**Technology of Surface Coating**
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**Lecture 26**
**Coating on Abrasive Grain**

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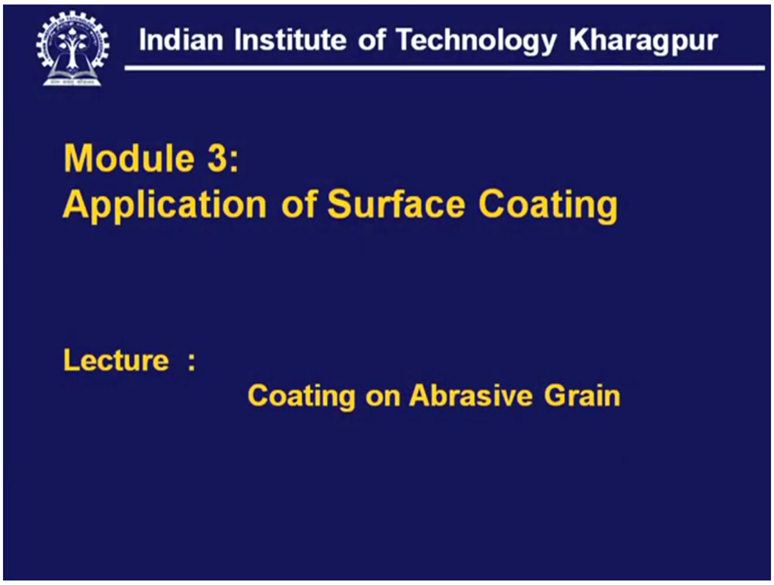


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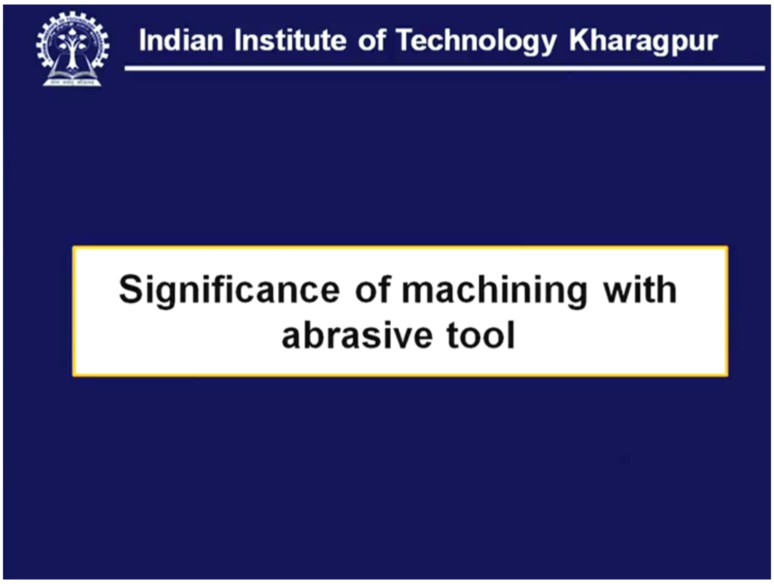


Application of surface coating on abrasive grain. Now let us look to the significance of machining with abrasive tool where we can find one of the most important applications of the abrasive grain.

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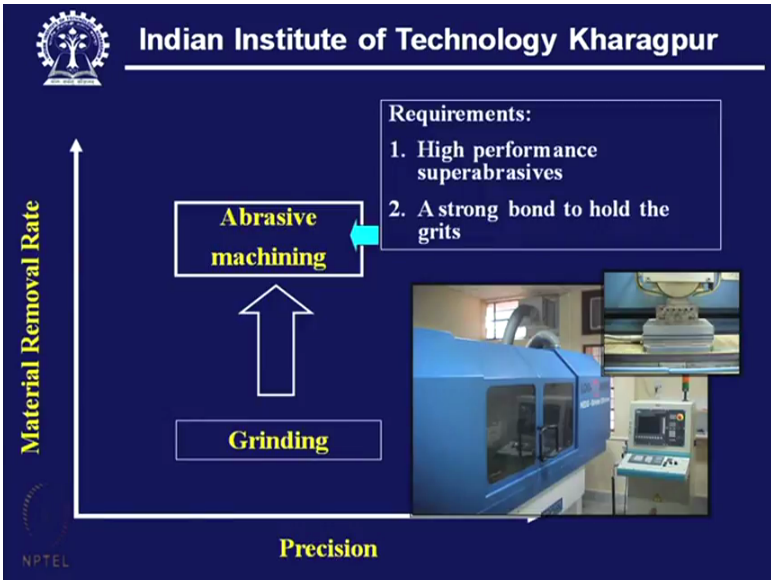


In this figure what we see? That on one side we have material removal rate and on the other side it is a precision of Manufacturing. Now in this whole process what is employed? That is the cutting tool and this cutting tool is employed here to get a very high material removal rate but not as high as precision which is provided by grinding. So this is the characteristics of machining by a cutting tool.

On the other hand if we see the situation with grinding we can see the precision is quite high but the material removal rate is not adequate. So that is what we see here, the machining by a cutting tool and machining by one abrasive tool they have their own domain of application. However this grinding can be elevated and it can attain the status of abrasive machining if we increase the material removal rate which is comparable with that of, which is provided by a cutting tool and then this grinding becomes abrasive machining.

However to achieve this there are at least 2 minimum requirements to be met. One is the abrasive material must be a high-performance super abrasive and there must be a strong bond to hold the grits. Now if we compare cutting tool which is used in turning, milling or drilling and one abrasive tool which is used in abrasive machining these abrasive grits, these are actually micro point cutting tools.

And just like we use a tool holder to hold the Carbide inserts or a HSS bit, there must be a tool holder and in this case, this bond plays the role of the tool holder. So it is obvious that this abrasive material which is high-performance that should be strongly held in the bond material. Now here obviously high-performance super abrasive means it must have extraordinary wear resistance, high temperature stability, chemical inertness and adequate toughness and we know already that conventional abrasive, Aluminium Oxide and silicon Carbide those cannot be the best candidate for this abrasive machining purpose. So we have to really look for some kind of grit material which is suitable for this abrasive machining.

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Now here we find that the super abrasive grit material can convert this grinding or abrasive machining to super abrasive machining and here what we get accuracy and surface finish of super abrasive grinding plus extremely high material removal rate.

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So this is one example of super abrasive machining engaging a super abrasive tool and this is just a steel core on which one of super abrasive grits are anchored or bonded and that works at a very high speed generating huge amount of spark but at the same time removing large volume of material which is comparable with that of machining but at the same time its surface quality which it is going to produce that is as good as that of grinding.

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Now what is meant by super abrasive material? As we know that conventional abrasive material which is used in traditional grinding those are actually Aluminium Oxide and silicon Carbide. So Aluminium Oxide is used for all sort of ferrous material processing whereas Silicon Carbide that is used for processing nonferrous material Carbide and some of say cast-iron base.

Now here we can find that this diamond that is one of the strategic material which can also be used for machining nonferrous material ceramic then Tungsten Carbide and so on whereas if we have our focus on cubic Boron Nitride then that is earmarked that is fixed for taking those grinding task as grinding of various grades of steel and which are quite hardened. So these are 2 class of materials diamond and cBN they are known as super abrasive which are fit for super abrasive machining.

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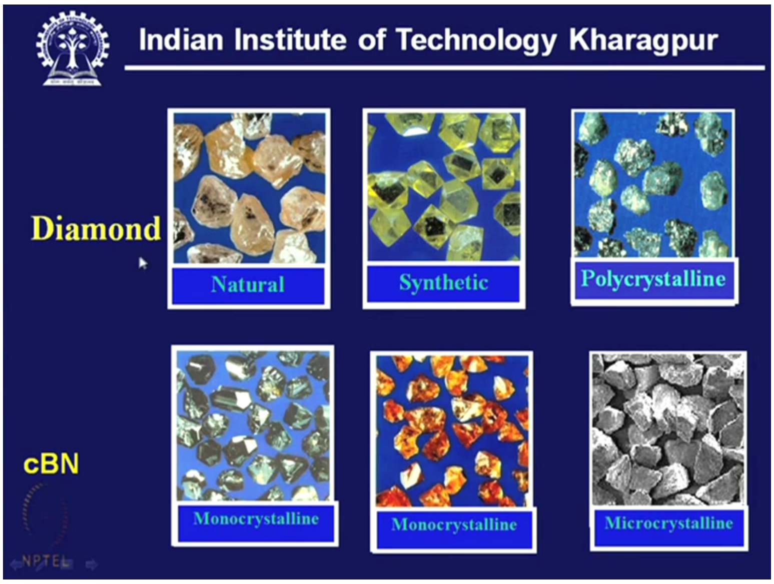


Here we see various types of diamond and cBN this is one of the natural variety which is mine one, mine diamond, this is synthetic man-made which is a single crystal type having a blocky shape very strong and tough these are used for difficult grinding task. Here we have also polycrystalline diamonds which are used for grinding delicate material just like Tungsten Carbide grinding where the work material is very sensitive to heat and force associated with grinding.

Now in the cBN family what we see? That basically we have 2 types of cBN, one is monocrystalline that means here we have these 2 are monocrystalline and this is actually the microcrystalline. So in monocrystalline we can see this is little dark in appearance while you have the Amber colour that this difference comes from the fact that this has some access boron that means excess boron whereas this is having excess nitrogen but both are of single monocrystalline type, one is blocky very strong but another has little friability that means its ability to breakdown in a very controlled manner.

Whereas this microcrystalline it is extremely tough material, it doesn’t have a well-defined crystallographic plane and as a result of that we don’t expect or there is no risk of any cleavage along a particular direction and it can be used for taking any difficulty grinding task.

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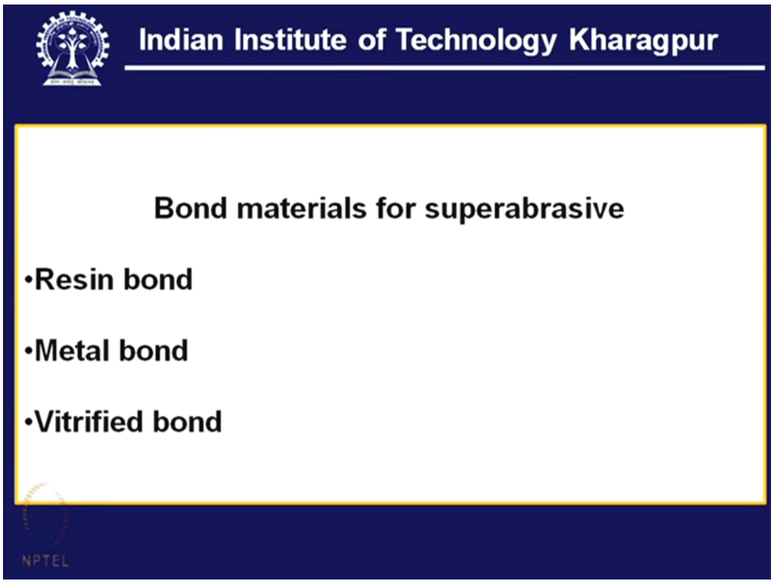


Now comes the bond for super abrasive material as we know that if it has to act like a cutting tool then this diamond or cBN these are the cutting tool. However the resin bond or the metal bond or even vitreous bond they are actually the tool holder. So very important issue here is that, this material during grinding should have adequate strength it should not crumble or crushed.

It should not have some plastic deformation have some rigidity and at the same time it should not have any thermal damage or thermal degradation during grinding or super abrasive machining operation. So depending upon the grinding problem one can have a resin bond or a metal bond or even vitrified bond and if we again look into these various types of diamond or cBN that there is a correlation between this type of crystal and the type of bond which are best fitted for a particular grinding operation.

That means this synthetic material diamond or cBN along with the bond material that becomes a integral body to match a particular grinding operation and it depends upon the work material compositions mechanical characteristic and chemical characteristic.

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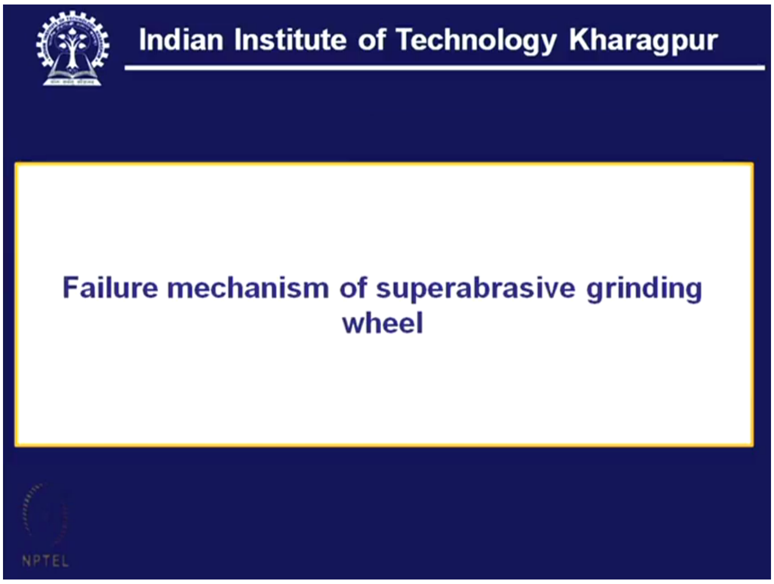


Now what is mean by failure mechanism of super abrasive grinding wheel? It has been well understood that in super abrasive machining or grinding the grit is a high-performance material. So this material has a very long service life it is in contrast to conventional abrasive. So what is very important in this case? That this grit material must be held with the strongest possible grip on the bond material and this grit should not have any premature dislodgement during the course of grinding.

So what is meant by this? That this grit material with the passage of grinding can have natural wear that means it is the grit wear it can be at attrition or micro-fracturing but this grit should not have any premature dislodgement. So what is important here? The interface between this bond material and the grit material has to be developed with strongest possible adhesion and that becomes the primary or the main challenge in bringing up one of the high-performance tool which is supposed to work in super abrasive machining.

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So here we see attritious wear, microfracture, microfracture of the grit these are all on the grit but this is exactly grit pullout that means as a whole the grit is removed from the bond's leaving just a socket or a pocket or it looks like a whole. So this has to be prevented at any cost.

Now failure of the bond material, in fact the grit and the bond they must work like an integral body neither of these 2 should fell. So if we consider failure of the bond then we can see at least thermal degradation of the bond, it is particularly applicable for resin bond. If the temperature of grinding is too high then this heat load, heat flux will be transferred by the grit material to the resin bond and this resin bond may simply burn.

Fraction of the bond, if the bond is too brittle it can also collapse under the action of high magnitude cutting force. Yielding of the bond, if its rigidity is not too high it can also undergo some plastic deformation then comes the bond erosion. Now during the process of abrasive machining, what is going to happen? The chip material which is continuously being produced and flowing, it is flowing pass the bond material which is similar to the rake surface of the cutting tool and just like crater wear, what we see on the face of the cutting tool?

We can also have very similar to that which will appear as erosion on the bond and it is erosion takes place at a faster rate than there will not be any material support and within a short period of time the grit will lose bond support and there could be also fallout of the grit.

So this is one very important illustration highlighting this failure mode of the wheel by this grit pullout this can be a cBN grain or diamond grain which are bonded or anchored to the bond. However if this bond is not adequate which depends upon the coverage around the grit and also the nature of adhesion, what if? If it is physical adhesion, mechanical adhesion or even chemical adhesion that will determine how strongly it is held in the bond.

So if we don't have adhesive strength then it will end up and it is going to happen within a short spell of grinding and what we can see here that so many numbers of pockets appear that means these grits hardly could engage themselves in effective grinding, so what we can see? Individually the grits are very strong, durable all sort of stability, chemical, thermal everything they possess.

The bond material in its individual capacity it has all physical, mechanical characteristics but their interface is one of the extreme link and that is the weakest zone and that's why there is this large amount of pullout which has taken place.

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So here we can find out some solution, some ways and means, how to prevent this premature fallout of the grit? If we refer to a cutting tool when we put coating to improve its wear resistance or to reduce the friction at the chip tool or work tool interface but in this case it is not the tool, it is a micro tool, thousands of micro tools which are very much in place in the grinding wheel and which are actively participating their surface is coated in order that they can have a better attachment with the bond material and exactly for that this surface coating comes in aid of abrasive tool.

However apart from that this coating can also protect the bond material against any thermal damage that means this coating that shield that can act like a heat shield and it is just like an encapsulation around the grit material and it at acts like a heat shield or a heat sink protecting the bond material. It can be another quality of this coating that means if during the manufacturer of this grinding wheel the bond material comes in close contact with the abrasive.

During this high-temperature processing of sintering or liquid phase bonding there may be a risk that one of the constituent material of the bond may chemically or metallurgicallly attack the abrasive grit. So in that case also if coating is given on the surface of this grit material then a direct contact between the bond material on the grit is prevented and that's why this attack metallurgical or chemical from the bond side towards the grit that is also prevented.

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Here what we see? On diamond grit which are used for making one resin bonded abrasive wheel which is exclusively used for grinding of Tungsten Carbide which are used on the cutting tool, so it is one of the very delicate and sensitive operation that means the force or the temperature during grinding should not be allowed to rise I mean above a threshold value which may otherwise cause damage to the work piece.

So this is actually dry grinding, this is a poly crystalline diamond which is having a good micro fracturing characteristics always keeping the grit material sharp. Holding the force and temperature within a control limit, now this dry grinding is essential for this grinding of Carbide.

However during grinding temperature may rise and this diamond is also sensitive to this temperature there could be some thermal degradation of this diamond, so in this case this coating of copper which is used as a heat sink which can conduct the heat from the grinding zone and that will be accumulated in this sheet which is a film of copper. Now this is a grit specifically use for dry grinding of Tungsten Carbide. Now these coatings of copper on this diamond grit that can be given either by electrodeposition that means a galvanic deposition or also by electro-less deposition both are possible.

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Now comes Nickel coated diamond grit, so these are the Nickel coating on diamond grit. As we have seen that copper coated diamond grit those are specifically meant for dry grinding. This Nickel coating is given on the diamond grit it is for that grinding purpose. So in this case we can increase the material removal rate or grinding parameters expectedly the temperature or force will rise but in that case this Nickel being a pure conductor of heat that will act like a heat shield and it won't allow this heat flux to move towards the resin bond does the bond is protected against any thermal degradation.

So this Nickel grit, Nickel coated grit here the coating is thickness of the coating or the amount of coating is assessed by the wet percent discount amount it is almost about 60 to 65 percent by weight by weight of that of a diamond grit. So this is used for this wet grinding purpose and this is used with resin bond.

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Now we come to Nickel coated cBN grit. One thing we have already seen that this surface is also rough textured that means it is not only for protecting the grain against any heat flux or protecting the resin bond against any thermal damage but more important is how to hold this grit within this resin? Because the resin and the diamond there is no chemical attachment as a result of that there is every chance of fallout. So it is intentionally a rough texture is developed on this diamond surface by this particular coating process.

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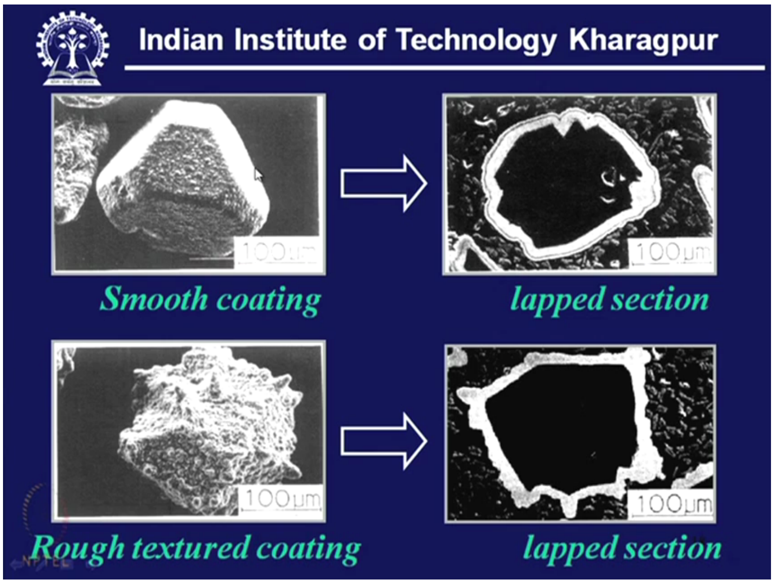


So when we see, this is actually a cBN grit, this one too it is coated with Nickel and here we can see the cross-section of this Nickel, these 2 pictures that show the thickness of this Nickel, this is the core area that means the original grit. Here it is a smooth coating and that is a rough texture coating and this grain's grit goes with the resin bond. So here mechanical Anchorage is more important and we can have a careful look that we can see the spikes and these spikes actually act like good mechanical anchor and this resin bond have performed grip on the surface and as a result we expect longer life of this grain within the bond and there is hardly any premature dislodgement of the grain.

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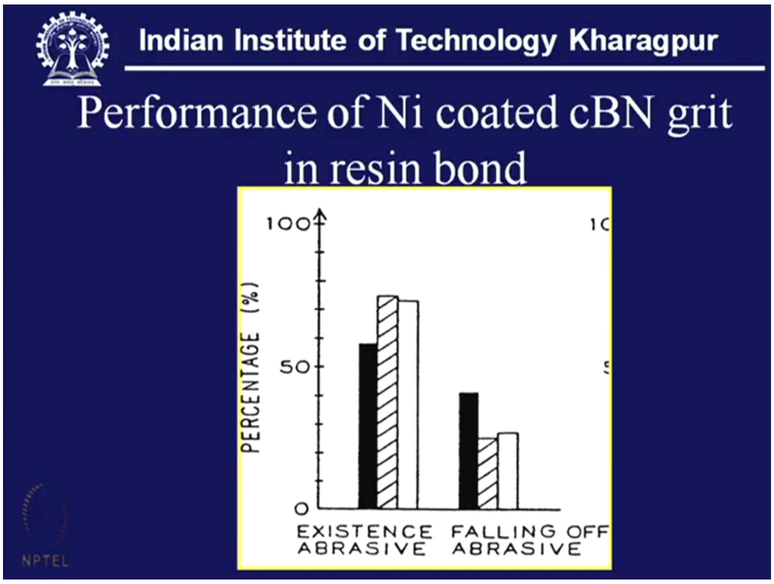

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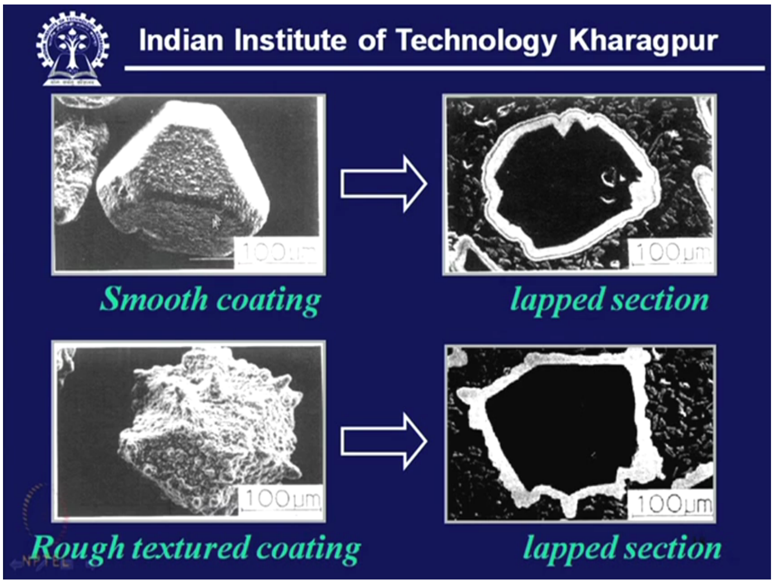


So if we see the performance of this Nickel coated cBN grit in resin bond, what we can see here this black bar diagram? That shows that this is the grit retain and that is fallout. So here we can see this fallout number is quite large, quite substantial but when we put this coating then we can see that retention is much better and fallout has also come down and this difference is because of this roughness value which is a relatively smooth coating and which is a coating with this outgrown Nickel which are acting like Spike and serving like an anchor in the bonding process. So one can immediately realize the very significance of this grain coating in reducing the premature fallout of the grit.

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Now comes Titanium coating on super abrasive grit. So this Titanium coating is given by vacuum evaporation, ion plating or by sputtering. So these are all PVD processes, for Titanium CVD within a range of 1000-1100 is just not possible because of the chemical stability of Titanium Tetrachloride which doesn't allow one to reduce Titanium and here these processes are well matched with this grain coating.

So this coated surface, we can have a look here these are the Titanium coating about 1 micron thick on cBN and these are the very strong cBN grit which is having a blocky shape. It is a monocrystalline in its structure this is the surface morphology of that coating. Now this coated grit can be used either in a metal bond or in a vitreous bond. Now in metal bond since it is ceramic and metal there is a chemical mismatch.

So this metal bond ordinarily cannot have any chemical attachment, conventionally it can't have. However if we provide a coating of Titanium in that case this Titanium can have a chemical attachment with this cBN because of the reactivity of Titanium and at the same time this outer surface of the Titanium can go well with the conventional metal bond and there we can have a good bonding.

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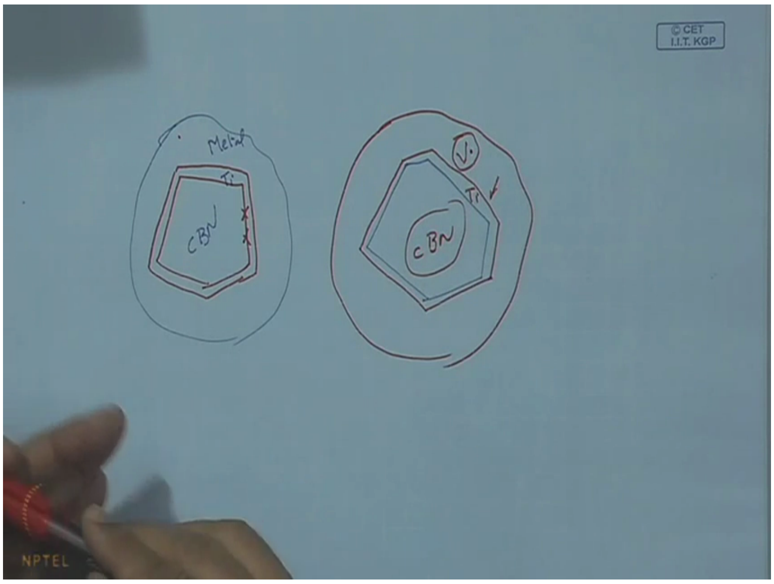


So it will be something like this, so this is the cBN grain and on that we have a Titanium coating. So this is one interface and it will be embedded in a metal metrics and this metal metrics normally is inert towards these highly chemically stable cBN. So inside you have cBN this is Titanium coating and here you have the metal metrics. So Titanium is making a chemical attachment here and then outer surface of the Titanium is also making a metallurgical attachment with the metal metrics. So this way we can have a very strong bond.

But this cBN with this Titanium coating can also be used in vitreous bond. Say this is for example a cBN grit over which we can put a Titanium coating this coating is essential it is just not for enhancing the bond between the vitreous bonding agent and the grit, no. That is not the requirement, here just outside what we have? This is CBN, this is Titanium coating and here we have vitreous bond.

So this vitreous bond contains many alkaline element and compound which during this high processing temperature that means high-firing temperature this vitrified bond may chemically attack cBN this alkaline material can attack boron, so to prevent that a coating of Titanium is well suited and this Titanium the outer side of this Titanium during this firing can become Titanium oxide and this Titanium oxide can fit well with this vitreous bond chemically. So this way this cBN grain can be also protected against any possible attack by this vitrified bond at a high firing temperature.

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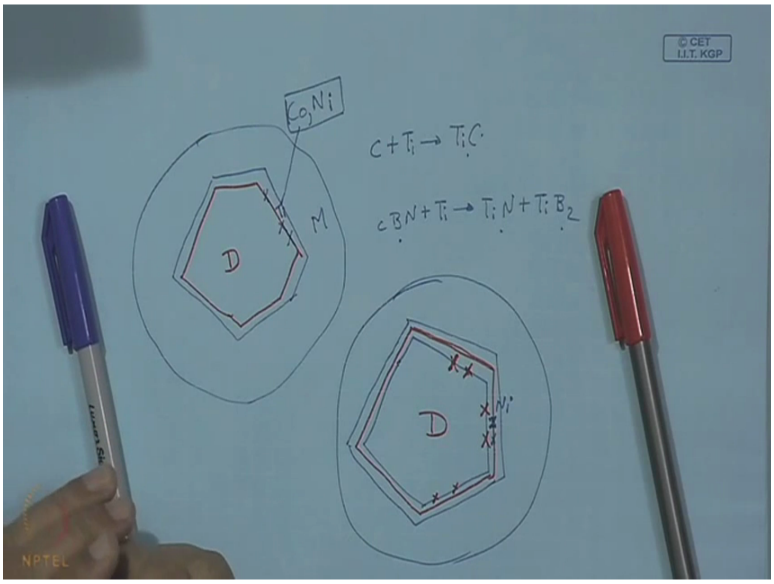


We can also have Titanium coated diamond grit. So in this case what we see? A diamond grit, of course these are the strongest grit, what we have seen? This is a blocky very strong and these are meant for many challenging grinding task using diamond. So here this is diamond, so outside surface is coated with Titanium, a coating of Titanium and just add is embedded in a metal metrics and this metal metrics ordinarily cannot have a chemical attachment as is the case what we have seen with cBN?

So this is a metal metrics, this is Titanium film diamond. So here we have chemical attachment because this is Carbon and Titanium, we expect here to form TiC and in case of cBN what we have seen? Here we expect to have Tin and TiB2. So this chemical attachment, chemical bridge formation is quite possible because of this thermodynamic property these are more stable than this one, this TiC is also more stable than Carbon.

So this part is well accepted but what we can see further to this? The outer surface of Titanium can have good bonding with this conventional metal metrics and we had a very good bond. However it is also observed that in certain case this metal metrics which may contain cobalt, Nickel particularly this material during this high-temperature processing can also attack diamond.

So in that case if we have a coating of Nickel that attack, chances are remote and that Titanium coating actually is protecting diamond. In this connection it can be said further that if this is the diamond coating then we have a primary, this is the diamond grit. We have a primary coating of Titanium which has a chemical bond with diamond. However it is seen that this Titanium is actually prone to oxidation.

So if we have a Titanium oxide on the outer surface then this oxide may not facilitate bond formation with conventional metal binder. So this surface is chemically attached however the whole idea is that here we have Titanium Carbide formation but on this side it should be metallic Titanium and on this metallic Titanium conventional metal alloys can have chemical or metallurgical bonding.

But if this Titanium is exposed to atmosphere there can be a Titanium oxide. Now to prevent that, what is done? It is also a routine practice to put the secondary coating of Nickel. So we have 2 coatings, here the interface between this is Nickel coating, so this is the interface between Titanium coating of Nickel, outer surface is Nickel, so Titanium is totally protected I mean covered.

It is shielded by Nickel and this Nickel is not so easily oxidised, so conventional metal which are not very reactive that can have very easy bond formation over this outer surface of diamond which is now just a coating of Nickel. So this way diamond grits which are used in metal bond which were that grinding task or the abrasive machining task is one of the difficult one.

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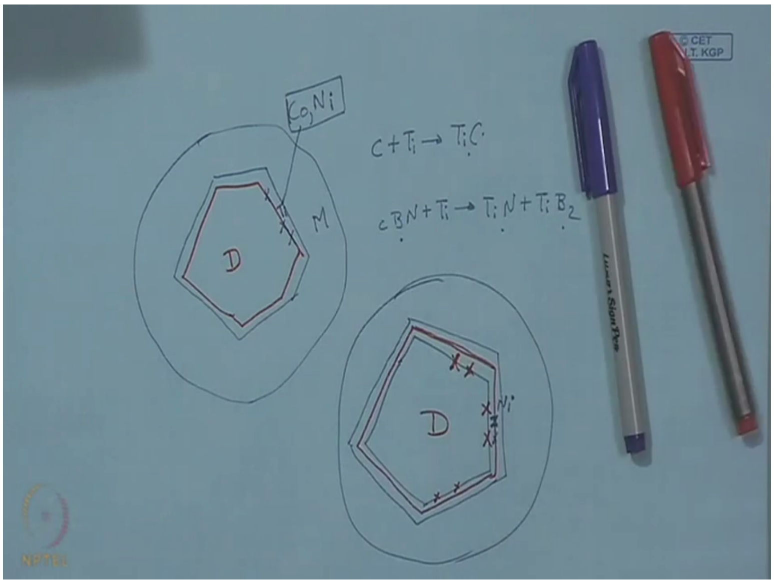


So in that case we expect to have the strongest possible bond formation between the binding agent and diamond. So here we can see that immediate benefit, out of that we can see here that this is a diamond grit which was used in some sawing. So it is a diamond saw and where Titanium coated grits were used and this works without this coating. So what we can see? Cumulative radial wear that means fallout of the material when it is without coating you have large fallout but when it is with coating then fallout is less or I mean sizably less.

So the coating of Titanium and a subsequent Coating of Nickel as when necessary that is found to be much more beneficial in retaining the diamond grit and then these tools can work for a longer life and they don't suffer from premature fallout of this grit material.

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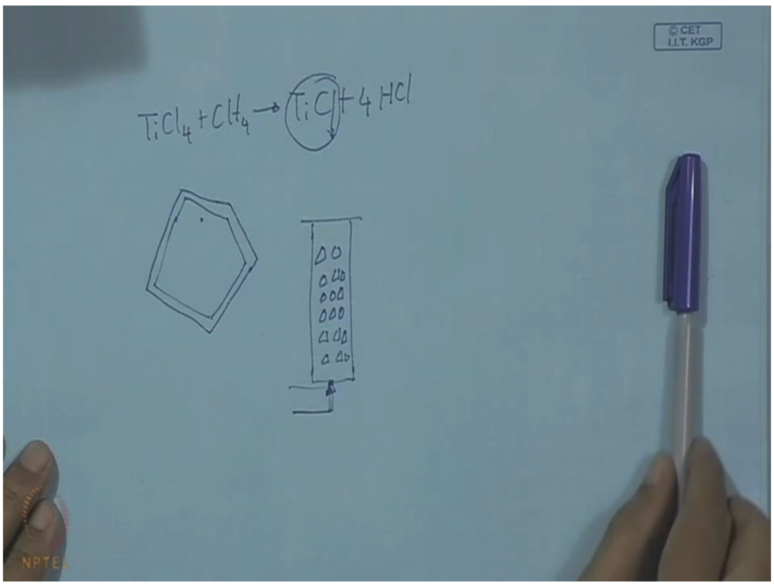

Tic coating on diamond grit where the diamond grits are embedded in vitreous bond, cow we know that Tic coating deposition by CVD that is one of the most interesting process in the CVD technology. So it is TiCl4, CH4 that can easily give TiC plus 4 HCl, so this is the TiC which can be deposited on a cutting tool but in this case it is deposited on the diamond surface and in this case obviously first of all TiCl4 and the Carbon from diamond that will participate to get a TiC sharing Carbon from the core area and followed by the actual deposition by overlay process.

However this TiC is found TiC coating on this diamond surface is found to be quite useful and a CVD technology very easily it can be practiced and it can be used to have a better uniformity of coating over the diamond surface. Of course in this case, what is necessary? It is just not a conventional reactor but it should be a fluidised bed reactor, so that in the vertical tube reactor there will be a suspension of the grit material, so all the reacting gases should be fate.

So it is almost like a vertical reactor and the reacting gases will be fate from the bottom, so here the grits will be in, it will be like a suspended particle and on this grit surface this reaction will take place. So this CVD technology can be used for TiC coating on diamond.

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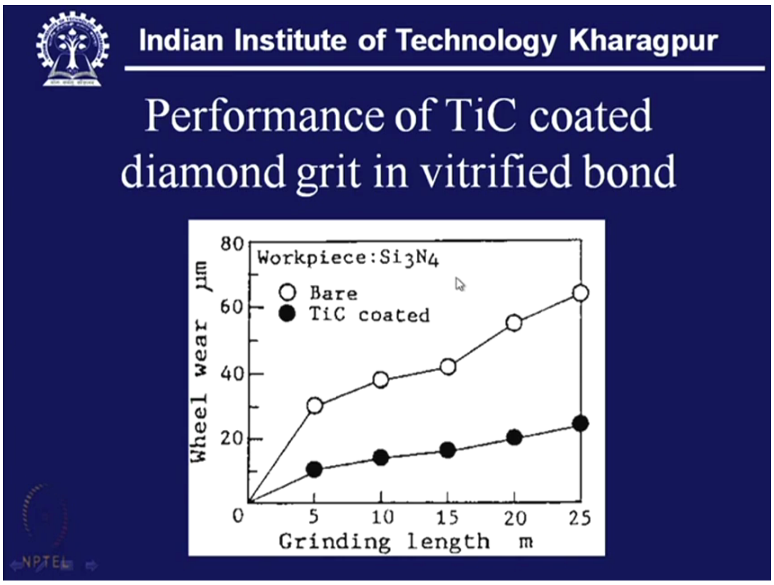


So here we can see immediate benefit that this one with this TiC coating and this is without TiC coating and this diamond was used for grinding of silicon Nitride, a material like silicon Nitride and what is very interesting observation? That just by virtue of this TiC coating the performance of this grit material is augmented significantly and here this is the amount of wear without on a unquoted grit material this is the amount of wear.

So the benefit of this TiC coating which can be obtained just by using the well-established CVD technology for TiC with little modification in the reactor having a fluidised bed. So this TiC deposition on diamond grit is possible and the benefit is immediately recognized.

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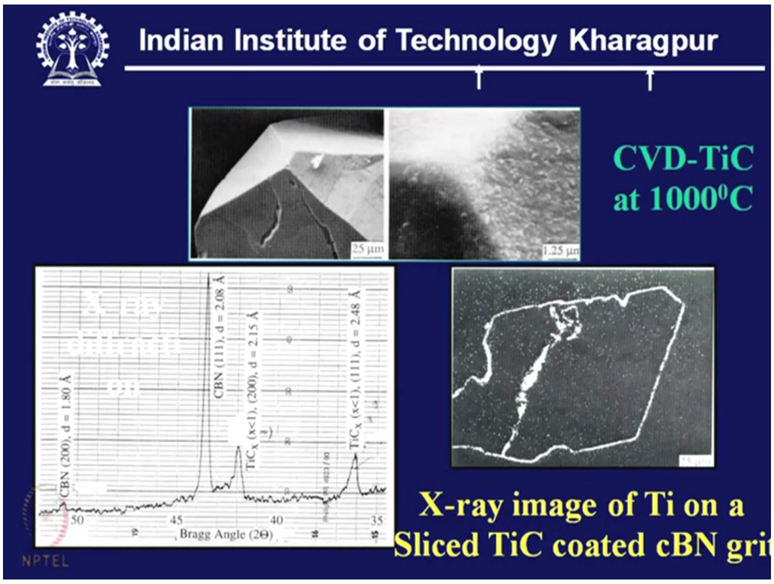


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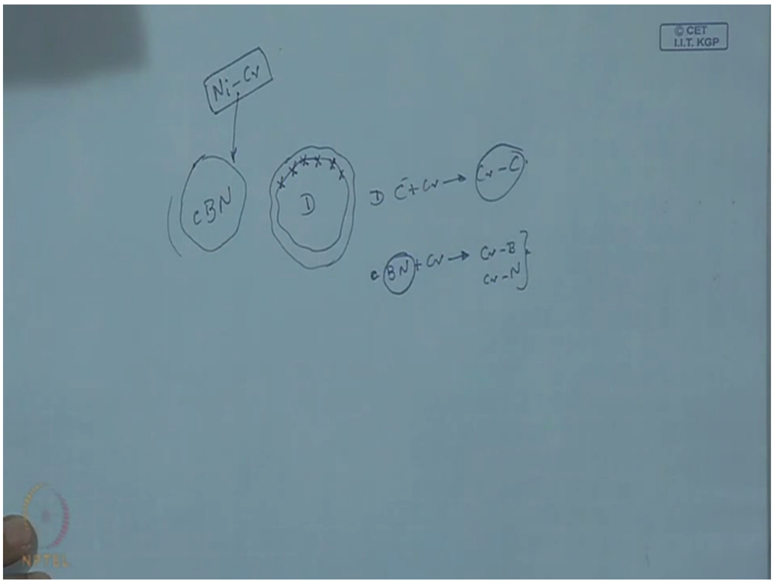

Now this is another very interesting example of TiC coating application on cBN grain. Normally what happens? cBN is extremely stable, this CBN particle and if we put a diamond particle, so this is cBN and this is diamond and what is our observation? That if we have a material Nickel-Chromium base material and if this material comes in contact with this bond with this cBN or diamond that this material can have very good adhesion with this diamond.

It is because of the presence of Chromium, which makes Chromium Carbide and then we have a very good bond formation. Now this diamond that means this Carbon and Chromium that can lead to Chromium Carbide formation. So free energy data actually indicates that, so when this material becomes a liquid than Chromium segregates towards the surface and we can have a very good bonding and wetting.

But this is just not possible with cBN when we have this Chromium with cBN that means boron and nitrogen and Chromium which is actually the strategic material but thermodynamic properties they don't suggest that Chromium-Boride or Chromium-Nitride are evident and they will form that means this is more stable than these 2 whereas this is more stable than Carbon or diamond.

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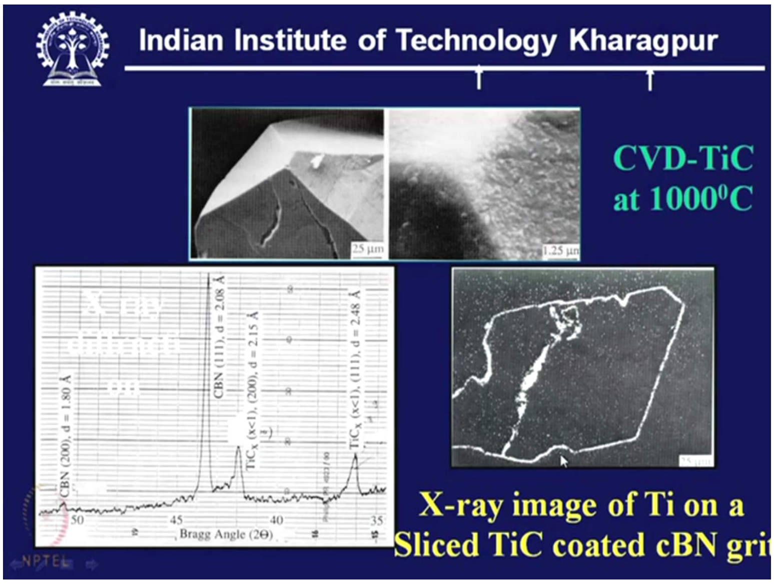


So what is done here to make it wettable? What has been done? An attempt was made it was a success made with success. So in this case this TiC was deposited using the well established CVD technology and this is the coating on this cBN grain and this cBN grain that is actually a monocrystalline very strong grain, it is seen that this intersection of these 2 crystallographic planes on this side, these are well covered the edge is also very sharp edge there also we have very good coverage of the coating.

In the XRD diagram along with CBN we can also recognized the peak of TiC, so it is a Titanium Carbide coating phase that is that can be recognized here and when this grit was polished and it was probed with microprobe analyser and when this image of Titanium was taken it shows that entire periphery this area, so this is actually a poly section and here we can see coating because of this some flaws and voids on the surface.

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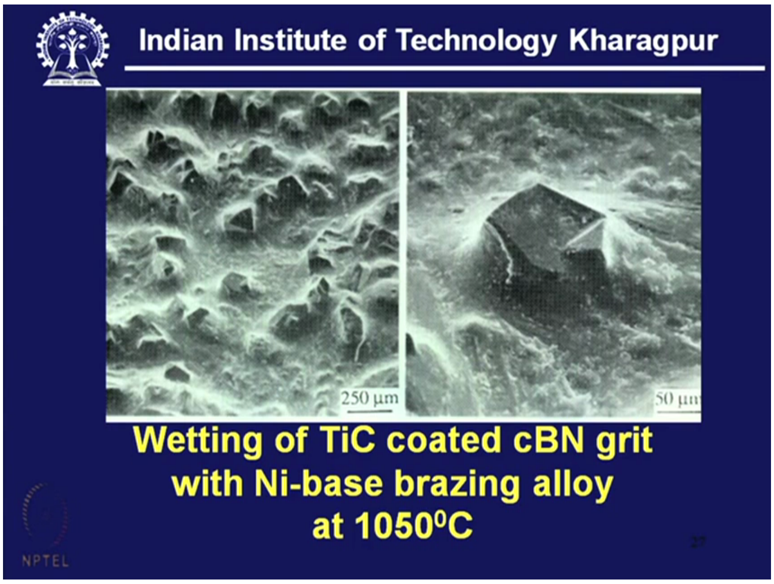


So this even this voids Micro voids which are well covered by this CVD, so this part could not be polished remain unaffected. So what we can see here? That the whole periphery is covered with this coating of Titanium Carbide and this Titanium Carbide really helps in improving the wettability.

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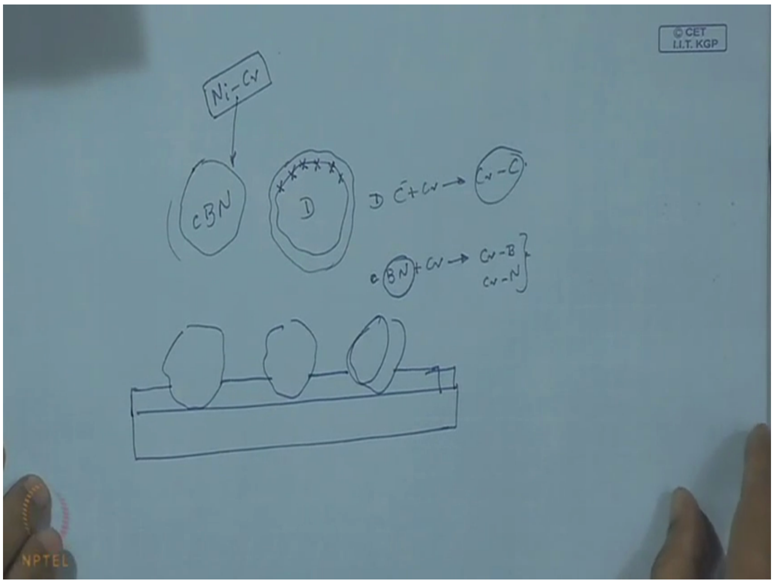


As we have mentioned that when we put this CBN grain on a substrate and here we have this liquid, this metal Nickel Chromium base alloy which was melted and after melting when it is unquoted it didn't wet the surface. So what actually happened?

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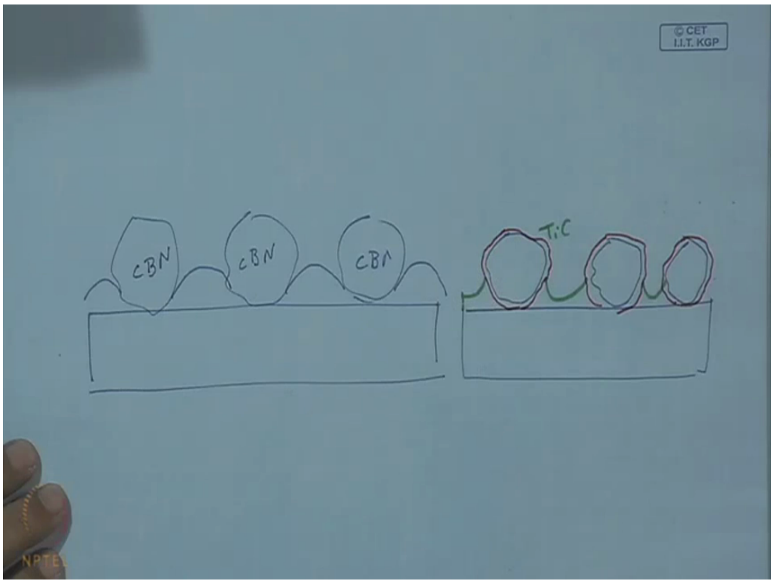


That after this melting, if these are the cBN grain after melting, so this is a substrate on which this grits are resting. So after melting we have a nonwetting profile of this Nickel Chromium alloy. So that means it did not wet cBN, cBN means unquoted cBN but when it is coated with this TiC. So now we have a TiC, these are the grains of cBN and here we have a coating of

TiC and these are again interesting and here we have this binder alloy which will be melted at around 1000 degree or 1050.

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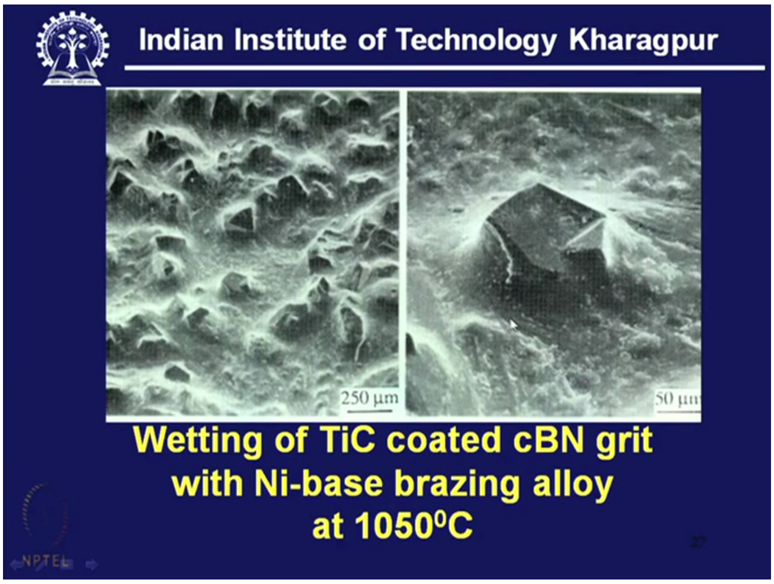


So in that case what we find? This material really has wettability. So this is getting wetted and this is clearly evident in this picture. So this is actually pulled by this coated surface that means this TiC coating virtually pulling this alloy thereby decreasing the interfacial surface tension.

So this is also one interesting study showing that this TiC coating which is conventionally we use to provide a hard coating on a cutting tool or on the surface of the ball of a ball bearing that can be well used for increasing the wettability of a metal which is otherwise is inert and non-wettable towards cBN just by putting this TiC coating this alloy, this liquid becomes wettable.

Also in case of diamond, what we have seen? That the vitreous bond which was otherwise not had that adhesion and as a result of that huge amount of fallout took place just by applying a TiC coating we can improve its adhesion with that vitreous bond.

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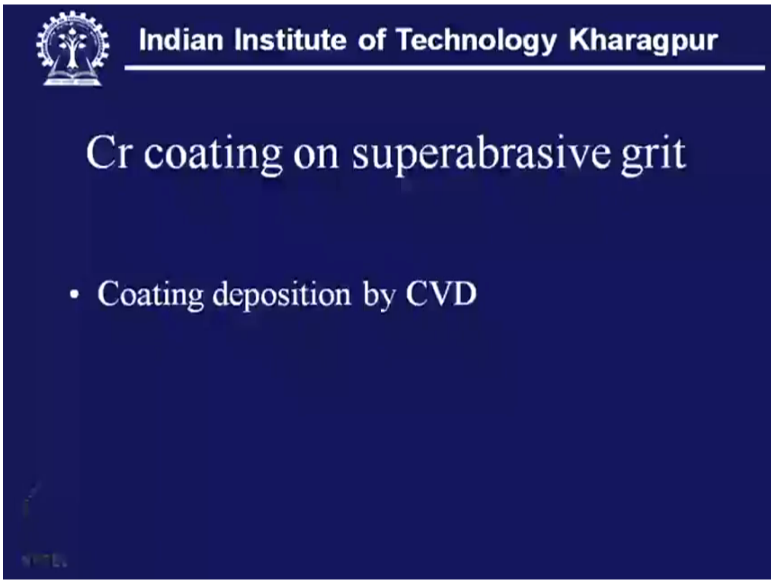


So this TiC coated, so this is further we can see that when the tool was used for this grinding action the holding was so strong that great might have attention fracture but there was no fallout from this surface of this substrate. Chromium coating by CVD that is a routine thing, Chromium coating is used for to mainly to graduate the property of steel, to receive a coating of TiC or TiN.

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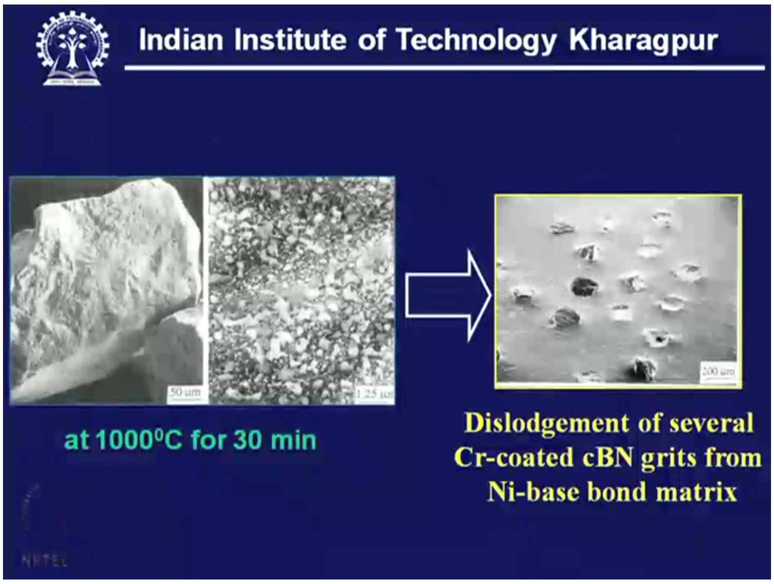


But here we can see that this CVD coating of Chromium can be also attempted on cBN and diamond. However what has been seen? That in this case this Chromium coating the result was not successful in that this coating was not appear like a continuous one, we have some island of this coating which appears to be a non-wettable.

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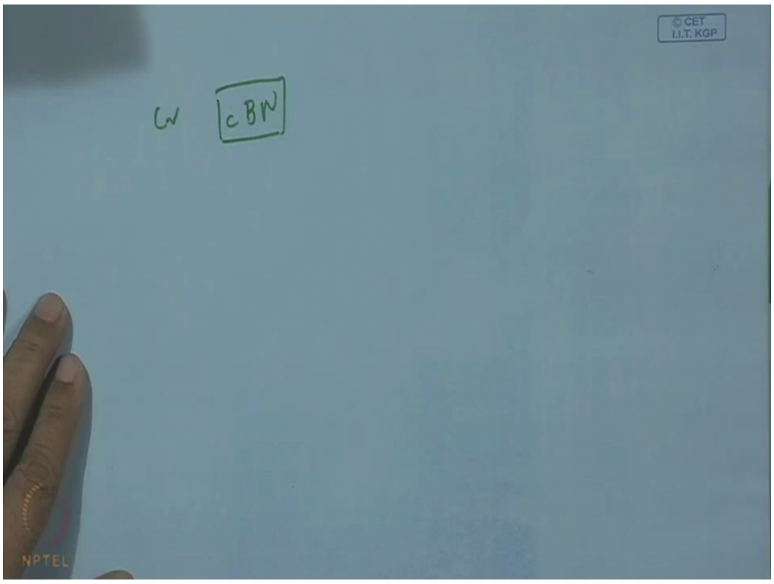


And here also the bonding is also very poor with a metal metrics that means this coating, so this coating of Chromium on CBN that could not be effectively given the reason may be that this CBN is not a very good receptor surface. One reason could be that chemical stability of

Boron Nitride is quite high and Chromium Carbide and Chromium Nitride this material could not be formed so easily to initiate the process of nucleation and growth of coating.

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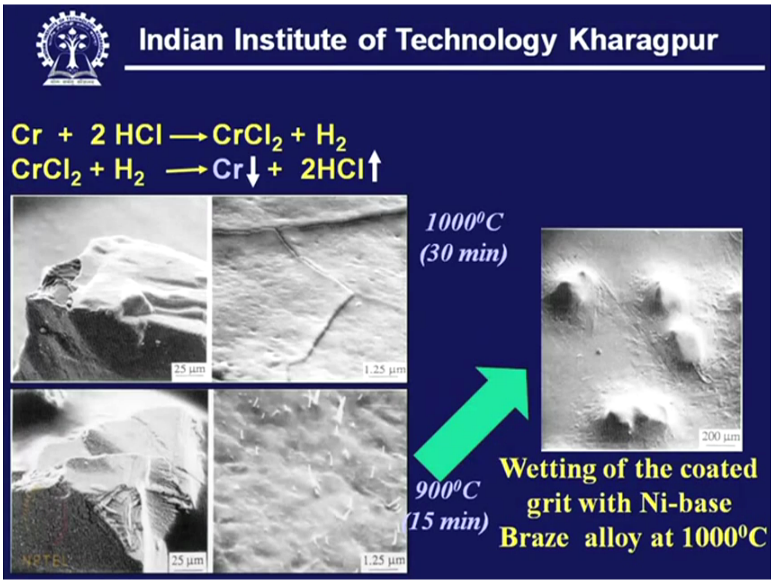


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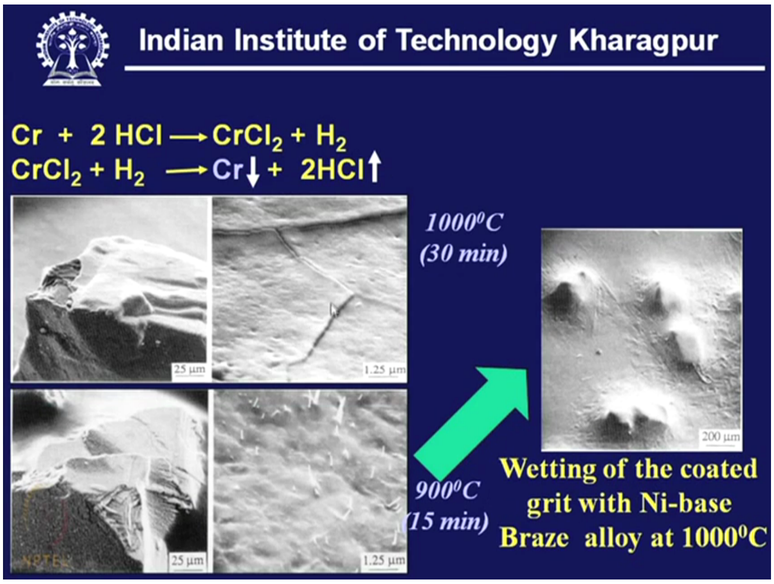


However when this was put on diamond the result was totally different and here even at 900 we could get a continuous coating which is in contrast with what we can see here and this one with 1000 they could have a crack because of the difference differential thermal expansion. So if it is handled with little delicacy then we can have a good coating of Chromium over this diamond surface then these grains are extremely wettable, very good wetting can be achieved with Nickel base alloy which is otherwise inert towards diamond surface. So this Chromium coating can be also used for this purpose.

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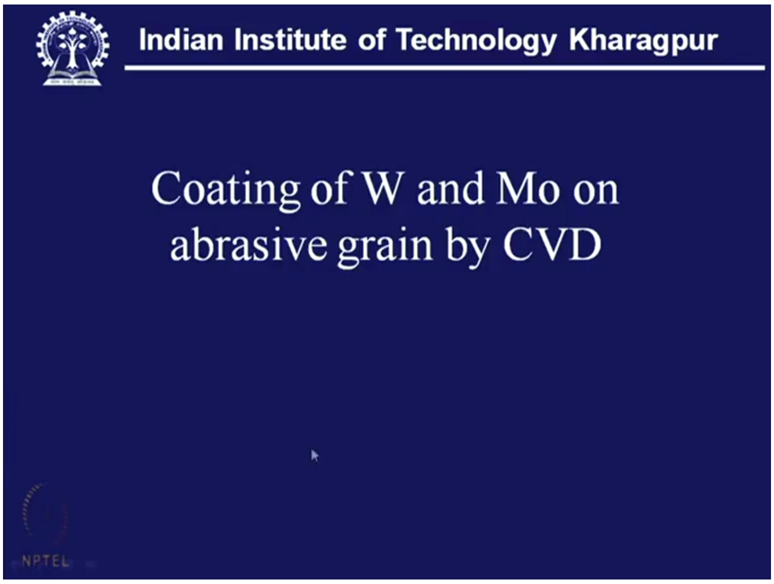


Coating of Tungsten and Molybdenum on abrasive grain on by CVD can be also applied and here of course one thing should be taken into consideration that the reactivity of this Tungsten and Molybdenum towards the cBN or diamond because unless this reactivity exists or a compound is formed then this coating process cannot be facilitated by this CVD operation.

So in this case what we see that Molybdenum and Tungsten these are the material in the group 6B where Titanium is the material transitional element in group 4. Obviously stability of Nitride or Boride of Titanium would be much higher than that of Tungsten and Molybdenum. However the most interesting thing with tension and Molybdenum, so far as diamond is concerned is that they are matching thermal coefficient of expansion.

So if Tungsten-Carbide and Molybdenum-Carbide forms during CVD as a result of interaction between the substrate and the coating then this Molybdenum and Tungsten can be very good candidate for converting a modifying the substrate surface.

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Coating of diamond and cBN grain can be also given in this case, what is going to be achieved? The diamond has good wettability towards many metals where cBN has shown its inertness. So a coating of diamond and cBN can be a good way of enhancing the wettability of cBN surface.

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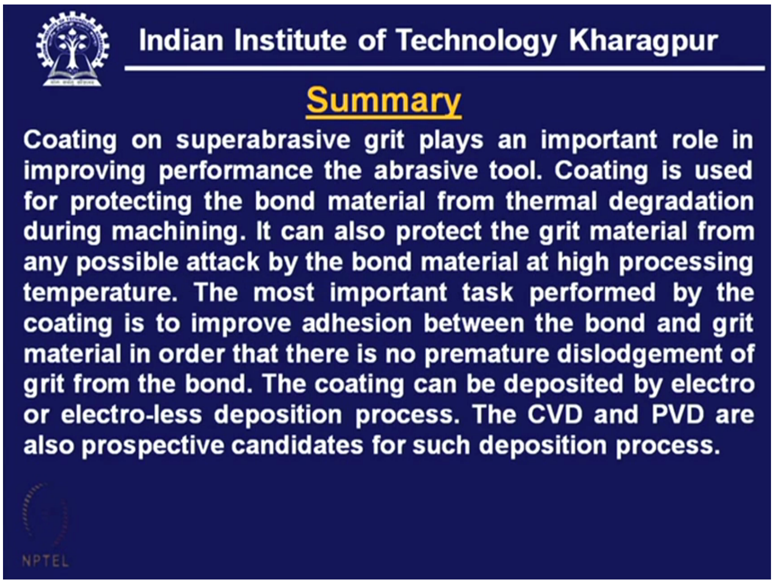


So with that we come to the summary, coating on super abrasive grit plays an important role in improving performance of the abrasive tool. Coating is used for protecting the bond material from thermal degradation during machining. It can also protect the grit material from any possible attack by the bond material at high processing temperature. The most important task performed by the coating is to improve adhesion between the bond and the grit material in order that there is no premature dislodgement of grit from the bond. The coating can be deposited by electro or electro-less deposition process. The CVD and PVD are also prospective candidates for such deposition process.