Technology of Surface Coating
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Lecture-01
Introduction

Surface coating, in the introduction this basic question can be raised, what is meant by surface coating and for what this is going to be used?

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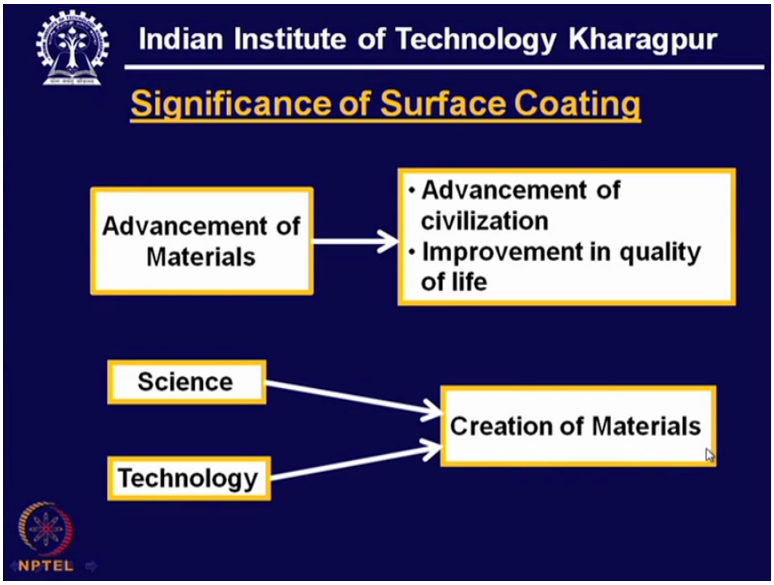

Now this is one illustration from which we like to understand the very significance of surface coating. If we can see the role of material on the overall advancement of civilization and improvement in quality of life, if we look around us the various gadgetries, equipments, implements whether it is household or industrial, it is actually the contribution of the engineering materials that actually risk the quality of life or improvement in the quality of life.

Now there has been always a great demand for these materials with better property and this is actually known as the high performance materials. So engineers always look for this high performance material to create a new equipment or a new product which can bring even a better quality of life. Now what we can see here, it is actually the creation of the material which is going to be used in any discipline of engineering.

Now behind this creation we find there is always a backbone of scientific understanding and a strong base of science. But at the same time, it is the technology which carries forward the process leading to this creation of the material. So we can say it is both science and technology going together leading to this creation of the materials.

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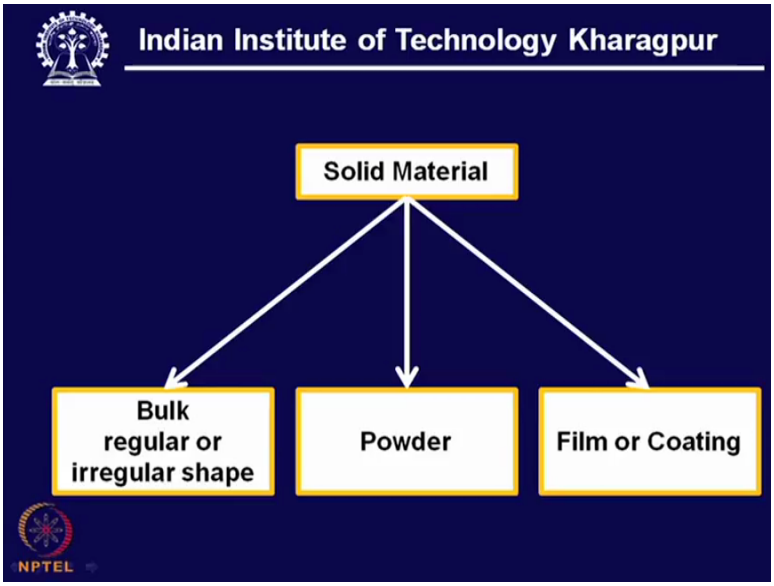

We go now to the this slide. If we concentrate on the material which is solid in nature, then we can find a solid material which may find some engineering use. It can be either bulk, it can be regular or having irregular shape. It can be even available in the form of powder. Both can be used for making some product of utility or it can be available in the form of a foil or a coating or a film so all these things can be used for any engineering application.

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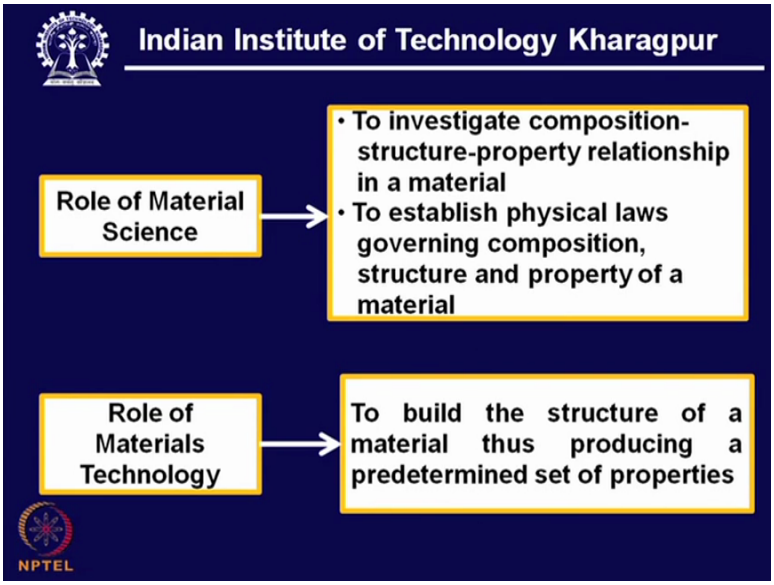

Now here we try to understand the role of material science. That means the science behind the material and also the technology behind the material. If we look, have our focused attention, what this science is going to do, it is actually with this knowledge of science and foundation, one can try to investigate that very important relationship between amongst this composition of the material, then the structure which is build up and ultimately the property. So it is composition-structure-property relationship in a material.

And with this understanding through this process of investigation, the scientist, what I mean the material scientist try to establish the physical laws governing this composition of the material, its structure and ultimately the property of the material. Now where is the role of materials technology? The technology means it is actually the process of building this structure of material and this structure will thus produce a predetermined set of properties.

So here we find the physical laws governing this structure-property relationship and here we find the ways or means, how to create that structure so that we automatically get that predetermined properties. So role of material science and the scientist and that of that technologist, their responsibilities are clearly divided. Of course, there is some overlap, one has to understand other's domain of activities and thus we can get one of the best creation in terms of engineering material.

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What is interesting to know, we can make this statement that materials make things happen and engineering product obviously require materials. It is the engineer which can make the thing and a thing means a product. It can be equipment, machinery, device, implements and in that process we can find the very role of a solid material. Say for example, what we find here, a material which is to be used in making some component. It is supposed to support some load which is applied on it which it is subjected to, and if it is sliding in nature, it has also to combat wear.

Here we mean that this material is mechanically functional. So we have a load which it has to bear and at the same time if it has a relative motion against the guide, then it has to also retard the growth of wear. Similarly in the area of thermal application, we have to have some material which either can insulate heat or it can quickly conduct this heat. And we find numerous example of such application where the material of which this particular object is made of, either it is serving as heat insulator or heat conductor.

Similarly, the application can be extended in the area of electrical engineering, the material is supposed to insulate or conduct electricity. Similarly, we can also have the material which either can accept the magnetic flux or it may refuse the magnetic flux. But all those materials of, the material with engineer, with its creative mind utilizes to make final product of utility. It can be even in the field of optics, it can be just to transmit the light or to have full reflection as it is the case with reflector. When it is lens, we have to transmit the light.

In the field of chemical engineering, we find the application of material. The material or the component has to survive one of the very hostile environment. Say for example, corrosion resistance at a very elevated temperature. So these are the some of the properties which often the engineer needs to build up some of the product of utility. And last but not the least, the question of economy cannot be just ignored, that it should not be too expensive either.

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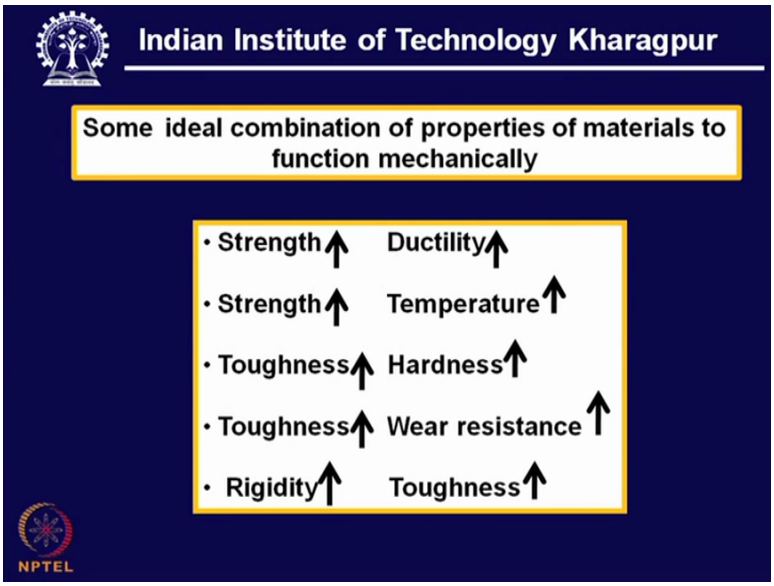

Now we go to some ideal combination of properties of materials which may function mechanically. Say for example, we like to have both high strength and high ductility. Or, say we may have another property, say the strength at elevated temperature. The third desire could be the high toughness with high hardness. It can be even high toughness with augmentation of wear resistance. We can also look for a material where which can provide high toughness and high rigidity. So these are few examples of requirement on the material which is going to be used in some mechanical component and that component has to work efficiently by possessing this combination which are shown here.

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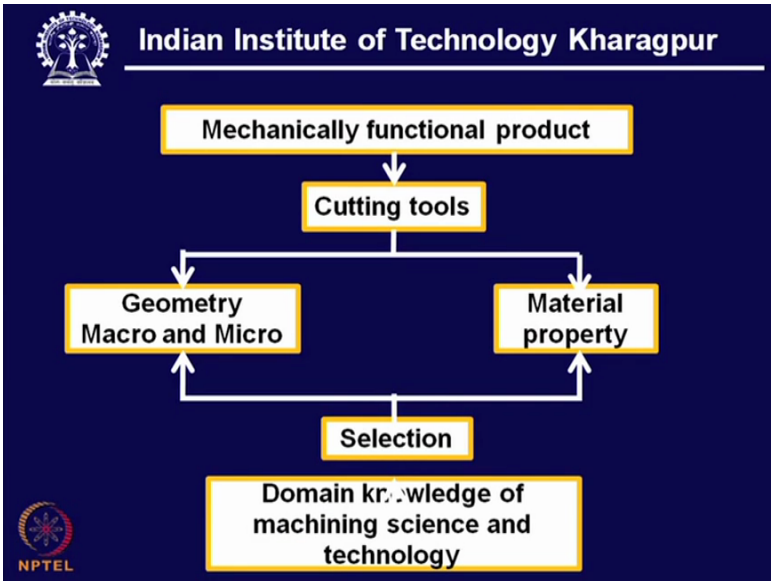

Now we come to very specific application of a product which is mechanically functional and which is a cutting tool used in manufacturing or more specifically in machining so let us look how does this cutting tool function.

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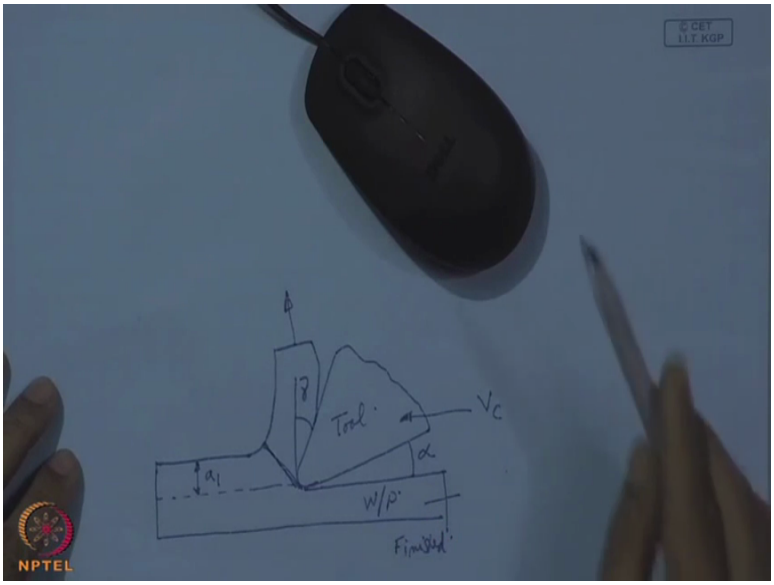

This is the cutting tool and here this is going to be the workpiece. And this is actually the cutting action, so more or less this is the cutting action. This is the tool. This is the workpiece. It is of course, this is the finished product, finished. And this is the original material and here what we

can find, this is the thickness of the uncut layer. And the tool has its proper geometry as we have pointed out here. This, without this geometry this tool cannot work.

So the geometry means at least we have to put some clearance angle and here what we call in the language of machining, the rake angle. So this rake and clearance are the fundamental geometry of this cutting tool. And then there should be some relative speed. So the tool is moving with this speed relative to the job and what we can find that this chip is emerging out and this is actually called the shearing zone, so where this shearing takes place and uncut layer is converted into chip. So that is just the machining.

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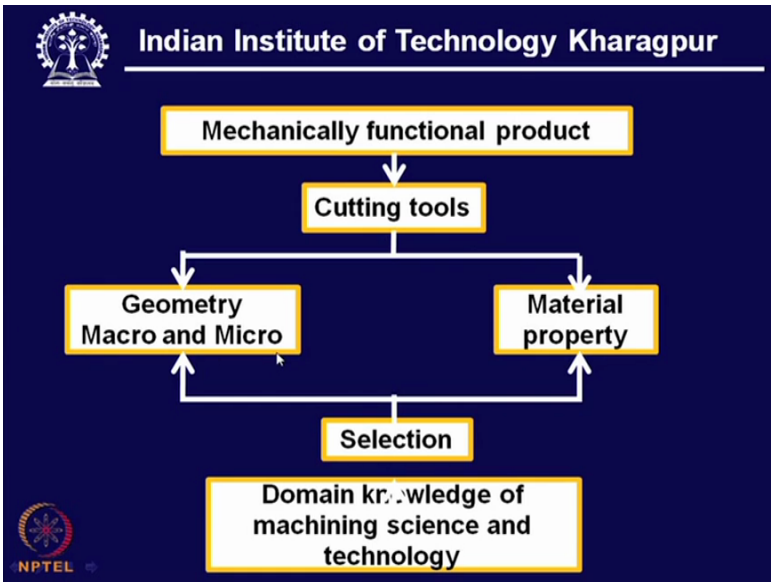

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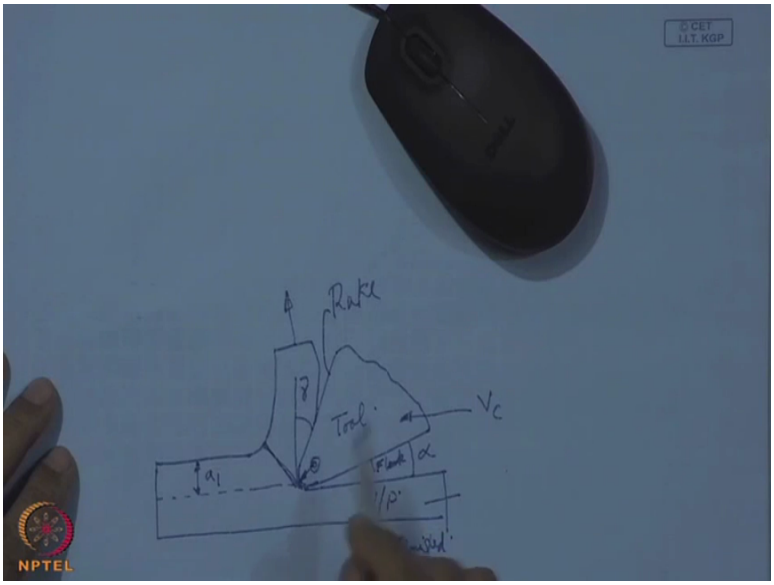

Now let us emphasize on this role of the cutting tool. So it must have both micro geometry and macro geometry. Micro geometry we mean that this edge where the flank of the tool, this is called the flank of the tool and that is called the rake surface, these are meeting. So they are actually, there is a continuity by providing a edge rounding radius. So this is going to be an edge rounding radius. So how to choose this clearance angle, rake angle and edge rounding radius?

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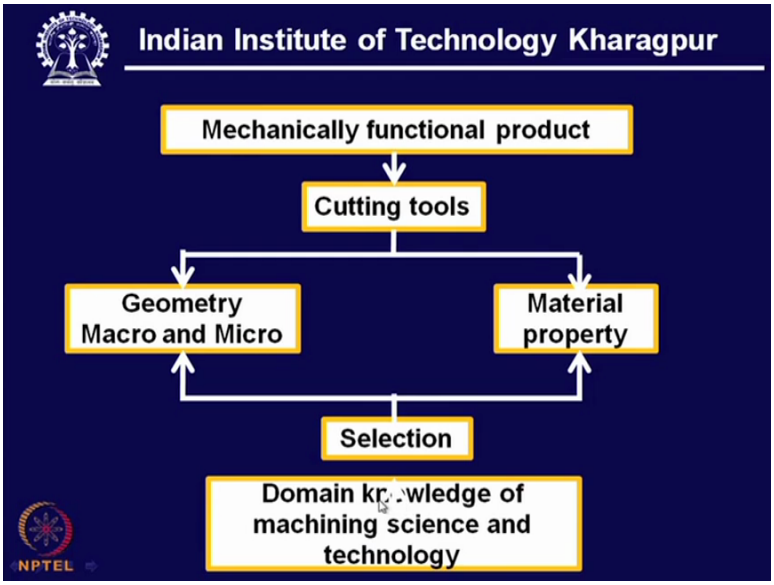

This is actually the domain of, domain knowledge of machining science and technology. So this is actually the domain knowledge of machining science and technology and from which we have

to have the proper selection of the material. And then comes the material property. So on one side, we have to choose the geometry and on the other side, the correctly chosen material so that ultimately we get a product.

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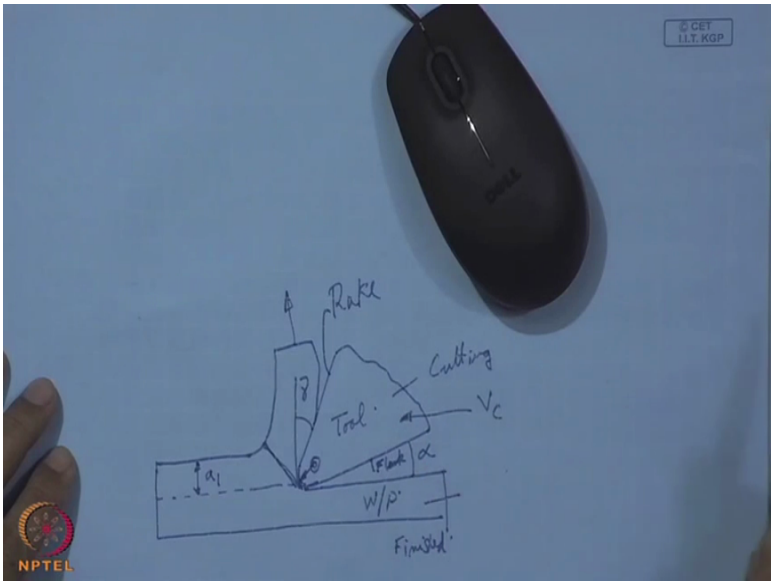

This is the tool and which has both the material and the right combination of the tool material that makes it a very high performance product. And it is supposed to be one of the high performance product.

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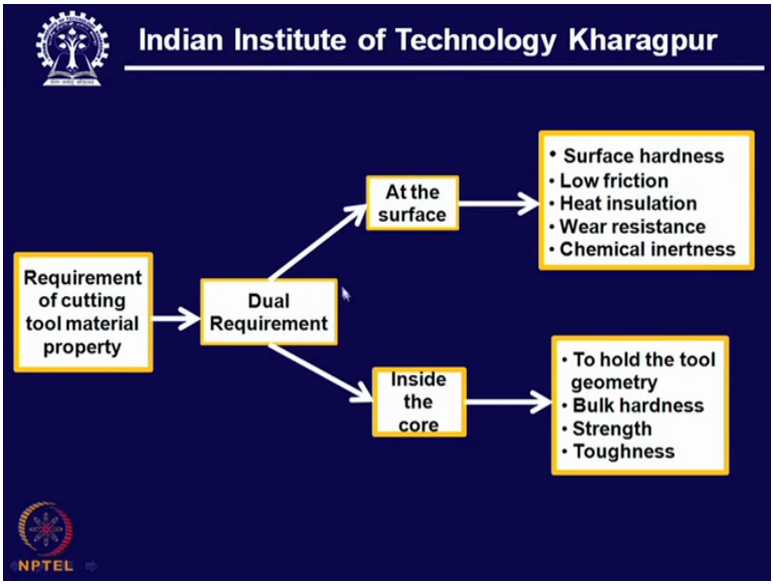

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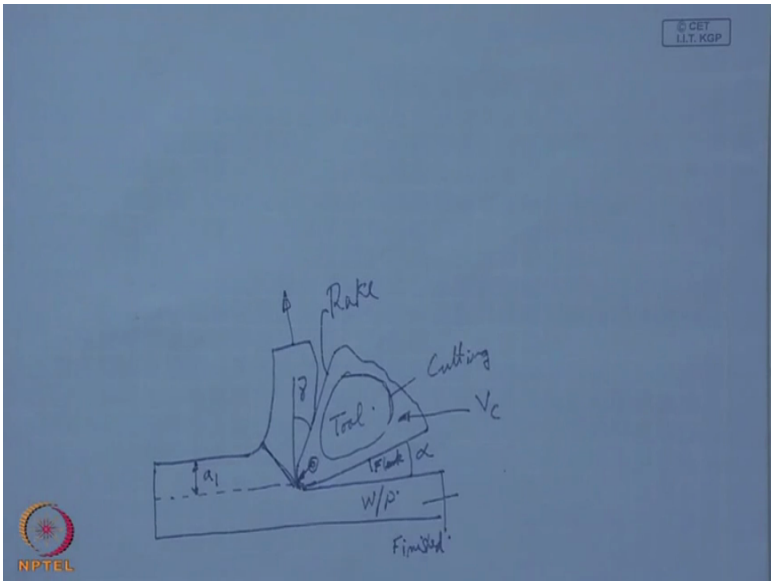

Now let us see, the thing is here very conflicting and contradictory. That means requirement of this cutting tool material property. It is in fact a dual requirement; it is just not one single requirement.

If we see that this tool has the core area, this is the core area of the tool and it has one surface, so this is actually the surface. So here what we see that, we, one property at the surface and we have something, some property, important property inside the core. That means within this, within the core. And this is actually called substrate. Now let us look what are those property desirable at the surface: surface hardness, low friction, heat insulation, wear resistance and chemical inertness. All these things are necessary.

You have, so all those things are necessary here because at the surface we want surface hardness, then low coefficient of friction, heat shielding, that means heat should not be transmitted inside the core. Then obviously, we need wear resistance and chemical inertness, so there must not be any reaction between the tool and this chip material. Also, the case with this side. But this geometry which means this edge rounding radius, the rake angle and this clearance angle, they have to be maintained with much, I mean much stability.

That means this tool must hold its geometry over the entire working domain and working span. So this is one of the role of the core material. Core material must hold the geometry. Then we must have the bulk hardness that means the material should not undergo any deformation during

this application or use of the tool. It should not undergo any sort of plastic deformation. And what is equally important, the toughness because there will be tremendous amount of resistance offered by this workpiece. So we see here the mechanical force plus the heat flux, their combined effect will lead to finally wear or the failure of the tool.

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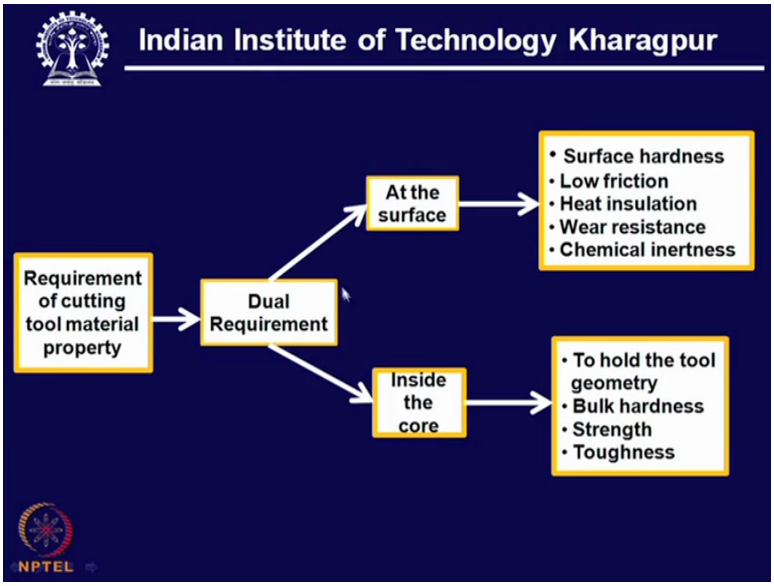

And what has been correctly identified in this case that we must have a dual property and this dual property means we have to have sharing of the responsibilities between the surface and the inside core area. And these are the responsibility, this is the responsibility of the surface to provide these properties, characteristics and that had been the task of the core area to hold these characteristics.

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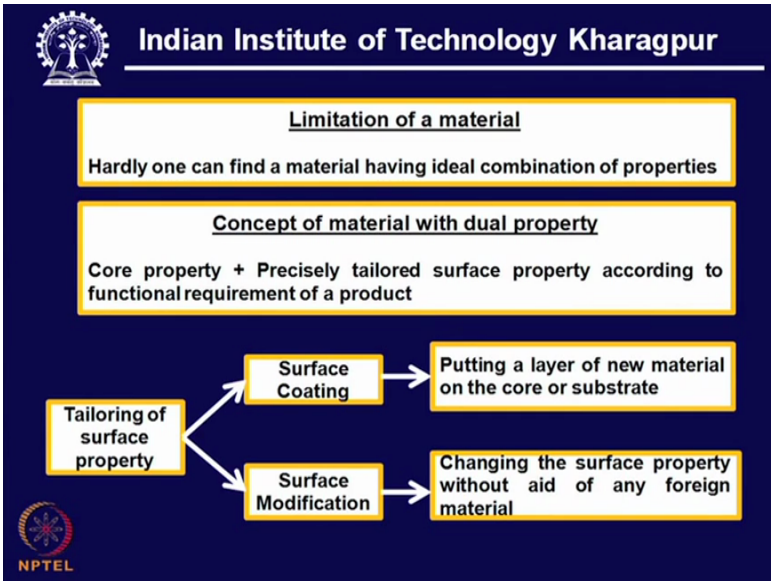

Now comes the very limitation of the tool material or any material. So what we see hardly one can find a material having ideal combination of properties, so that is why we have to go for this concept of material with dual property. It means exactly what I shown already.

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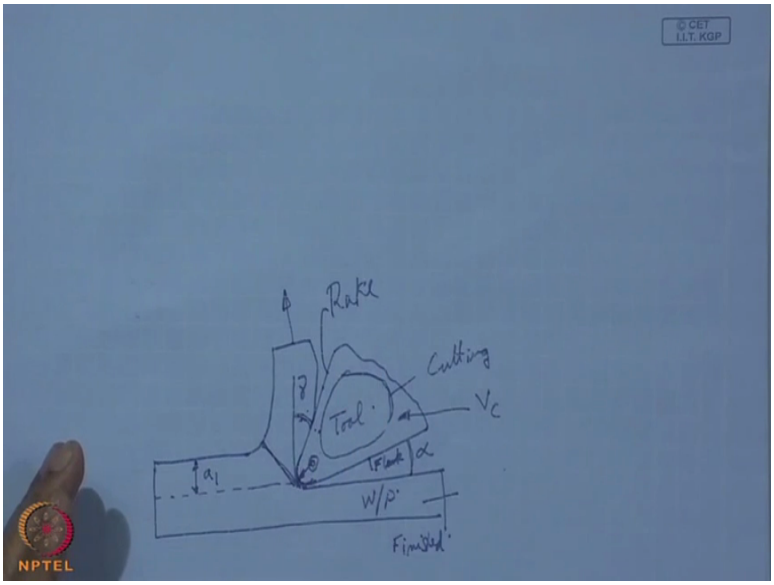

That means we have a core property and on the surface a precisely tailored surface property according to the functional requirement of the product. That means we have to have a very careful study of the product, where it is going to be used, what is the condition, environment and

you have to address all those issues and finally we can have a suitable core property and one of the very important surface property.

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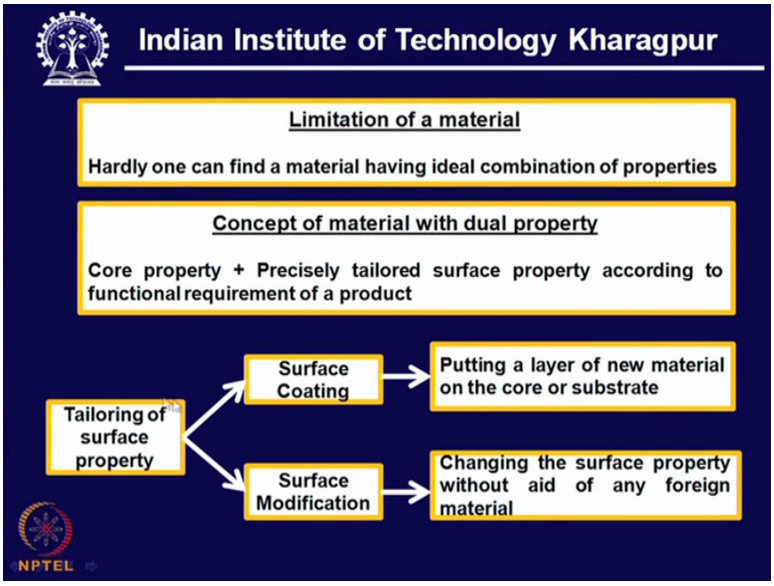

So what we can see here that this is actually tailoring of the surface property. Now this tailoring of the surface property, actually we are referring to the surface coating. So surface coating means actually it is tailoring of the surface property, changing the mechanical characteristics, physical characteristics or even chemical characteristics. It can be thermal, it can be any sort of characteristics which is required for smooth functioning of that particular product. So we have actually two rounds. One is surface coating and the second is surface modification. The surface coating means putting a layer of a new material on the core or the substrate.

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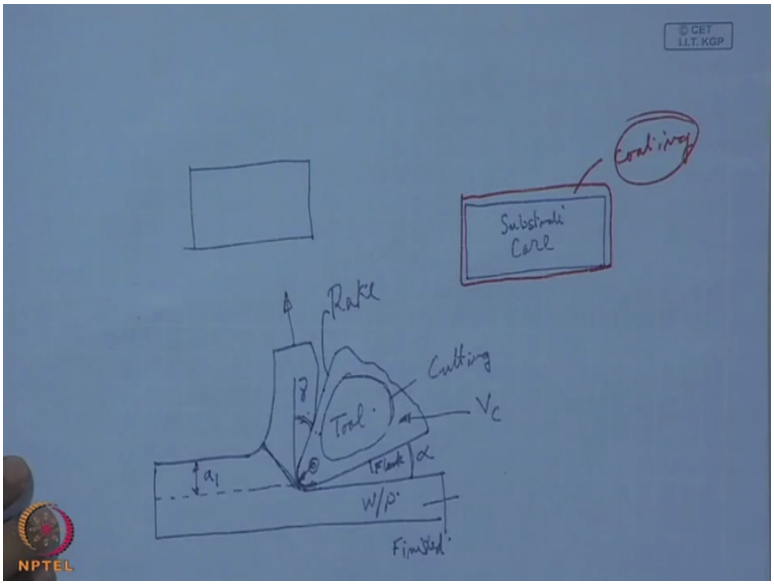

That means if we have, this is the core material as received and on that we can put a coating of another material and which has the required surface property. So this is actually the core or the substrate, we also call it substrate. And this is the coating, so this is actually the coating. So this coating material having those desired properties as we have mentioned in reference to the cutting tool it will offer.

There can be another way of doing the thing. That, in this case we do not, I have to have a foreign material for participation. So what we can do, it can be just changing the surface property, it can be mechanically, it can be chemically or it can be physically, just changing the surface property. It could be changing just the structure, the lattice pattern or it can be the change of hardness, change of stress level. Whatever may be the change which takes place, and if there be some benefit, it is said that it is surface modification.

So we understand the basic difference between the surface modification and surface coating, but both are meaning tailoring the surface property. So we understand now what is meant by surface coating and what for this surface coating is.

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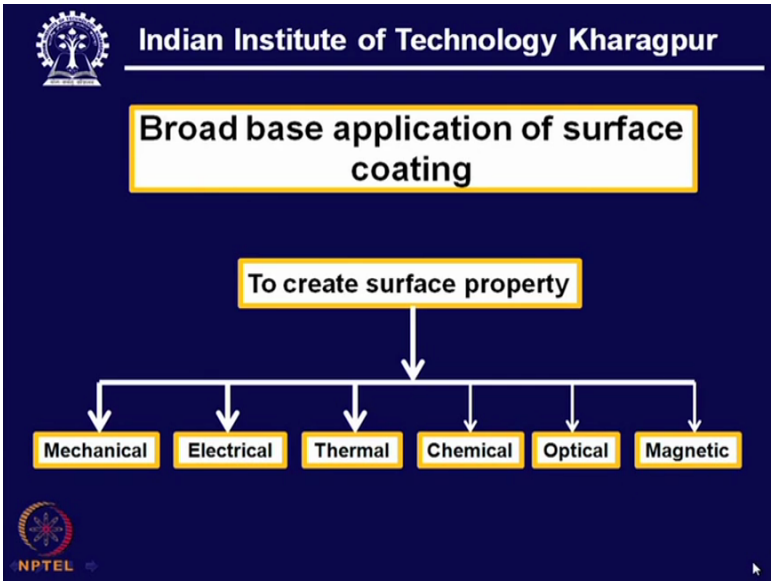

Now already we have enormous amount of literature, knowledge base and information in the area of surface coating. And we have a very large domain of engineering where this surface coating can be judiciously used. But concerning this limit of this course, we have to be little selective and we just restrict taking few of those example, but it can be used in any of those. That means broad base application of the surface coating, what we find here broad base application and in this broad base application, we have it is mechanically functional. Just means only the top surface, mechanically functional.

It can be electrically functional, we can have insulation on the surface or a conducting coating on the surface. We can have the thermally conducting surface or thermally insulating. It can be also chemically active, that means it can react or it can be a passive layer. Optical, it can be a reflecting surface or it can be anti-reflection surface. Similarly, magnetic, it can accept the flux or it can refuse the flux. So this way we have a broad base. It can be used for numerous example in electronics also.

So we can find out any discipline of engineering and it is the job or objective, sole objective to find out some of those materials and a process, suitable process just to create a surface property which actually enhances the capability of that product, which can be mechanical or any of these characteristics.

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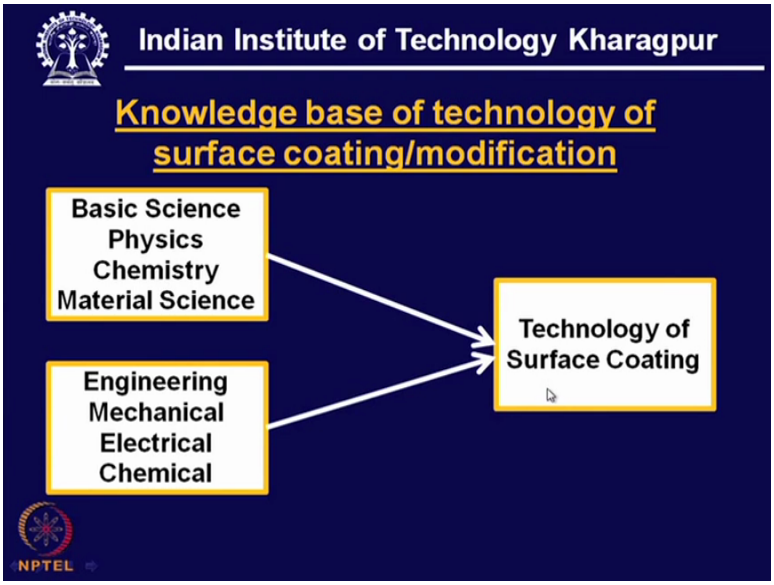

What is very important here that technology of surface coating so knowledge base for technology of surface coating, how to apply, how to understand this whole domain of this surface coating. So we have to have a creation of knowledge pool by using the basic science and a particular domain of engineering. That means this basic science and mechanical engineering it can be basic science, this combination. It can be electrical engineering, it can be, it depends upon the particular demand placed by one particular discipline of mechanical engineering, the characteristics of the device, component or the element.

And accordingly, this domain knowledge, what is the requirement, functional requirement and how these functional requirements are met by this technology of surface coating and this is, gives you the foundation for understanding of the scientific part of the surface coating.

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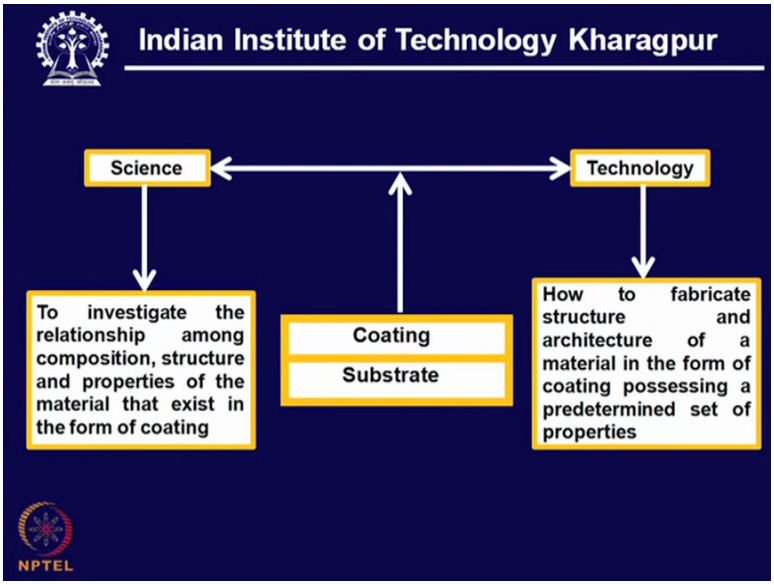

Now where we find the substrate and the coating? Coating is at the top, so we find here one is scientific aspect, it is to investigate the relationship amongst the composition, structure and property and this is concerning the coating, not the substrate. It is the material, the new material which is put on the substrate and this material in the form of a coating and its composition, structure, properties, relationship should be understood in the scientific term. And it is now the technology, very important component of the entire exercise.

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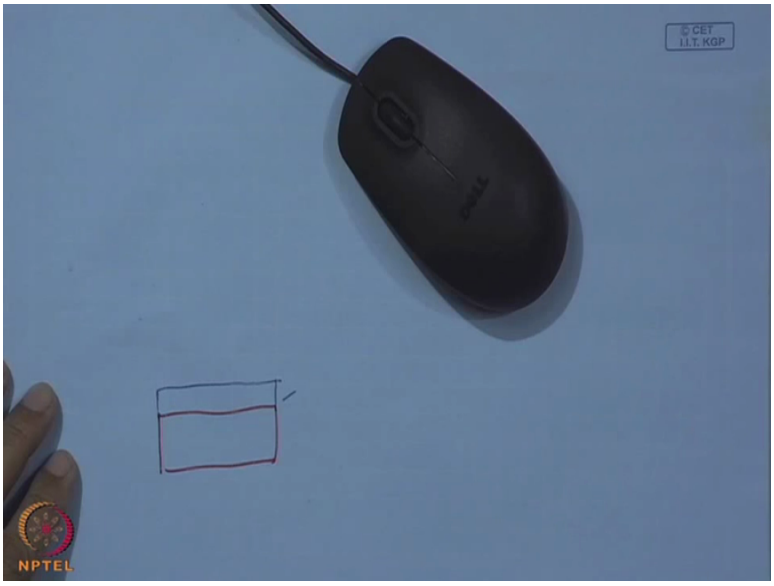

How to fabricate that structure in the form of coating? That means here I have the coating if it is the substrate, and then I have the coating and how to create this structure in the form of film? It can be 1 micron, it can be submicron, it can be few hundreds submicron, but here the structure has to be erected, it has to be created.

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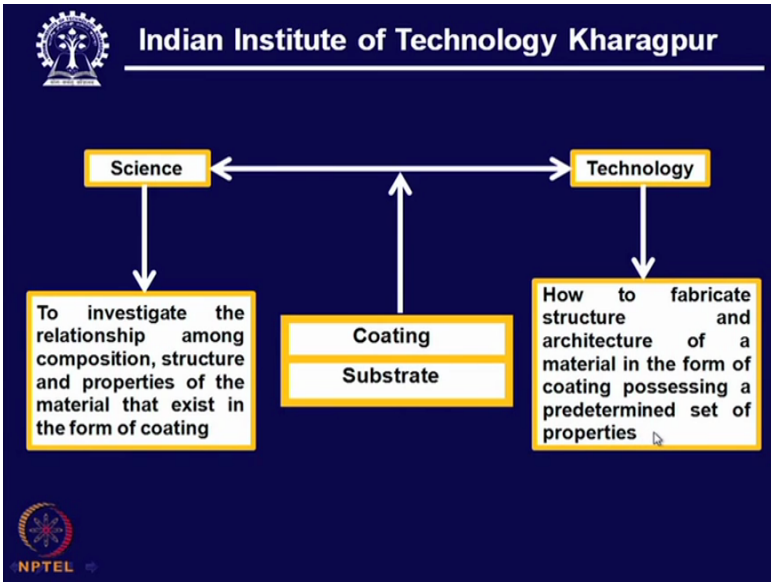

And for this, we must know the technology, how to fabricate this thing in the form of coating process and having all the predetermined set of properties as we have already mentioned citing the example of a cutting tool.

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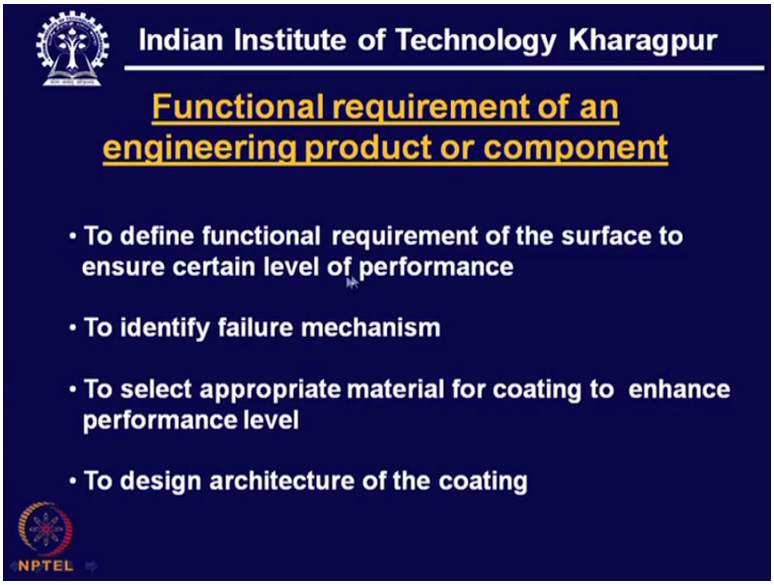

Functional requirement of engineering product or component here we must define the functional requirement of the surface to ensure certain level of performance. We know what is the level of performance and then if we identify, make a diagnosis of the failure mechanism, if we like to push this one, definitely this product or material is going to fail. And then we must have to select the appropriate material for coating to enhance that performance level. So it attains certain level, we like to augment this one understanding the failure mechanism and then we raise this performance level. And finally comes, who is going to give this performance level augmentation. It is actually to design the architecture of the coating.

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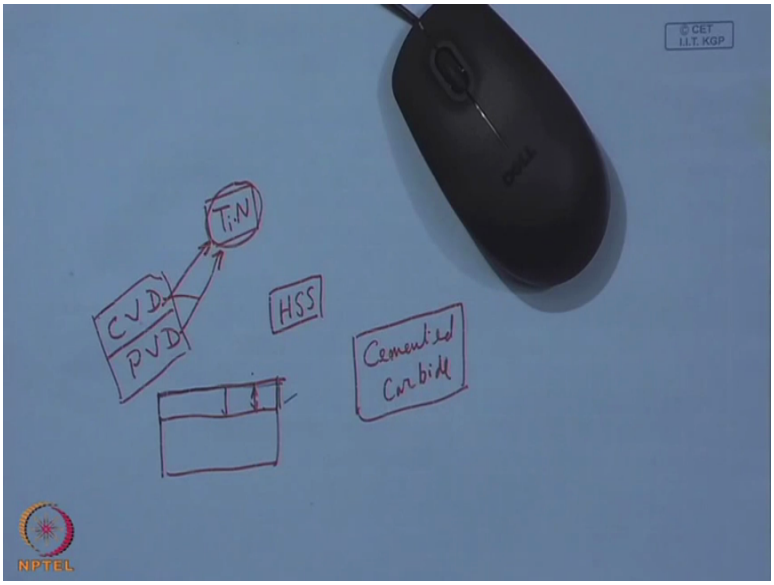

That means this architecture of the coating, how we are going to build this thickness, what will be the structure, grain size and many things. Many more things will come in picture. This is just a continuation, so here we have to select the coating process, economics of the process extremely important. Say for example, we can coat on the cutting tool, say titanium nitride for example, to augment its performance level. Now we have two cutting tools. One is high speed steel and another is what we call cemented carbide.

Now we have at least two choices. How to put it? Either by CVD process or by PVD process what should be the process? How to give this answer? So we have to know which is the compatibility. What we have shown here that compatibility of the coating process with the coating material and the substrate material. This, what we mean that all the material cannot be put in the form of coating using any of the coating process. Similarly, we can also say that one particular material cannot be put here just using one of the process.

So a coating material which can be formed either by CVD or by PVD, this coating material formation is possible either by CVD or PVD. But the question is whether I can use both of them, both of this coating process on both of HSS and cemented carbide. So these are the thing has to be looked in much detail.

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And finally it comes to conservation of the environment. It is obviously this coating process finally should not lead to any environment pollution. So there we must have all sort of to meet extremely strict requirement.

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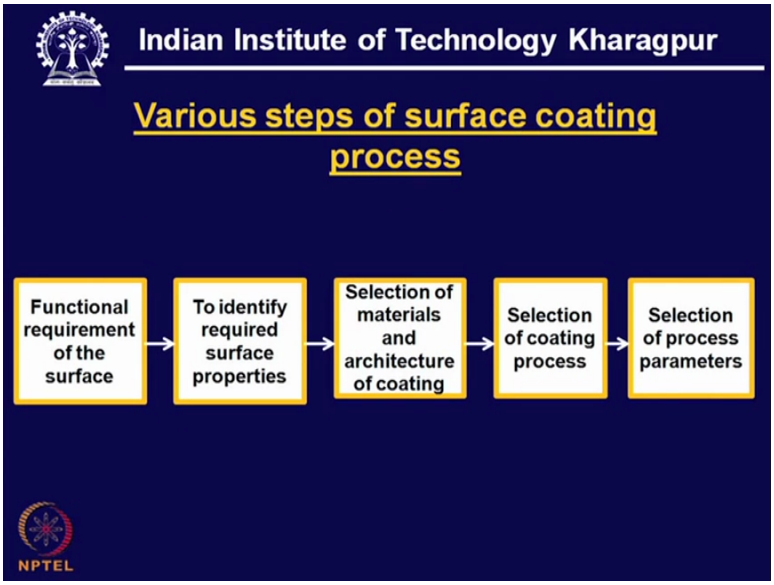

Now here we try to follow the various steps of surface coating process. It is one step and which is following. So we find out functional requirement of the surface, then we can find out to have this functional requirement fulfilled what are the required surface properties. It can be lowering the friction, it can be a heat shield, it can be chemically resistant or it can be heat resistant, like

that. So once that is done, we must find out the best material for this task, best material. So once we find out one of the very best material, how it should be constructed?

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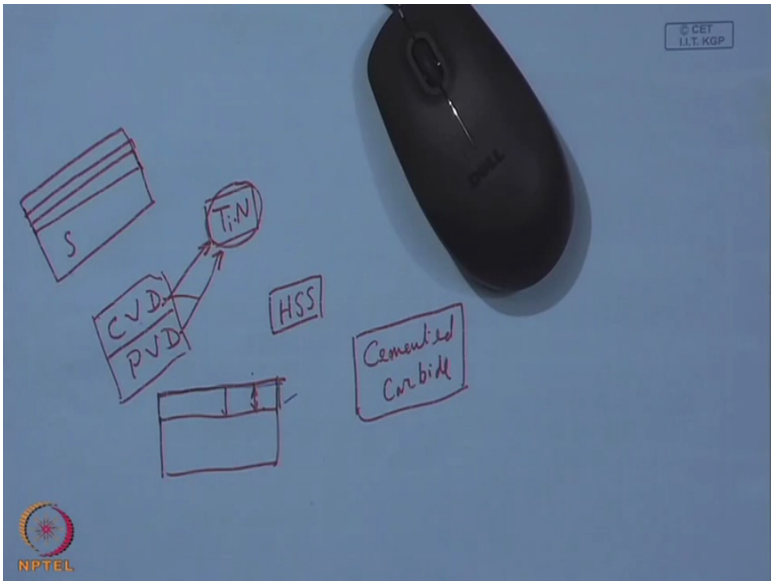

In many instances, we have seen that this is the substrate; it can be just not one layer, it can be multilayer. And multilayer of this coating can take that particular challenge and can perform in a very efficient manner. So this is just by way of illustration we can say that it can be the selection of the material as well as architecture of the coating. Then comes the selection of the coating process just what I have illustrated by this choice of CVD or PVD. It equally holds good here.

How to select this coating process? Once we fix, okay, let us say it is PVD for this TiN coating. For HSS, what are those coating parameters, process parameters which will lead to this particular property of the coating which can give you the best possible performance?

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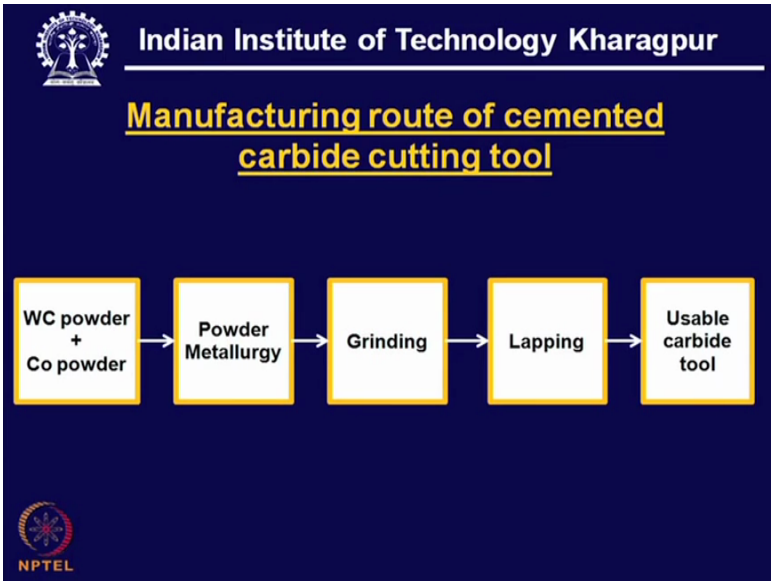

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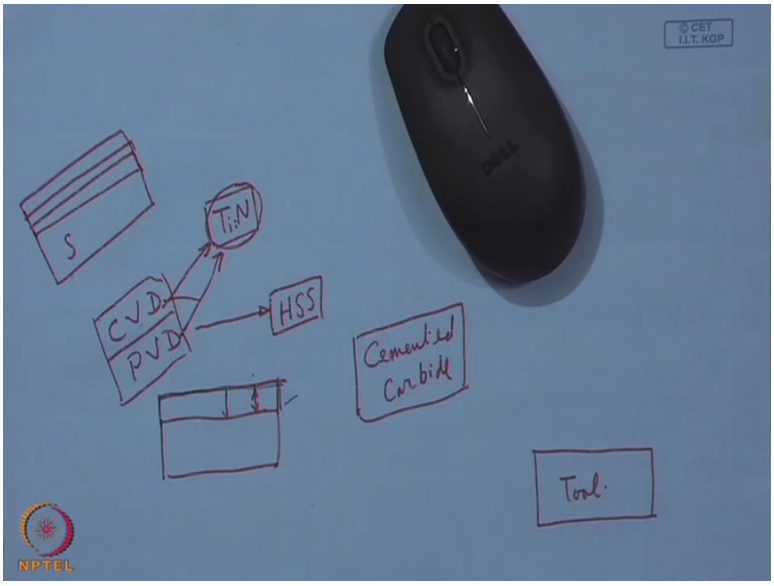

Say this is one of the example, how we make a conventional carbide tool which is also used in cutting. It is without any enhanced surface property, ordinary tool and which is just we call it a tool without any coating. It is made following this powder metallurgy process. This is well known in art and science. So these are the series of process routes one has to follow.

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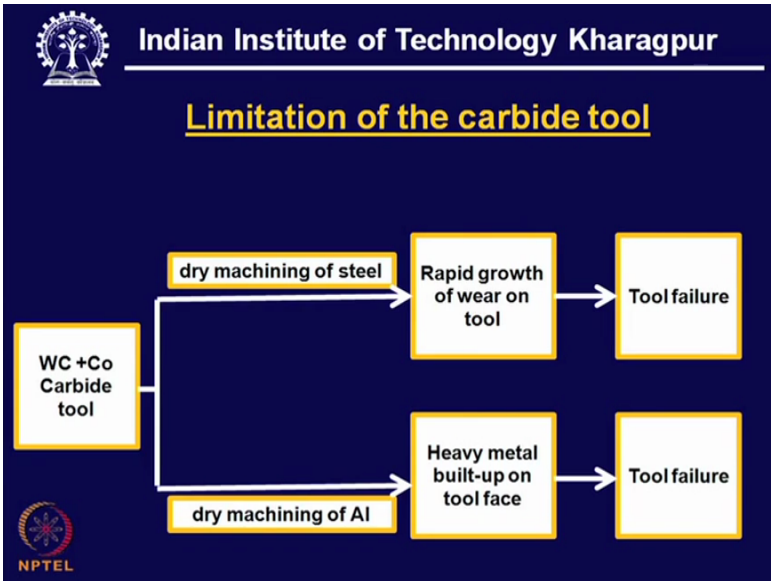

But what is important to look at? When we use such carbide tool to have some machining task, so this is actually the limitation of the carbide tool, one can immediately recognize. We like to have dry machining of steel and we can see rapid growth of wear on the tool which leads to tool failure.

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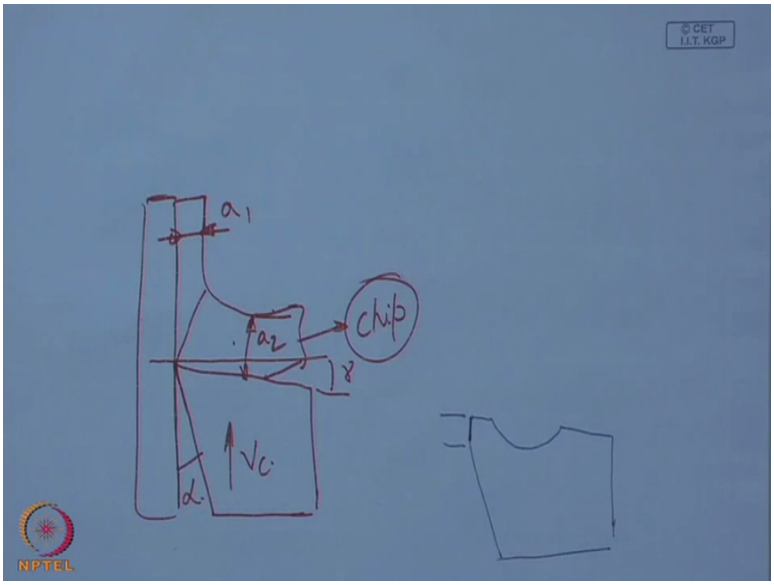

It means that originally the tool is like this, what I have already shown. So this is actually the rake angle, this is the clearance angle. And it is actually the chip which is flowing from this side. So here we see that rubbing action, one rubbing action between this finished surface and the side

of the tool, another rubbing action between this chip which is moving at a very high speed and this is the velocity of this tool. And this is the chip which is emerging out at a very high velocity.

So after some prolonged use, what we find, the geometry will change and we can have a careful look that this is no longer the tool but because of this wear we can find a tool having such kind of thing. So you have rapid wear in this, so it is a sharp and which is now flattened and which is now already flattened. So this is flank wear, and because of this rubbing action we have created cavity formation. And this to, actually limits the use of the, further use of the tool and we call it failure of the tool. Okay, we can put it here. So that is called the failure of the tool.

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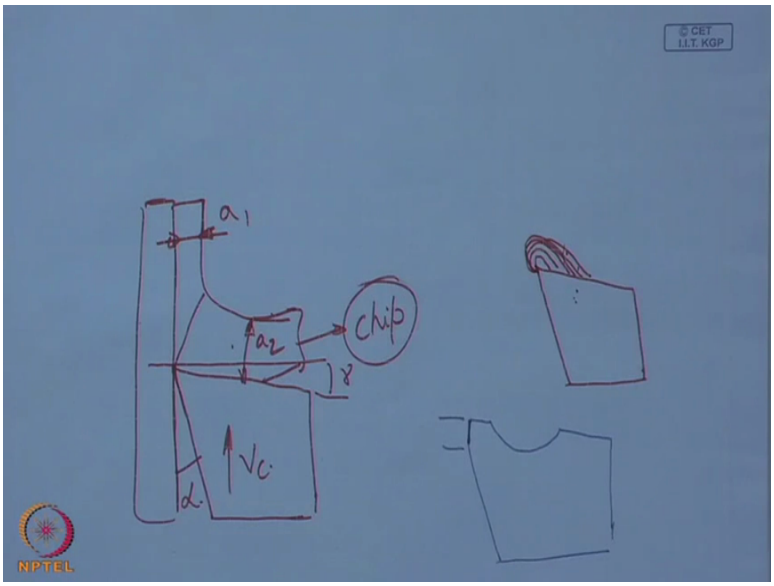

Let us take this example, dry machining of aluminum. It is not exactly the wear on the tool. What we can see in this case, this is the tool and here we have heavy metal built up on this surface and it actually disturb, it distorts the geometry of the tool which is a sharp one and it is now this particular material heavy buildup which is very stable and the material also loses its cutting capability. Increasing the friction, changing the geometry it also leads to tool failure. So both are dry machining and dry machining should be encouraged considering this environmental restriction on use of this cutting fluid or lubricant.

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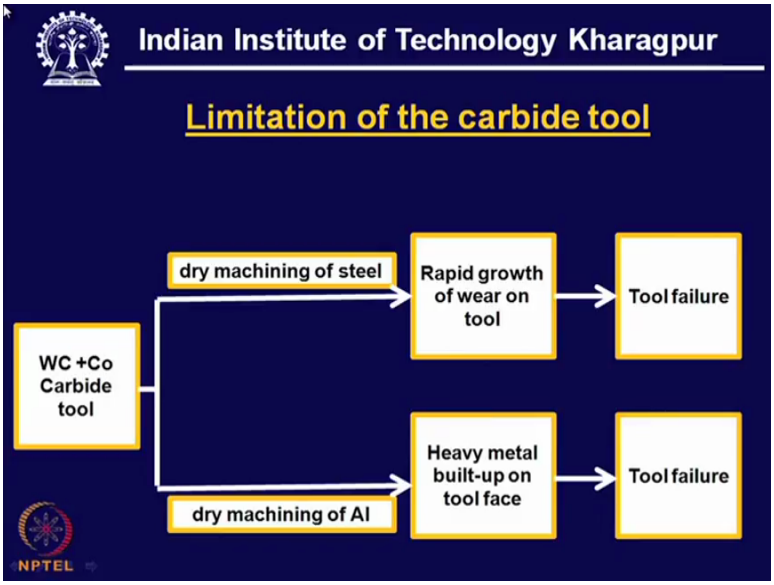

But these two tools just cannot work under this condition. If we go for high speed machining or dry machining of aluminum, we can say that this tool are going to fail and how to get rid of this problem or offer a solution?

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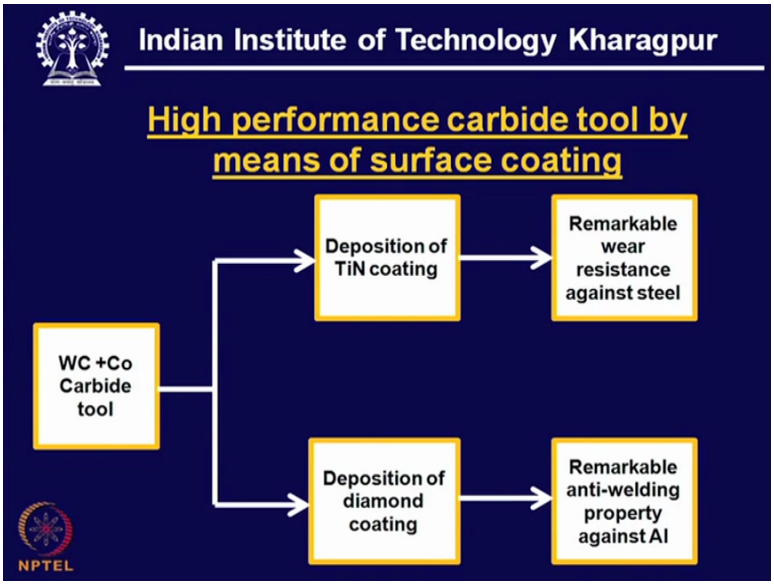

The solution is here. We have now from this ordinary tool, this limitation is overcome. We have high performance carbide tool by just means of surface coating. So this is the carbide tool. We have a deposition of titanium nitride coating.

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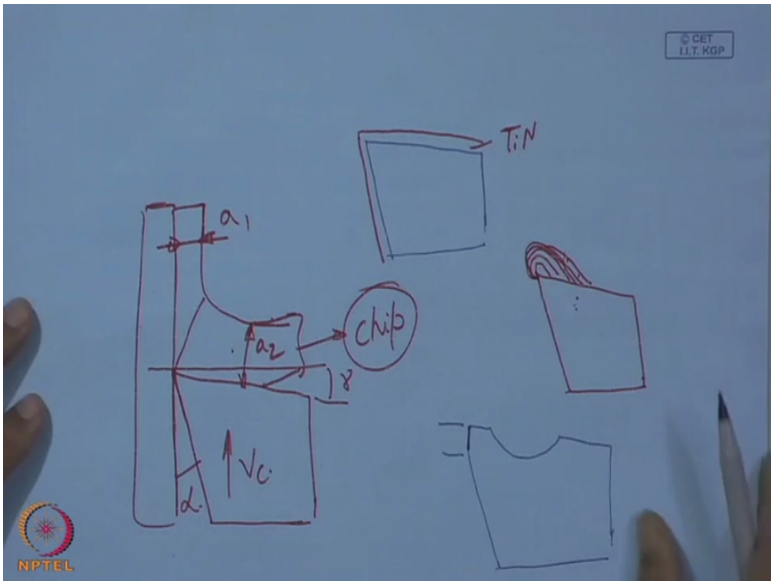

That means here we have the tool, the same tool and we put a coating of titanium nitride over this. And this coating of titanium nitride now protect it will protect the tool and wear resistance, it will take to a greater height. So this tool which was non-performing, now become a high performance carbide tool just because of a titanium nitride coating, maybe 4 to 5 micron thick.

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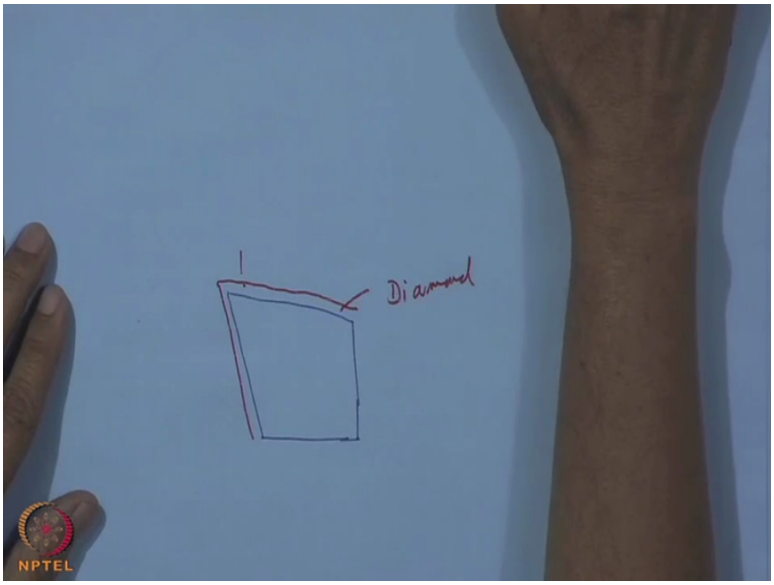

Similar is the case with this machining of aluminum. We can also see here that this is the same carbide tool which was used with lot of limitation, shortcomings but now those will disappear. Just we put a coating of diamond on the surface. So this is diamond coating and we can

immediately see that this tool, not a single particle of diamond, aluminum will stick to this surface. It is giving a very clean-cut, force is reduced, surface quality improves and it is simply because of this anti-welding property of diamond against aluminum.

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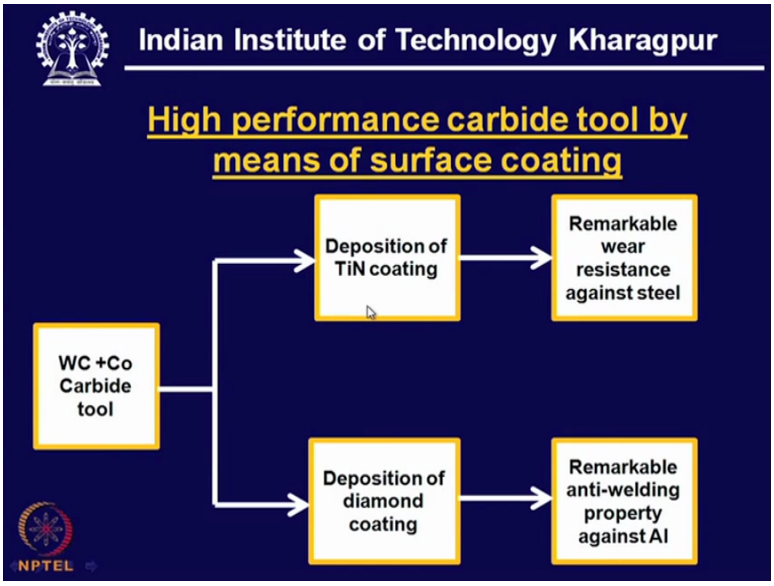

So we find here, what we can illustrate that this is the compatibility of this coating material with the work material. This is the compatibility, so we should use diamond coating on the same carbide for machining aluminum whereas we should use titanium nitride and similar material for machining steel and we get the benefit of this coating or coated product.

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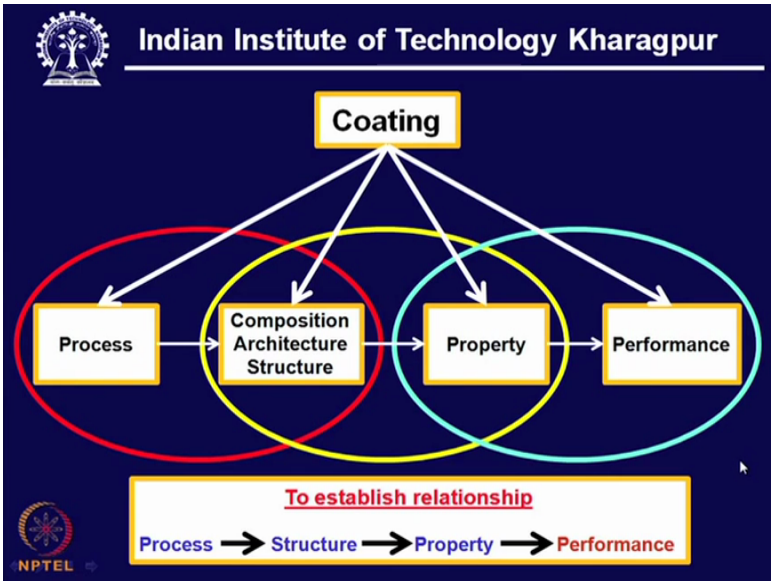

Now comes this slide which gives the clear responsibility and a joint responsibility between various people involved in this coating activities or coating technology. What we try to see here, look here, what we find, what is our job? To establish this relationship, its process, structure, property and performance.

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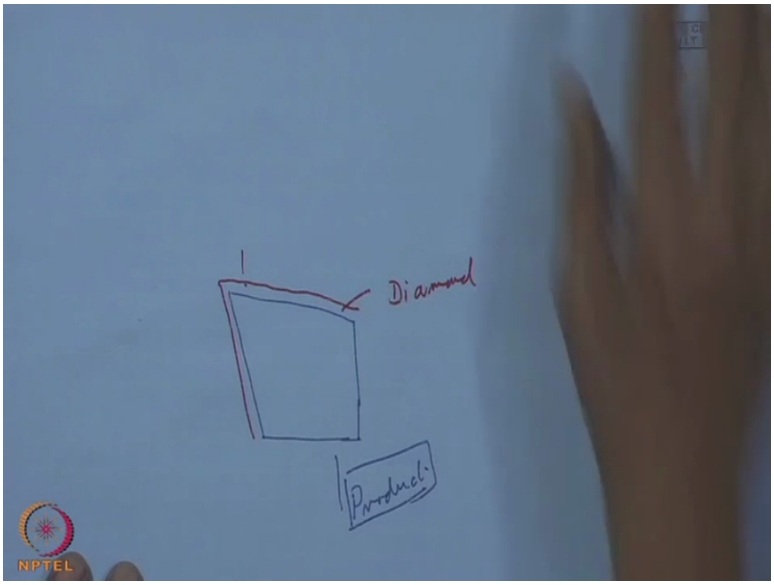

That means whatever I have mentioned here, this is the product and this product has certain new characteristics because of this coating. And this coating is used.

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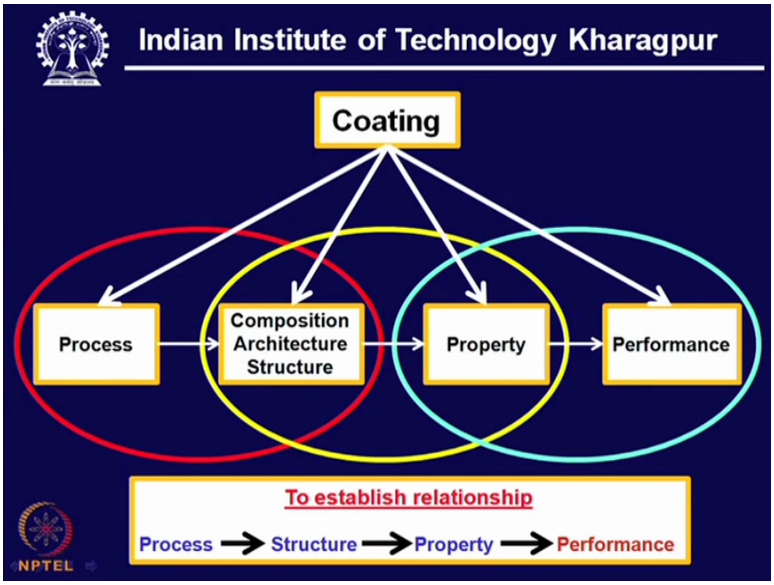

So here you have the coating. Say, titanium nitride coating. So this titanium nitride coating, what should be the coating process, we have to analyze. Then what should be the composition of this coating, its architecture, its structure, whether it is like a broomstick, this columnar structure or whether it is a granular structure, epitaxial growth, (())(40:33) structure, all these things have to be (dis), I mean considered so that we can have proper control on the process because it is the process that gives us this compositional characteristics, architecture and the structure.

And from this structure it comes to this property. So here the coating technologist has to work, he must know what are the process combination, process parametric combination, what is the process and what is the substrate, where we are going to put it. And then comes, it is the scientific exercise, scientific work that this composition of the coating, architecture of the coating and structure too which gives the functional property and this functional property is going to affect, it can have an overriding influence on the overall performance.

That way it has been illustrated just how this coating of diamond or a coating of titanium nitride totally change the face of this cutting or the cutting tool. So this is actually the job of the application engineer. Application engineer means here the tool application engineer, cutting tool expert. He knows property-performance relationship. The coating, science of coating that domain, that will be, research will be done in this zone. And this is actually the domain of

coating technologist. That means he has to have all sort of skillful adjustment, manipulation of the process parameter to give structure.

But if one like to know the final application of the coating starting from the coating material, what should be the substrate, he must be an expert covering the entire domain. That means this process, structure, property and performance. The whole thing, one should be able to understand and appreciate the need of understanding this relationship.

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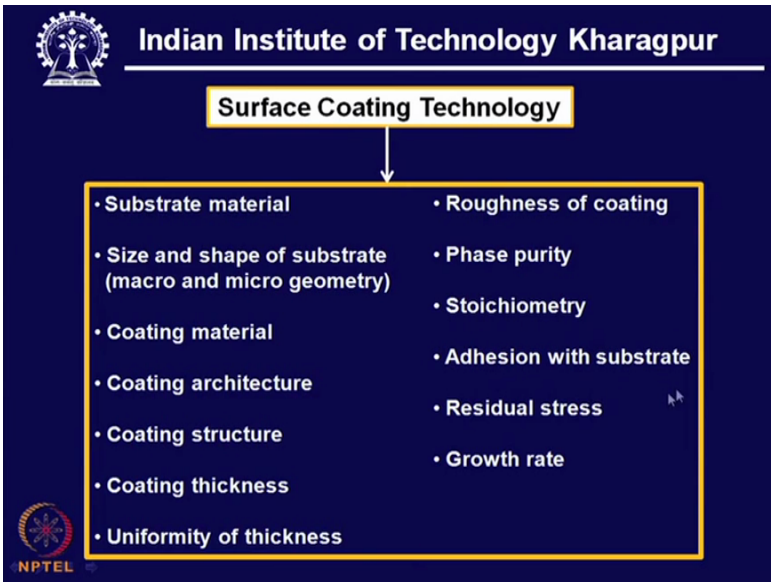

Surface coating technology, so what are those thing we like to have? First of all, substrate material. How to choose the surface coating? Substrate material, size and shape of substrate, that matters very much. If it is regular geometry or irregular geometry, it is also the size whether it is in millimeter or few hundreds of millimeter. What is the coating material, the coating architecture, the structure, the thickness of the coating, whether it is submicron, few tens of micron or few hundreds of micron?

What is the level of uniformity we must have? That means the precision and the coating, all this thing must be properly addressed or properly specified so that we can have correct choice on the coating technology. Then comes also surface roughness of the coating. During the condensation, nucleation and growth of the coating we have the roughness of the coating. So this is just during the condensation and synthesis.

Then it is the question of phase purity. For example, in case of diamond coating we can also have non-diamond phase which can go inside this coating. So this phase purity, both are carbon but we must look into this phase purity. Stoichiometry, say for example, we like to have titanium nitride, whether it is the stoichiometric TiN or it is other than stoichiometry. Then very important thing for mechanically functional coating, adhesion of the substrate.

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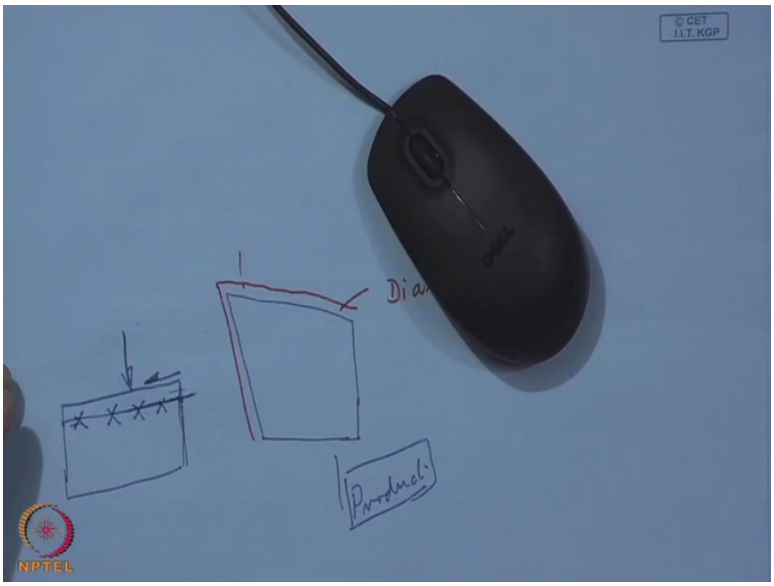

So this is actually the adhesion of the substrate. Here we have the coating, now this mechanically functional coating, it will be under the action of this normal force and sliding force. And this is actually the interface, coating may be one of the very best. Substrate is also judiciously chosen. But if we have poor adhesion, it will lead to a premature failure. That means the whole thing will be delaminated without any appreciable use. Ideally, a coating should have normal wear on the surface. That means it is gradual wear and normal end-of-life, but this is going to be a premature end-of-life which is not at all desirable.

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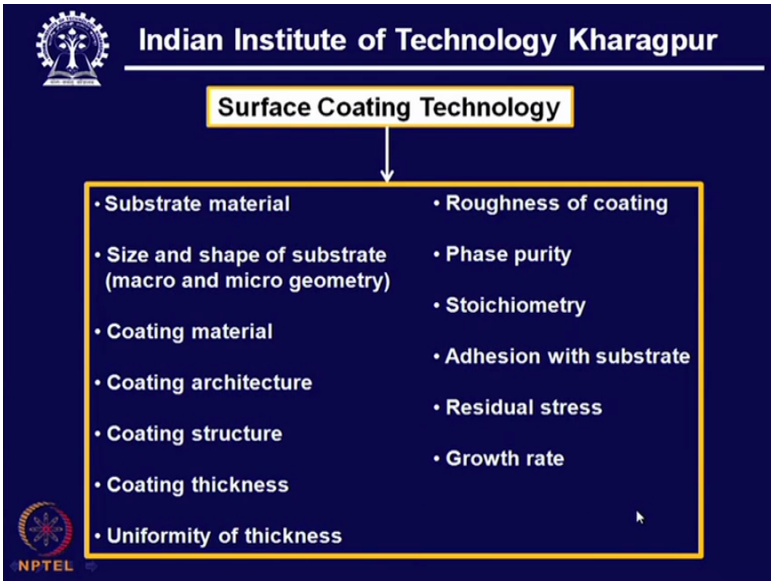

Then residual stress. This residual stress may also build up in the coating, that has to be also looked in. And the growth rate is very much connected with the productivity, so this growth rate should be also linked up.

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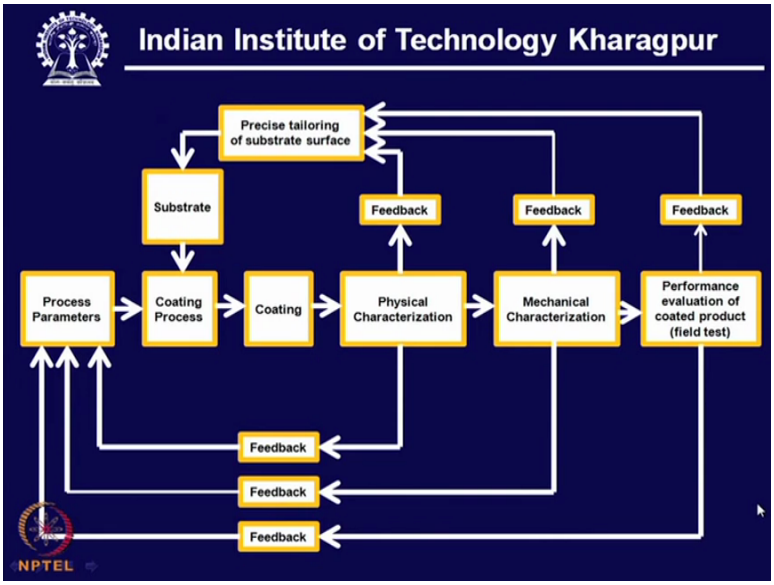

Now we see the overall activity in the domain of coating technology. We see, we start with the substrate. Substrate material once it is chosen, we have to precisely tailor the substrate surface so that it becomes a good receptor surface. That means the coating material should be received, well

received and it will stick to that; it will, should not bounce back or there should not be any repulsion, so that we have to look in. So that is one of the activity.

Then the substrate goes into the reactor coating process. So here we have the process parameters, we have the coating process, so this is the outcome of the coating process. Then we must go for this physical characterization followed by mechanical characterization and finally it is going to be the actual field test. That means the real product must be made with the surface coated product. It is a surface coated, it can be cutting tool. It can be to gears, cam follower, all mechanically functional coating.

However, there are you see, there are feedback path. That means if we feel that physical characterization does not show any positive result, does not show any promise or encouraging result, there must be some shortcomings either in the process parameter, in the coating process; it can be on the chemistry of the substrate or it can be in the tailoring of the substrate surface. So all these things should be looked into in their totality, not in isolation.

So it, suppose physical characterization is over, we go for mechanical characterization and there we see that there is scope of lot of improvement then also, we must look into that this feedback path will also lead to this, I mean origin, that what can be the rectification, what can be done on this side to get a better mechanical property. And finally when this coating, it passes physical characterization, mechanical characterization, we put it in the actual test bed where the real test is performed. And if it is really a success, it is successful, then we can go for commercialization and further use.

So we can find here the total activity domain and role of various persons involving, involved in various activities of this total coating process.

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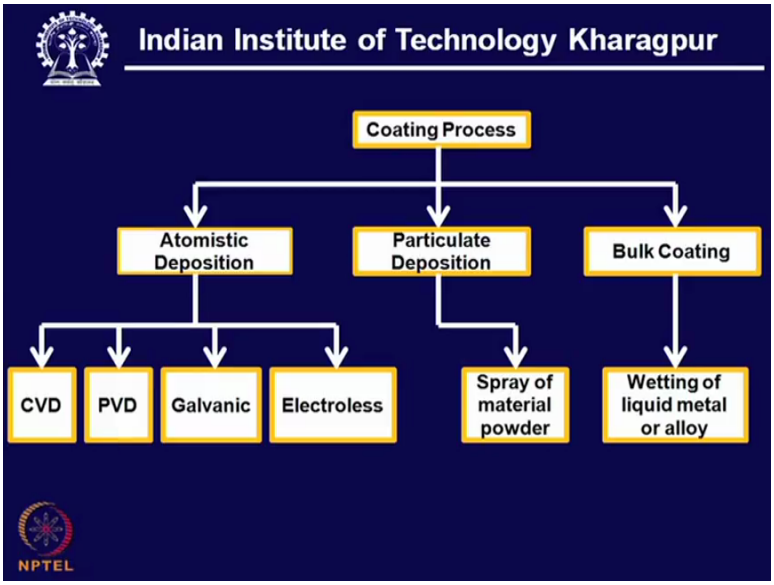

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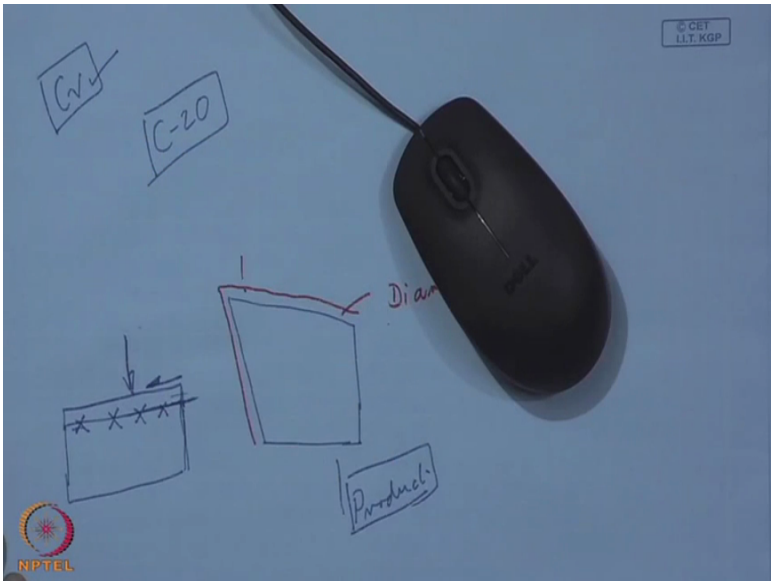

Now comes the coating process. Now coating process, we can have a broad classification: Atomistic deposition, we have particulate deposition or we have bulk coating. In atomistic deposition, it can be chemical vapor deposition, it can be physical vapor deposition. Either we can go to this galvanic route or it can be even electroless.

Say for example, we are interested in chromium coating. Chromium coating on a low carbon steel. At least we have three choices: CVD, PVD and galvanic, electroplating. Which one is the best? How to give this answer? So these are the questions and issues we have to address. This is

just for illustration. Then we have particulate deposition, it is just the spray of material powder which is already synthesized but in this case the material gets synthesized from vapor phase to the solid phase, however of course in the form of coating.

Similarly, we can have a coating by bulk process. Say for example, by wetting say coating of zinc. So in the zinc bath, we can immerse the substrate of choice and it is by the wetting action the liquid material will adhere to this surface and we can have a coating. So this, the list is not exhaustive. So we have still more processes but we have to find out the best process again to look into this compatibility of the coating process with the coating material and the compatibility of the coating process with the substrate material and compatibility of the coating material with the substrate material.

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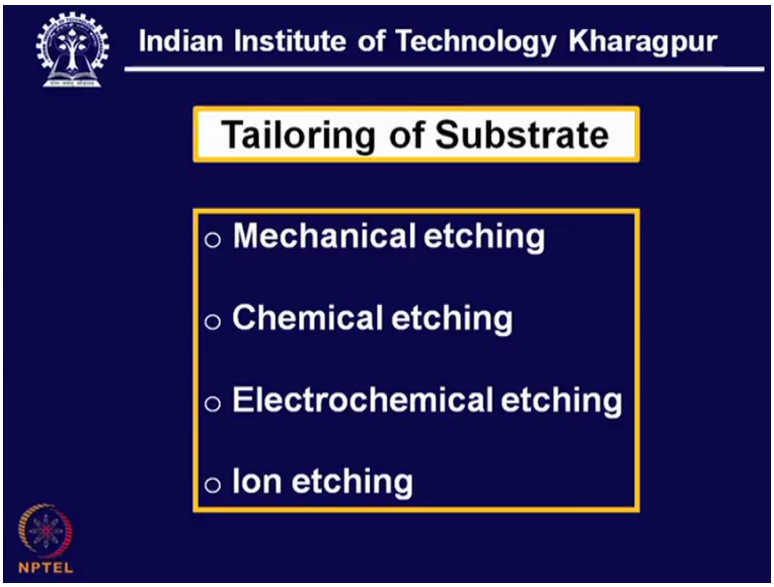

Then we come to this one, tailoring the substrate. What we have seen tailoring this substrate, we have, we can have mechanical etching. That means by blasting process, okay, by blasting process mechanical etching. We can have also chemical etching, we can prepare the surface by chemical treatment mostly to activate that surface which is passivated because of oxidation. And this mechanical etching means roughening of the surface. We can have electrochemical etching, it can be also by ion impingement. We can also have special preparation of the surface under a very restricted environment.

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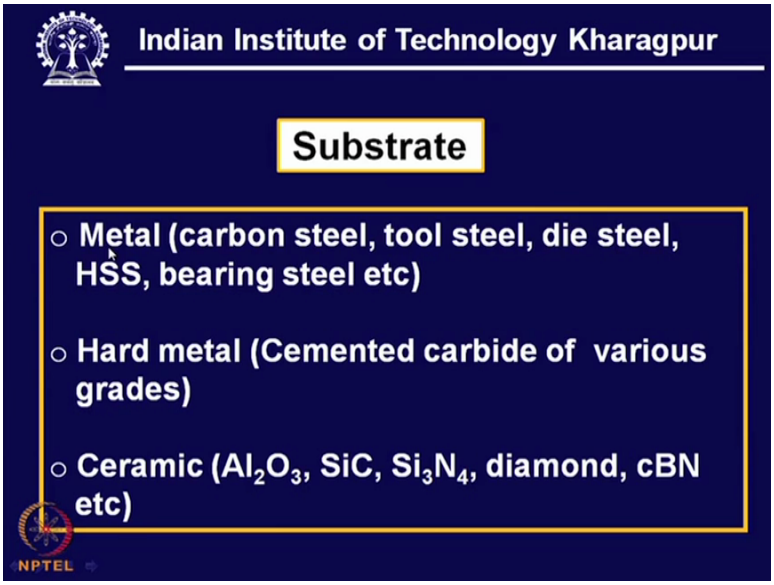

Substrate, substrate can be metal which are used mostly in functionally, mechanically functional material: carbon steel, die steel, HSS, bearing steel. In the hard metal family, we have lot of substrate. In the ceramic family, we are also having, few things we have mentioned here as for illustration.

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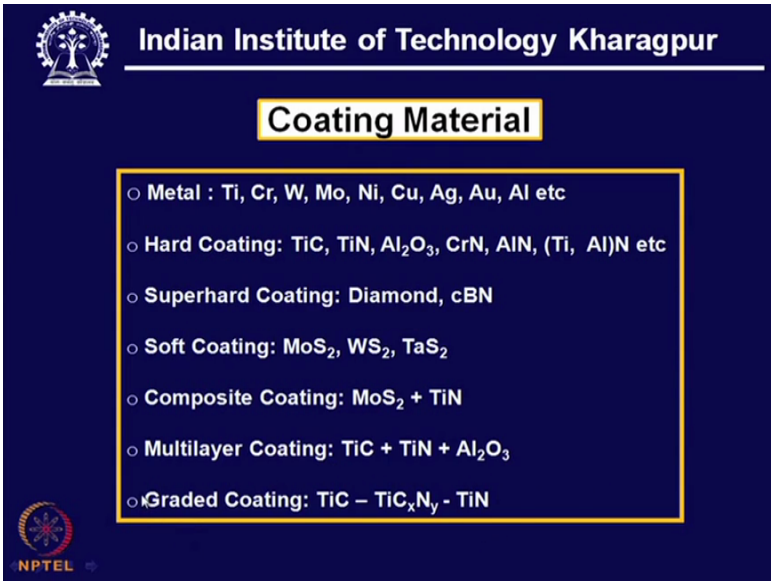

Coating material, these coating materials, it can be from metal family, it can be from hard coating. This metal family, these are used in any mechanically functional surface mostly for improving either the coefficient of friction or to increase brazability or wettability brazing. Then

we have super-hard coating: diamond, c-BN. We have also soft coating which are also used in many various mechanical component to reduce the coefficient of friction.

We can have hybrid coating. That means bringing this hard coating and soft coating together to get a another level of property or characteristics. It can be multilayer coating, that means one followed gradually, these are built up in three layers. It can be even a graded coating.

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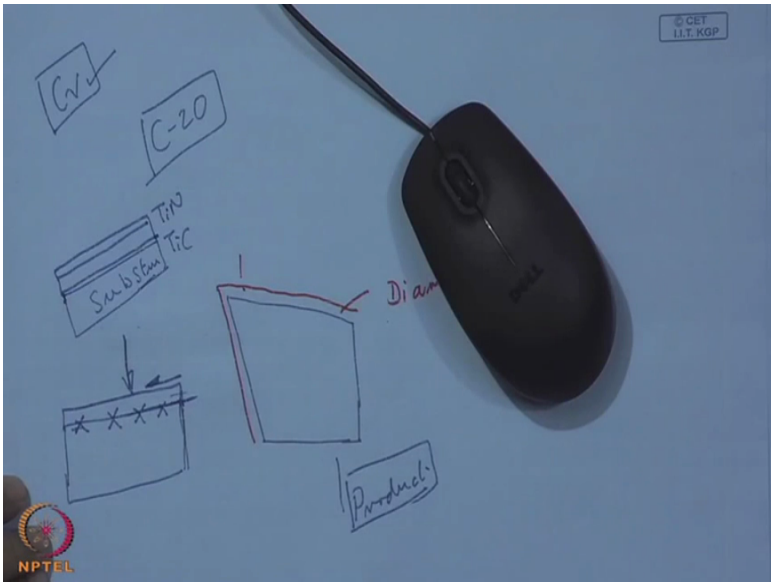

That means from the substrate we start with TiC and the top may be TiN, this top layer TiN. But we must, this is TiC, and we must gradually change the composition for various reasons. And in between we can put some (oxi), some carbonitride coating also. So these are the various coating materials which can be used to improve the surface property or to make the material high performing.

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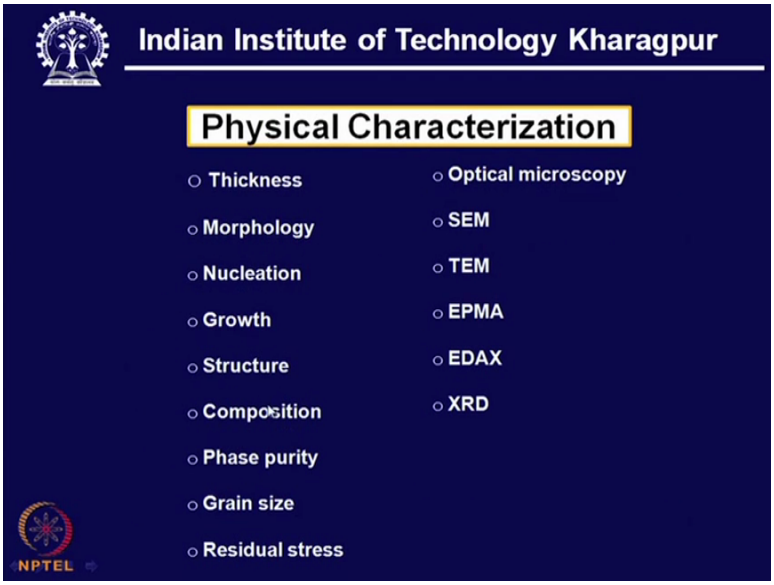

We have physical characterization, various things we have to characterize physically. Thickness, morphology, nucleation, growth, structure, composition, phase purity, these are the routine activity in the physical characterization. And for that we have these tools for physical characterization: optical microscopy, scanning electron microscope, transmission electron, microprobe analyzer, energy dispersive analysis of X-ray, XRD, even Raman spectroscopy.

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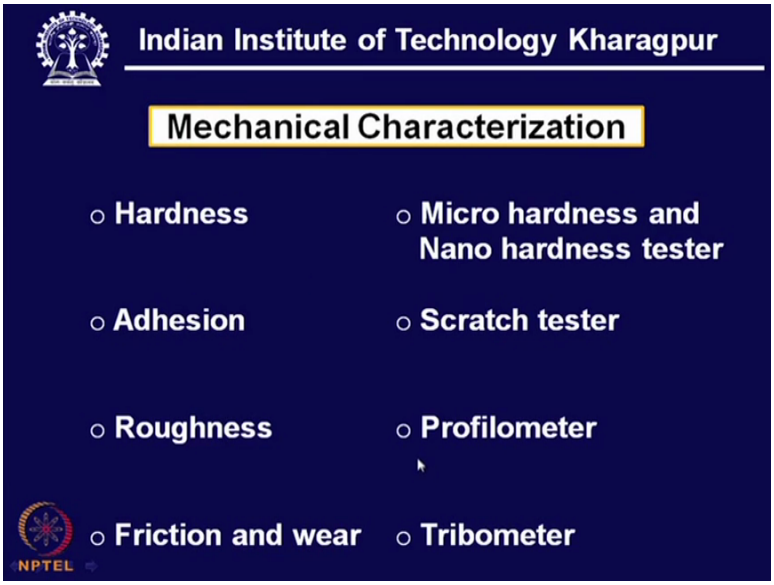

For mechanical characterization, what we see, it is actually the hardness which is of immediate interest very importantly, adhesion of the coating at this coating substrate interface. Roughness

of the coating, considering the coefficient of friction and finally it is the friction coefficient. And we have thus all the tools for mechanical characterization. Micro hardness, nano hardness tester, scratch tester, profilometer and tribometer, so these are the tools which goes with this mechanical characterization for this, making this diagnosis of these properties.

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Finally comes to the performance evaluation. It is the field test. If it is cutting tool with a proper coating, proper formulation of the coating, then this cutting tool should be put, submitted to this machining test. And in the machining test, we monitor, we measure the cutting force, temperature, chip morphology, tool wear, workpiece surface quality, so all these thing.

We should be able to make out a difference between the uncoated version of the tool and the coated product and between the coating materials depending upon then performance we can also able to say which one is the best performing, and which one is most suitable. So these are the activities one has to perform starting from this coating process, ultimately to the field test for the coated product.

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So in summary, what we can say that significance of surface coating technology is in bringing up high performance surface engineered materials is highlighted. Remarkable improvement of capability of a product just by means of surface coating is also demonstrated. The main activity with regard to surface coating is to establish the process-structure-property-performance relationship for the coating material.

Engineers of various disciplines may require advanced coating materials for developing high performance product. They need to know the above mentioned relationship in order to select the most suitable material and the best coating process for each task.