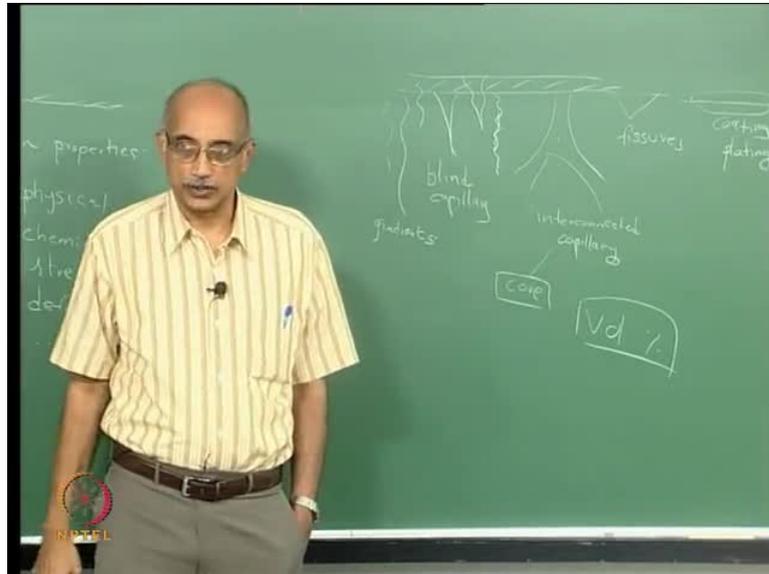
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The other thing that you will find is that, just like in this case, where the, the, the volume percentage plays a huge role in determining the properties of the surface, similarly, the

properties of the sub-surface are also affected by the volume percentage of the fluid, that has penetrated into the sub-surface region.

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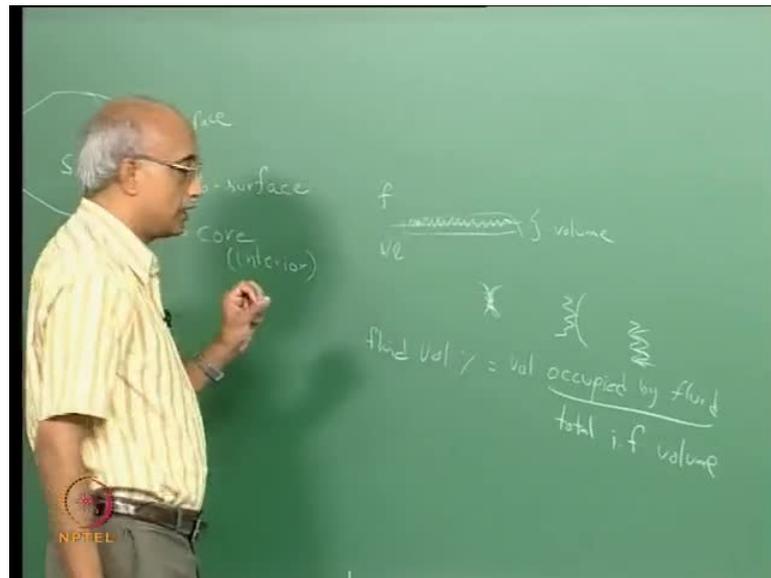


So, this volume percentage remains a key metric. The difference is, in the case of the surface, the volume of fluid penetration is basically, dictated by its ability to fill the three-dimensional structure, which represents a surface; whereas, the volume percentage of fluid in the sub-surface region, depends on the nature of the sub-surface. For example, how many capillaries exist; essentially, how many paths exist, by which fluids can enter using surface tension as the primary mechanism; how many fissures exist; you know, obviously, if there is more broken chips or fragments of the surface, which, which allow a physical opening, it is easier for the material to penetrate through to the sub-surface. So, the volume percentage is still the critical parameter, in deciding how the properties of the subsurface vary, from the properties of the surface; and, how that varies from the properties of the fluid, that is surrounding it. Another important consideration is, when you take a surface, and you put down something on top of it, like a plating, or a coating, the surface itself now becomes part of the sub-surface.

So, that is something that, it is important to appreciate that, our definition of the surface must be consistent; this, regardless of its composition. So, if we have, for example, a steel table, that has nickel plating on it, then, the surface is not steel; it is nickel; because, that is the surface that is exposed to the surrounding fluid. So, we have to be very clear in

our definition that, what, what we call the surface, is not based upon the material that it is made of, but rather, the physical surface, that comes in contact with the environment. So, as you build up a coating on top of it, this becomes part of the sub-surface and the properties will now start showing a variation, right, from this point onwards. So, the gradient, the reference point for the gradient also shifts, to the exterior surface of the coating, or plating, or whatever you are doing.

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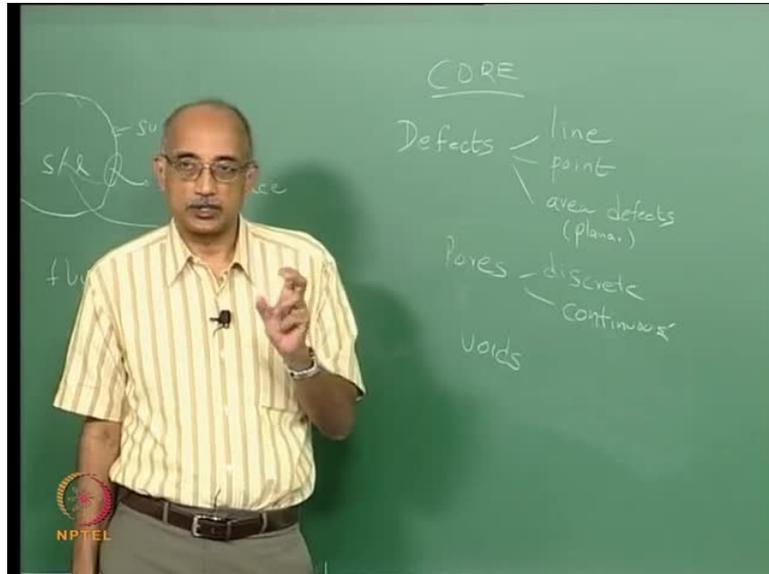


So, the, the surface and sub-surface are actually, very similar in character, except that, there is a gradient of properties between them. However, the third component of the particle, which is the core, or the nucleus, or the interior of the particle, is distinctly different in its properties, compared to, either the surface or the sub-surface. The core is actually, the purest representation of the material itself, because, the external processes can change the properties of the surface and the subsurface.

But, except under exceptional circumstances, they are not going to be able to change the core of the material, which will remain intact, even through extremely intensive processing. So, that applies, once again, to physical properties, chemical properties, stresses and defects and so on. The core will retain the properties of the original material that this particle is made out of. Now, in particular, we try to characterize the core by its defects; because, again, it represents the purest form of the material, we are interested in the defect level, that is present in this material, because, that has a huge influence on, for

example, the functional properties of the particle itself. So, we are interested in defects, which can be of various types.

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So, if you look at the core of a particle, and you look at defect types, there are really three of them; line defects, point defects and area defects or planar defects. So, a point defect is basically, as the name suggests, the defect that occurs locally, at a single isolated location on the material, or the core. A line defect is one, that is essentially, has a linear dimension to it and an area defect or planar defect or surface defect is one, that has an area associated with it. So, it is basically, a two-dimensional defect in the core of the material. Now, most materials will exhibit one or more of these defects. It is again, virtually impossible, to find a defect free material.

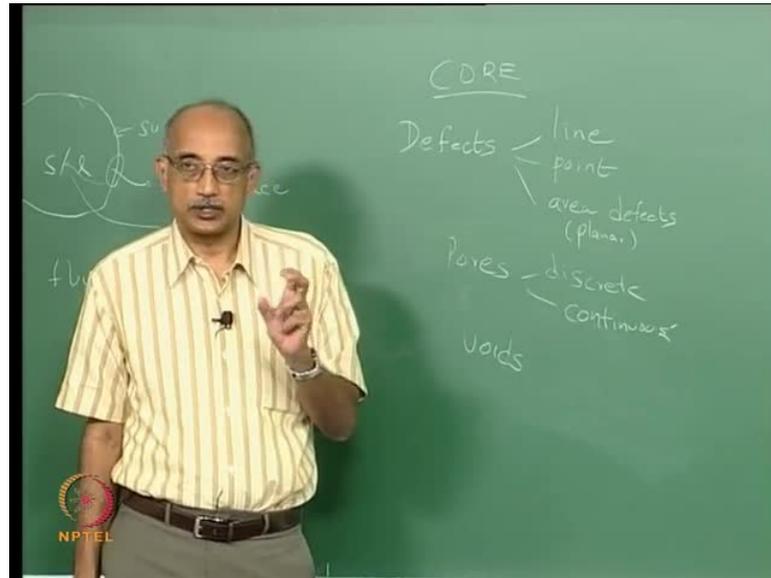
Now, what type of defects are we talking about? The defect could be, anything from an external impurity, for example, even if you are talking about a pure metal, that has just been excavated from a mine, the process of the excavation may have transferred some material or an impurity to this particle, which has become embedded in the core of the material. So, that type of the defect is basically, an impurity defect. Or, it could be a defect, that is more fundamental to the material itself. For example, the material may be supposed to have a certain crystal structure; but during its formation, the crystal structure itself, might have been altered; there might have been some, some slips, some stress formations, that led to a collapsing of the crystalline structure.

So, the defect maybe, essentially, a imperfection in the crystal, character of, of the material. So, there can be different types of these defects, that are visible, only when you actually penetrate all the way, down to the core or nucleus of the particle. You will not be able to get this type of information, simply by looking at the surface or the sub-surface, because, they are being influenced by too many parameters, that play a role in determining their properties.

Another type of defect that is frequently found in the core, is this pores. Now, porosity is a huge problem in the, in the manufacturing industry; particularly, when you are doing castings. You are trying to cast the material in its purest form. If during the casting process, you actually trap a gas, for example, inside the material, it eventually shows up as a porosity in the material. Now, porosity has some strong implications for the usability of the material in the process afterwards, because, the more porous the material is, the weaker it is. So, it actually, has an effect on the mechanical strength of the material. But, a more porous material is also susceptible, more susceptible to its exterior environment; because, virtually, anything can penetrate through these pores.

So, the, the, the characterization and control of porosities, is very important and here, we have basically, two kinds, the discrete pores and continuous pores. Again, the difference is, in the, in the degree of the problem. If you have discrete pores, the situation is, to some extent, under control, because, the effect of the pore is localized to the area where it is found. However, when you have continuous pores, it is just like the, the interconnected capillaries that we saw earlier; it essentially, provides a path throughout the entire particle, for any of the harmful effects associated with the porosity, to propagate. So, as far as possible, you try to obtain a material, that is, that has zero porosity, which is very difficult to achieve. Or, your fall back option is, to discretise the porosity, so that, they are not continuous in nature.

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Now, lot of attention has actually been paid to manufacturing processes, particularly, casting processes, to obtain pore free structures. For example, vacuum casting is one, where, by applying vacuum, you evacuate all gases from the immediate vicinity of the, of the material, as you are casting it, so that, the chances of actually leaving the gas behind as an impurity, during the casting process, is greatly reduced. So, you know, much progress has been made in reducing these, these pores. Now, another type of defect is voids. Now, a void happens, kind of, for the reverse reason, that a pore, porosity happens. Porosity happens because, you have some trapped gas, which is not completely vented, when you do the casting process. So, it prevents complete closure of the, of the material.

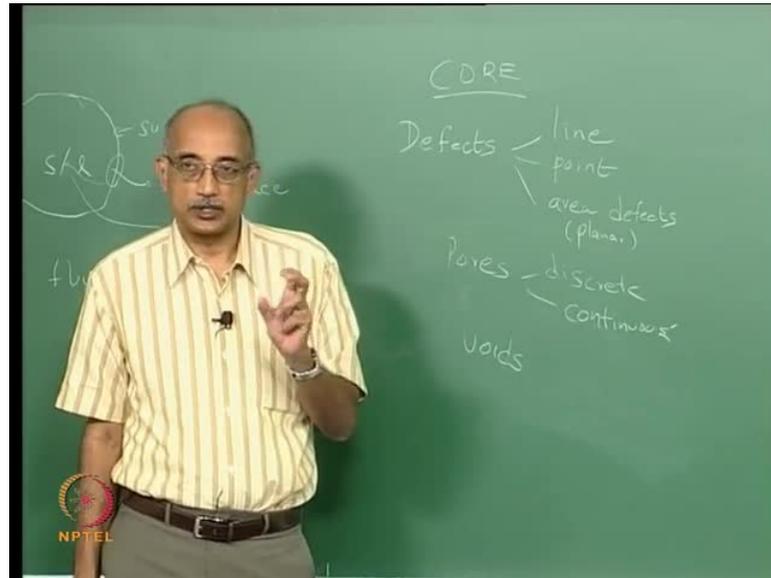
A void, on the other hand, is something that happens, when a material that is supposed to be present in the particle, or the surface that you are casting, is unintentionally removed during the process, thereby, leaving a cavity or a gap; and that is basically, what we mean by a void. So, the presence of voids, once again, is most sensitively detected, when you section all the way down to the core of the material. It is not immediately obvious, when you are looking at, either the surface or the subsurface of a particle. So, essentially, we have, we have discussed the three regions, somewhat in sequence. First, we talked about the surface, what are some typical characteristics of the surface, and what affects these characteristics. Then, we talked about the subsurface and then, we talked about the core of the particle. Now, in terms of particle characterization, which of these should you

be concerned about? For example, if you are a process engineer, and you are using the particle, let us say, as a catalyst, right, to run a chemical reaction; now, the aspect of the particle, or the critical feature of the structure that you care about the most would be, the surface and the sub-surface regions.

Now, the subsurface region is important in that case, because, the reactants need to diffuse into the sub-surface and that depends on the nature of the subsurface region. But more importantly, the products that are formed, have to diffuse back out. So, there has to be a sufficient pathway provided, to ensure, that both diffusion of reactants in and diffusion of products out, happens. So, as someone working in the catalysis industry, where you do not really care so much about purity of the core material... What you really care about is, surface area available to me, per unit volume of the product, right. And, I want to try and do, is increase that surface area, as much as possible. So, I want a porous structure. I want the reactants and the products to be able to diffuse easily down to the subsurface region and then, back out. So, I am not interested, in hermetically sealing the surface, so that, everything only happens on the surface.

What I really care about, again, is the total catalytic area, which promotes chemical reactions between the various reactants and to produce product. Now, let us take another application, such as use of particles in, say in the pharma industry, where you are taking some kind of a powder, let us say and you are compacting it to form a tablet, right, which is then packed in a bottle and sent to the patient for consumption. Now, here, what you really care about, from a structural viewpoint? How important, in this case, is the core, or the nucleus of the particle?

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Well, obviously, it is very important, because, you know, it is a medical application; the active ingredients are typically, packed into the interior of the particle, or the core of the particle, right. And then, the material is provided various coatings, in order to keep it intact during shipment and storage and so on. So, in the case of pharma, the importance is, almost in reverse; the most important part of the tablet is its core, that contains the medicinal ingredients. And then, the subsurface, is a surface important in a tablet? You know, you can take a tablet, even when it looks like, you know, it is, it is in bad shape, right.

You have been leaving it in a bottle, in a, in a humid environment, for a long period of time. The outside of this tablet or capsule, can actually, look very bad, because of all the degradation due to the exterior environment; but, if you take it, it will still work, right, as long as the, a expiration date is, is, is not been passed. So, clearly, the, the exterior of a tablet, is more cosmetic in its effect and not functional. The functionality of a, of a pharma particle, comes primarily from its core. So, if I am trying to do structural characterization, I would put a lot more emphasis on making sure that, the core ingredients are consistent from a lot to lot and not care so much, about what happens to it, if it is exposed to high temperature and high, and, and high humidity and so on.

Yes, the customer would like to see a tablet be intact and, and in good, good shape, for a long period of time; but, as long as it works, they are going to be happy, right. Another

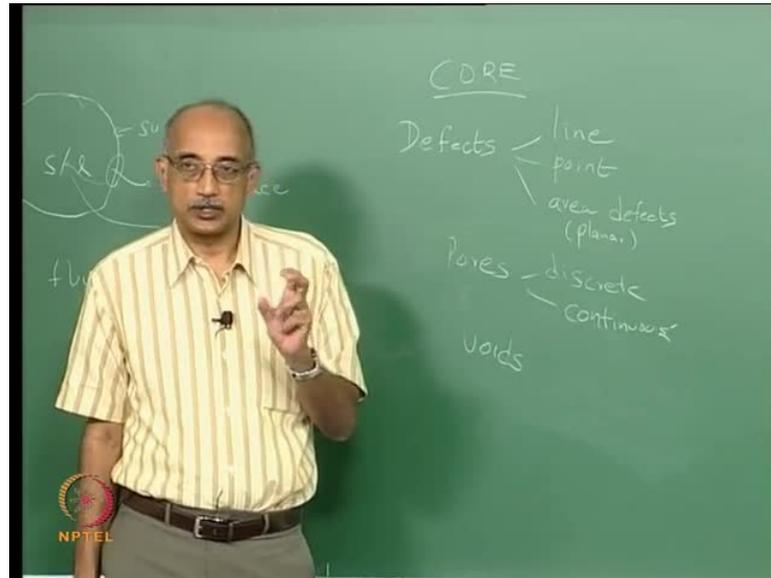
application that we can think of is, you know, things like, let us take detergent powder, right. Now, in the case of detergent powders, which are typically formulated in a spray dryer from a detergent liquid; if I am trying to characterize the detergent powder, what structural parameters should I be concerned about the most?

Detergency comes from the ability of that chemical, to essentially, wet the surface of the object being washed and essentially, provide a mechanism to lift the particles off the surface. We will talk about this in more detail, later on. So, what is the most important characteristic of a detergent powder? It should be able to dissolve well, you know, because if it is coming as a dry powder, and you put into water, it should be able to dissolve well, and immediately; and the, this, the active ingredients, the surfactants that are in the formulation, must be able to quickly penetrate into the surface between the dirt particles and the surface that they are sitting on, in order to provide maximum detergency.

So, in this particular case, how important are the surface characteristics? They are pretty important, because, the whole...In order for it to work, you have to have almost a, a complete and instantaneous release of the active ingredient, once the detergent is mixed in, for example, with clothes or dishes, that it is supposed to wash; but, it should be very, very stable until that point. So, the way that the detergent package is put together, the size distribution, for example, is very important; but structurally, what we would like to see, is a uniformity of its, a physical structure and its compositional structure, throughout its cross section.

We do not want to see a, a huge gradient in the properties of a detergent powder, going from its surface to subsurface, to its core. We want the detergent particle, every detergent particle to be identical to every other, so that, every time the customer takes its scoop of the detergent powder, and, and puts it in, and they get virtually, the same washing result, right. So, consistency and effectiveness are the, are the most important things. So, a structural analysis, the way I would probably do the inspection is, to look at the particle under some kind of an optical microscope, to ensure that surface characteristics remain the same.

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For example, you, you want to see, if, if it is a, if the spray dryer is normally producing spherically shaped powder material, you do not want to see that, change over time. So, the physical structure of the material should remain constant; and in terms of any compositional analysis I would do, I would do, certainly, some type of f d i r analysis, to make sure, that the active surfactant is present in all of this detergent particles, to the same extent; that is, uniformly distributed.

So, you know, different considerations, depending on different applications that, that we use these particles in. Another example would be, in micro electronics, we use abrasive particles to do polishing of surfaces. In this case, the most important structural aspect is the crystallinity of the material; because, what you need to do, in order to have good polishing, is to have a highly abrasive surface in contact with another surface. So, abrasiveness and hardness are very, very important parameters, or physical properties of these abrasive particles, that are being used.

And, you achieve that, primarily, by controlling the structure of the particle. As long as you can maintain its crystallinity, it is likely to be able to perform its function. But, for example, let us say, you are using silicon carbide as the abrasive material, you expect a certain structure of the silicon carbide; you, you expect to see a certain crystallinity; you expect to see a certain shape; it is all in the exterior of the particle, because, abrasion again, is a surface process; the core of the particle, never gets involved, right. So, what

you want to control, what you want to characterize in that case, is the surface region and possibly, to some extent, the sub-surface region. You would not even care to go into the interior of the particle, and analyze it, as long as your purpose, is only to be able to control the polishing process effectively.

So, just like with shape analysis and size analysis, structure is something that you can define and measure, to whatever extent you like. You know, you can make it as detailed an analysis, or as simple an analysis, as you want; the key thing is, to relate it to what you are trying to achieve. Now, there are certain techniques that are used for structure characterizations, such as X R D, A F M, which are very, very powerful techniques and we will discuss these in more detail, in one of the later lectures. But, the question you have to ask yourself is, do I need it? Is that really going to give me useful information, or am I better off, simply doing, say, an optical inspection of the particle to verify that, the outer surface is in control; or, maybe, I should do something like a, a porosity test, to make sure that, the, the porosity of the material has not changed; its compactability, which is more a function of the, particularly, the subsurface. Flowability is another parameter, that you may be interested in. In that case, again, what you most care about is the outer surface and the subsurface regions.

So, mentally, you should go through a list of what are the important functional features of the particles in your process and customize your structure, characterization techniques, to these functional properties that you are trying to achieve. Do not overdo it and do not under do it. Alright, now, in terms of the interaction of the particle with its environment, obviously, the surface is where it all starts, and so, when we talk about interfacial characterization, or the, determining the ability of the particle to interact and react with its environment, our analysis is typically confined, once again, to the surface and the sub-surface region. So, in the next lecture, we will start by discussing, how the surface characteristics of a particle, dictates the nature of its interaction with the surrounding system. Let us stop at this point. Any questions? See you at the next lecture, then.