Manufacturing Processes-II
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Lecture No.16
Advanced Tool Materials

So you are welcome to the course Manufacturing Processes II.

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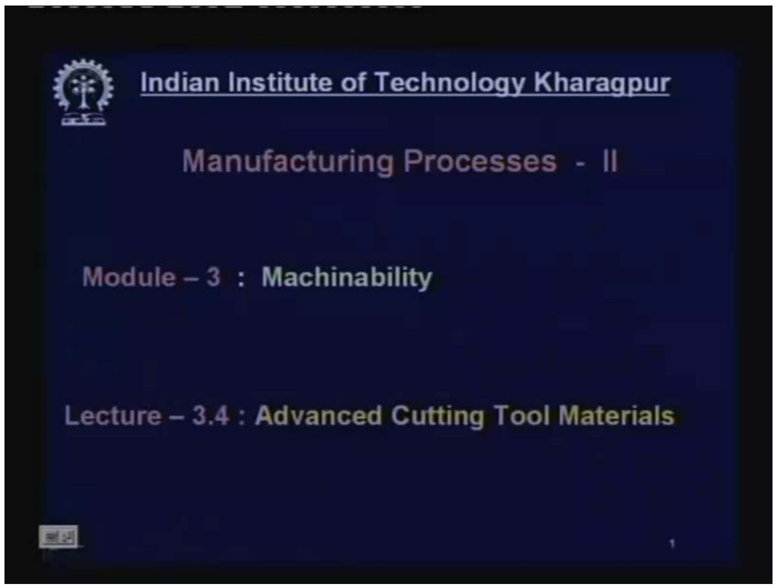

We are continuing Module-3: Machinability and this is the last lecture under machinability. Now today's lecture number 3.4: today we shall deal with advanced cutting tool materials. You know in manufacturing, cutting tools play very important role and the material specially has got significant effect. Last lecture we covered conventional cutting tool materials. Today, we shall cover the advanced cutting tool materials. Now what are the contents of today's lecture? After listening to this lecture, the student will be able to classify, illustrate the properties and suggest the applications of the advanced cutting tool materials like coated carbides, cermets, coronite, high performance ceramics, Cubic Boron Nitride and diamond.

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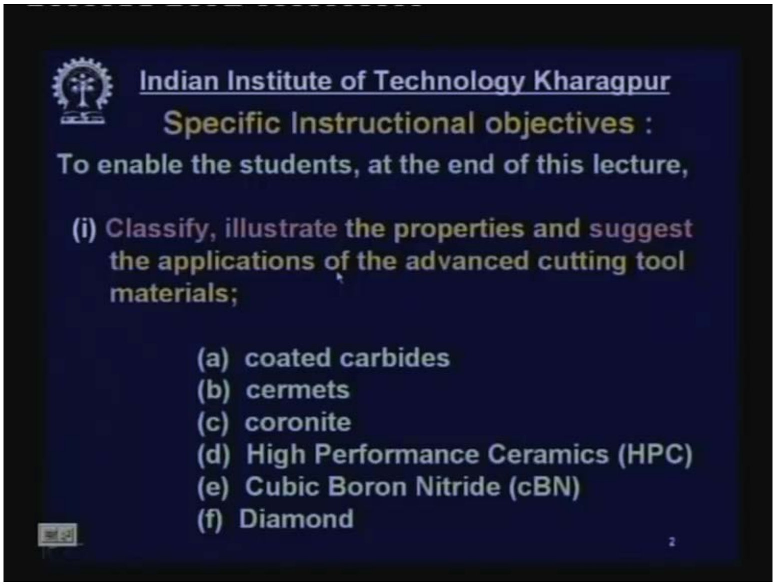

Now let us start with coated carbides. We have already discussed in the last lecture,

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the manufacturing technology, the history and applications of carbide cemented carbide tools comprising of cobalt as a binder and tungsten carbide grains held by the binder. Now it was also mentioned that there are certain properties which are essential required by the cutting tool. Some properties you know some times contradictory. Some properties the tools need at the surface but some other properties it may need at the bulk. For example, ideally a modern tool material for high production machining of different materials need at it is core bulk strength that is tensile strength compressive strength and bending strength, hot hardness for form stability to prevent plastic deformation and toughness to resist fracture and high thermal conductivity to disperse the heat and reduce the thermal gradient.

At the surface, what are needed? High hardness for abrasion resistance. Resistance to heat adhesion and diffusion kind of wear high chemical stability and anti-friction. Now these properties which are need at the core bulk strength, hot hardness, toughness, high thermal conductivity can be provided by the convictional uncoated carbides cemented carbides but what about this properties that are required at the surface that can be fulfilled by a thin hard coating on the carbide inserts. So a thin hard coating on carbide tools fulfills these requirements together. So the core carbide will fulfill the bulk requirement and the substrate and the coating will provide the qualities required at the surface. Now this diagram shows the construction of coated carbides.

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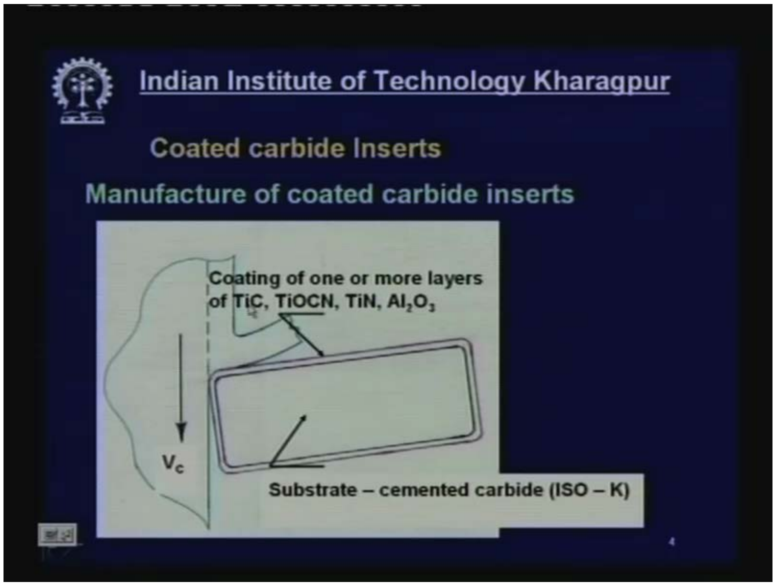

This is the the cross section of the cutting tool inserts, square inserts, and this is the work piece and this is chip flowing out this is the cutting velocity. Now here here you see the substrate the inside. Inside is made of cemented carbide and probably ISO K grade K grade means tougher grade. Comprising having less amount of gamma face. So this is the ah substrate central portion made of cemented carbide and then we get a fine coating at the top of some material like titanium carbide, titanium oxicarbonitride, titanium nitride alumina. Now this layer which is shown may be a single layer of a single material or it can be made of multi layer may be up to 13 layers one after another starting from titanium carbide ending will say alumina or titanium aluminum nitride and various materials. So the upper surface of the carbide a thin layer a thin but uniform layer, thin means may be say from 5 to 15th microns thick layer will be uniformly distracted on the surface and this will be done by CVD chemical vapor position or PVD physical vapor position both methods are possible. So what is the effect, benefits of coating:

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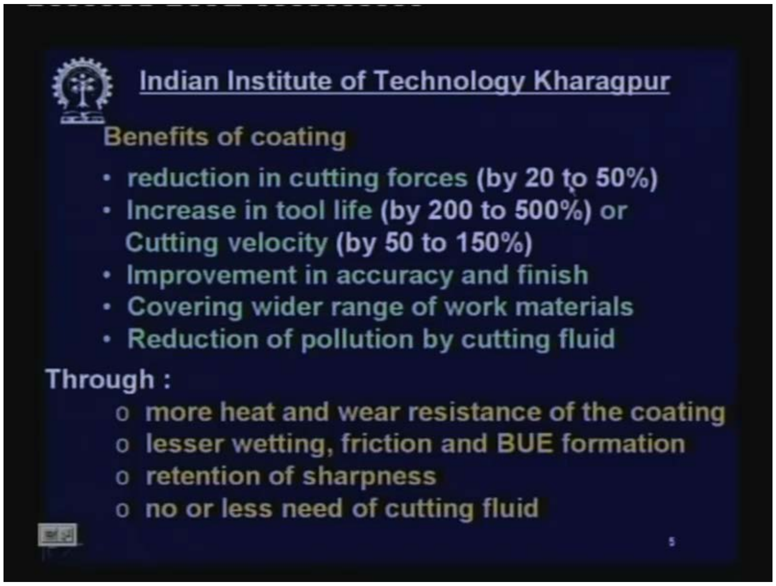

What benefits we get out of this coating process? Reduction in cutting forces by 20 to 50 percent. Now when we reduce the cutting force, what benefits we get? Reduction in cutting per conversion, reduction in energy consumption, reduction in dimensional deflection, or inaccuracy and reduction in vibration. So many problems will be reduced if we can reduce the cutting force. For example 20 to 50 percent by the coating. Increase in tool life. Yes, tool life increase drastically from 200 to 500 percent or we can increase the cutting velocity of the productivity keeping the tool life same say carbide tools normally they can be used at say 50 to 60 to 120.

Now you can use it even at 150, the cutting velocity can be increased by 50 to 150 percent that is earlier it was 120. So it can be 180 meter per minute and tool life will be such a large. Improvement in accuracy and finish. How? Since this tool is wear resistant and temperature resistant, so the cutting edges will remain sharp. So the finish and accuracy will be retained over a long time, covering wider range of work materials. Because of limitations of the uncoated carbide they could be used with in a reasonable range of work material, but when these carbides attain lot of qualities because of the coating can be used over a wider range of work materials. It also enables reduction of pollution of cutting fluid because this coated carbide needs or much less or not at all cutting fluid. Now these qualities can be achieved through more heat and wear resistance of the coating because the material of the coating like titanium carbide, titanium nitride, these are all most stable and wear resistance than tungsten carbide. Lesser wetting friction and built up edge formation that is most stability of the coating material with respect to the steels or work material. Retention of sharpness because of wear resistance and found stability and no or less need of cutting fluid for which pollution will also be definitely control to some extent.

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Now here you can see some you know some typical coated carbide inserts. They are available in form of square, rectangle, then rhombus, and hollow or solid and these patterns are given for chip breaking and compound rake, etcetera that is retained because the coating does not change the pattern. The patterns can be given as such in the uncoated tool and at the top of that the coating will be uniformly distributed irrespective of the pattern. So the benefits of the patterns like built up edge and chip breaking and all this chip breaking and compound rake, a control conduct cutting will be retained. Now further improvements on coated cutting tools are ongoing. It is not it is not being stop for the improvements are going on coating technology. How? By refining the microstructure of the coating, as well as the substrate. Multi layering-using number of layers. Say according to compatibility and other characteristics with in 15 micron or 17 micron, there can be 13 layers of different material to derive the benefits of all the materials possible using better coating materials which are more stable and heat resistive, increasing bond strength by the process improvement in CVD or PVD.

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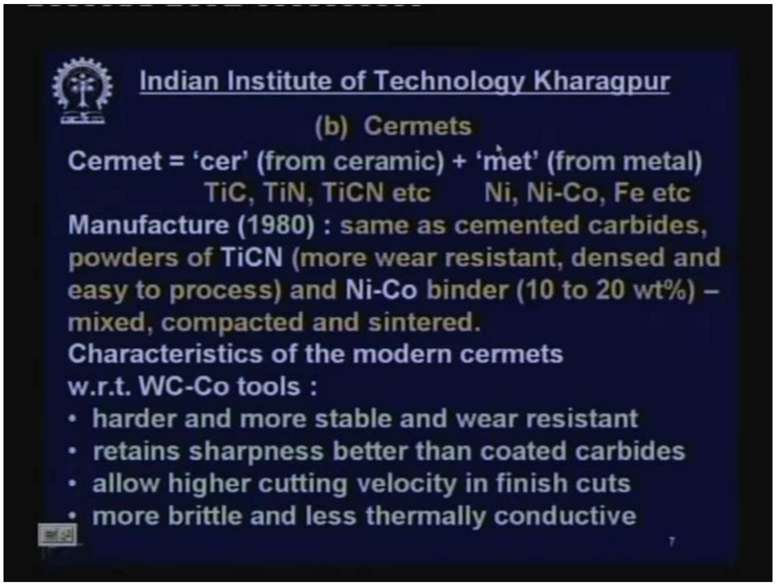

Now come to another class of advance cutting tool that is called cermet. We heard about ceramic plane ceramic in the last lecture. Now it is an improved version of ceramic. What is cermet? Cermet word is coined taking 'cer' c e r from ceramic, plus met from metal. What do you mean by ceramic? Titanium carbide, titanium nitride, titanium carbonitride which are refractory in nature and more stable against wear and therm temperature etcetera and metal which normally gives x is the binder as well as imparts strength and toughness nickel nickel cobalt or iron etcetera. How these are manufactured? These cermets. Some cermets are manufactured in the same way ceramic tool are cemented carbide tools are made that is powder metallurgical process okay that is powders of titanium corbonitride this is really this cermet concept of cermet come to being long back but in 1980 onward, this made a drastic improvement significant improvement.

Since 1980, the process became powders of titanium corbonitride which is much better more wear resistant, dense and easy to process compare to titanium carbide and titanium nitride and nickel cobalt binder 10 to 20 weight percent. These powders are mixed then compacted in die and then sintered at appropriate temperature and so in time. Now what are the characteristic of this modern cermets with respect to tungsten carbide tools or ceramic tools ordinary planes ceramic tools. These cermets are harder and more stable and wear resistant than carbide tools but less harder than plane ceramic retains sharpness this cermets retains sharpness better then coated carbides.

So coated carbides improve sharpness but these cermets can maintain even better sharpness. So this accuracy finish machining can be done better by these cermets. Allow higher cutting velocity in finish cuts. So finishing work can be done better and at high speed. But these cermets are more brittle and less thermally conductive compare to tungsten carbide cobalt tool that is general K grade single carbide. So these cermets cannot be used like tungsten carbide inserts in interrupted cutting or shock loading.

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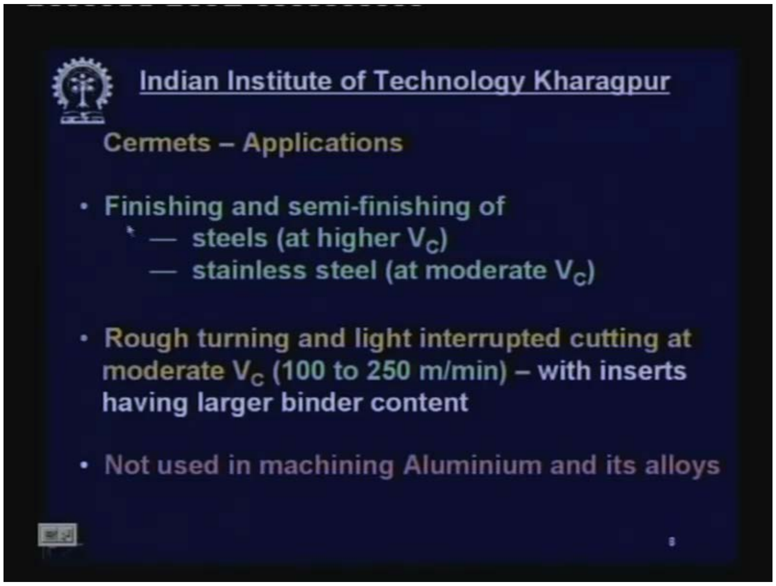

What are the applications of cermets which is a combination of ceramic and metal? Applications: Finishing and semi-finishing of steels at higher velocity that means around 200 to 200 and 250 meter per minute stainless steel at moderate velocity. So this is so stable and good the stainless steel can be machine rough turning and light interrupted cutting at moderate velocity 100 to 250 meter per minute. Now at moderate velocity at high production means large force and there can be little vibration also. So the material get need to be more tough that means having larger binder content that is nickel cobalt content should be more which will impart more toughness necessary for interrupted cutting. But one should be remember there are such cermets should not be used in machining aluminum and its alloys because of poor interaction. Now come to another tool namely coronite. It is very recent development.

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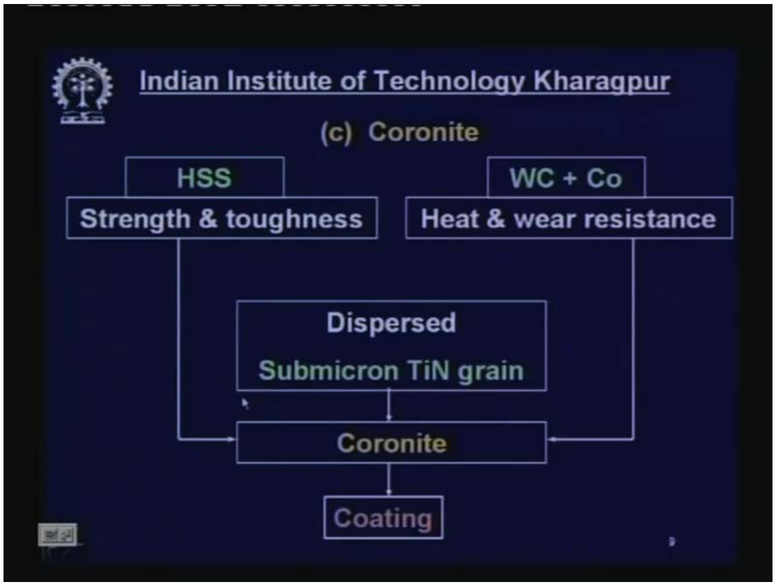

We know high speed steel which has got some unique properties like very good strength, tensile strength and toughness. Tungsten carbide and cobalt has some other properties like heat and wear resistance. So these two have to be combined to derive the benefits from both not only that to enhance the wear resistance, abrasion resistance, diffusion resistance some sub micron label titanium nitride grains will be dispersed throughout the matrix of high speed steel combined with tungsten carbide and cobalt. This will be very wear resistance, heat resistance, strong and tough. At the top of that the tool, will be coated feather by titanium nitride or titanium aluminum nitride which will be having very good bonding, being mixed with titanium nitride already dispersed into the matrix.

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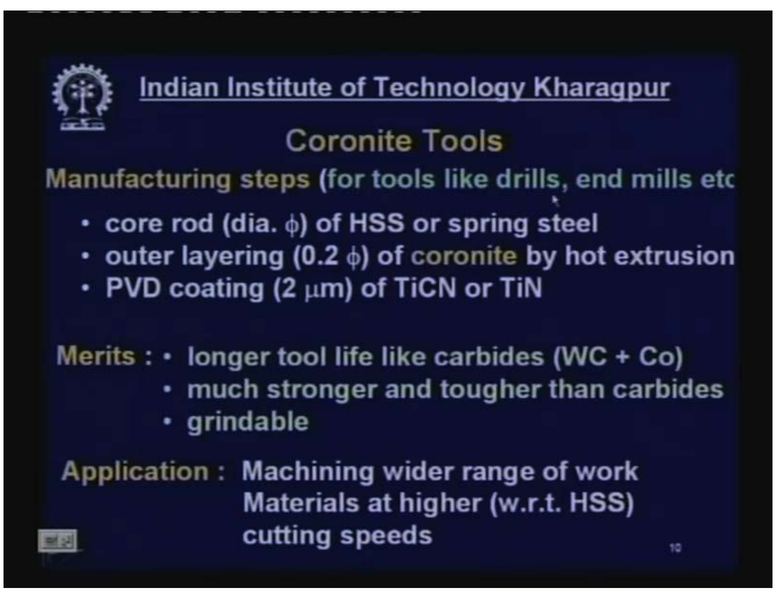

Now coronite tools how are they manufactured? Manufacturing steps for tools like drills and mills that is slander tools small slander like tools cutting tools are manufactured by this coronite material. Actually at the center a rod is taken first ordinary material core rod say diameter 520 millimeter of high speed steel for continuous machining or spring steel for milling type cutters for end mill for interrupted cutting or end mill cutters etcetera then around this stainless steel or spring steel core there will be a layer of coronate that is a combination of high speed steel tungsten carbide cobalt and dispersed titanium nitride so this material will be just you know put at that outer periphery of this central rod and that will be done by hot extrusion by hot extrusion and finally after giving the shape grinding etcetera this PVD coating around 2 micron of Titanium Carbonitride or Titanium Nitride.

This will give the further properties of coating. So this coronite tools with such combination works excellent for small drills, milling cutters, reamers and so on. What are the merits of such tool material compare to high speed steel as well as carbide longer tool lifelike carbides tungsten carbide plus cobalt must stronger and tougher then carbides because of the having lot of high speed steel and it is also grindable because of the grindability this can be resharp a number of times unlike stay light you know the stay light cannot be reground. So that has been absolute. Now, what are the applications? Machining wider range of work materials at higher with respect to high speed steel, cutting speed. So the material which could be cut the high speed steel at certain speed. Now the same material can be cut and some more materials can also be cut at higher speed and productivity by this coronite.

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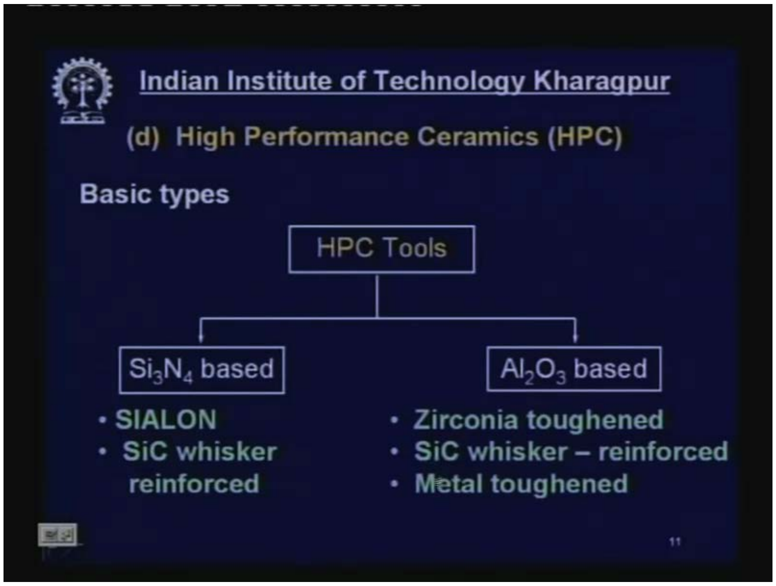

Now let us come to a very very important area of advanced cutting tools namely High Performance Ceramics, name simply as HPC. What are the basic types? HPC tools are of basically two types. Silicon nitride based that is called nitride based, otherwise oxide based alumina or oxide based. Now we know that the characteristic the favorable and unfavorable properties of silicon nitride as well as alumina based ceramics and it has got plenty of good properties like hot hardness, chemical stability, wear resistance, anti-adhesive, antibiotic, diffusing and so on but this ceramics have got the weakness major weaknesses are the lack of strength, lack of transverse of the strength, lack of tensile strength and facture toughness.

Now if these properties can be incorporative or induced into this plane ceramic by some method then this tool will work excellent and will be called it is high performance ceramic. Now here you see the high performance this silicon nitride based tools can be convert into high performance through some making sialon a kind of as tool ceramic tool nitride based. Silicon carbide whisker reinforced. Similarly alumina based tools can be you know strengthen and toughened by zirconia toughening. Silicon carbide whisker reinforcement and metal toughening metal. Earlier, it was done by say iron, molybdenum, cobalt, nickel but recently it has been seen that silver if added into alumina properly and it some brilliant cutting tool material.

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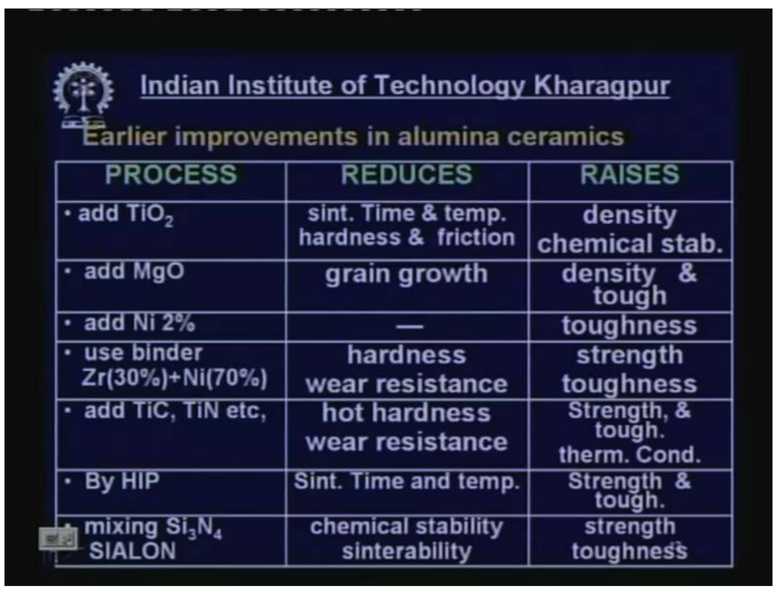
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Earlier improvements in alumina ceramics

PROCESS	REDUCES	RAISES
• add TiO_2	sint. Time & temp. hardness & friction	density chemical stab.
• add MgO	grain growth	density & tough
• add Ni 2%	—	toughness
• use binder Zr(30%)+Ni(70%)	hardness wear resistance	strength toughness
• add TiC, TiN etc,	hot hardness wear resistance	Strength, & tough. therm. Cond.
• By HIP	Sint. Time and temp.	Strength & tough.
• mixing Si_3N_4 SIALON	chemical stability sinterability	strength toughness

Now before making this high performance cutting ceramics, lot of attempts were made since 1950 to improve the strength and toughness of ordinary plane ceramic. What are those simple techniques? Adding titanium oxide which reduce sintering time and temperature. So it is a gain but hardness and friction hardness also decreased. But friction decreased is favorable. It raised the density and chemical stability. Adding little magnesium oxide into alumina. So grain growth was reduced, but density and toughness were raised. Adding nickel 2 percent toughness was raised using binders, special binders like zirconia and nickel combined 30 70 ratio that help reducing harden that helped improving strength and toughness at the cost of hardness and wear resistance. Then by HIP hot iso static pressing it is a costly process but sintering time and temperature substantially reduced. It made economic but as say the process expensive and strength and toughness increased substantially then mixing silicon nitride with alumina we produced sialon which is chemically stable, sinterability improved and strength and toughness improve. Now we shall discuss the high performance ceramic which have

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started in 1970 onwards, first say SIALON. It is a Silicon Nitride based tool what is it. How is it manufacture hot pressing of a mixture of alumina and Silicon Nitride in a powder in appropriate proportion. So we have to derive the benefit of alumina and we have to derive the benefit of silicon nitride that is toughness and alumina chemical stability and wear resistance. Combining these two, we can we will have to get a good cutting tool material targeting what is called sialon but it is producing by hot pressing. So this will be slightly costly. Now unique properties of SIALON: increased hot hardness, toughness and wear resistance. So all the good qualities required for modern cutting tool material are achieved.

An application machining cost iron steels at velocity as high as 250 to 300 per minute it can go. But if you want if you machine even at higher speed then problems will arise at very high speed and temperature rapid diffusion will begin particularly while machining material like steels because of presence of silicon nitride because you know Silicon Nitride is soluble in iron at high temperature. So this will cause diffusion wear. Now Silicon Carbide reinforced Silicon Nitride tools. Now Silicon Nitride is a very tough ceramic. If we add Silicon Nitride whiskers or its a fine rods of diameter say 1micron and length about 6 micron and cross section is hexagonal for a better grip and this whiskers rods are insert into alumina powder or silicon nitride powder just like you know the rods mild steels rods are inserted into concrete beam to enable them increase tensile strength or tens in allow tensile load. Similarly the tensile strength benny strength and toughness will be increase by adding silicon carbide whiskers into the ceramics. So when these ceramics whiskers are added in silicon nitride, we get an excellent performance cutting velocity can go up to 600 meter per minute so high for soft and hand steels and it can be around 300 to 400 meter per minute for harder steels even harder steels it is hard steels. But these tools are very expensive and it has got some other problem also.

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Now the high performance ceramics alumina base. I told you in the previous lecture that, alumina is a more preferred to Silicon Nitride for its some unique properties like it is more chemically stable and easy to fabricate easy to process and it is more stable against steel these are the reason why it is preferred to Silicon Nitride manufacture is easier handing. Now this alumina based ceramics are strengthen and toughened to get high performance ceramic by three methods. What are those three methods? One it is a zirconia toughening. So zirconia say partially stabilized zirconia or stabilized zirconia will be added say 5 to 20 percent into alumina. So that will cause transversion toughening then again addition of silicon carbide whiskers say 5 to 20 percent into alumina powder that will reinforced and finally alumina strengthen and toughened by metal composite metal like silver. Now we shall discuss one by one.

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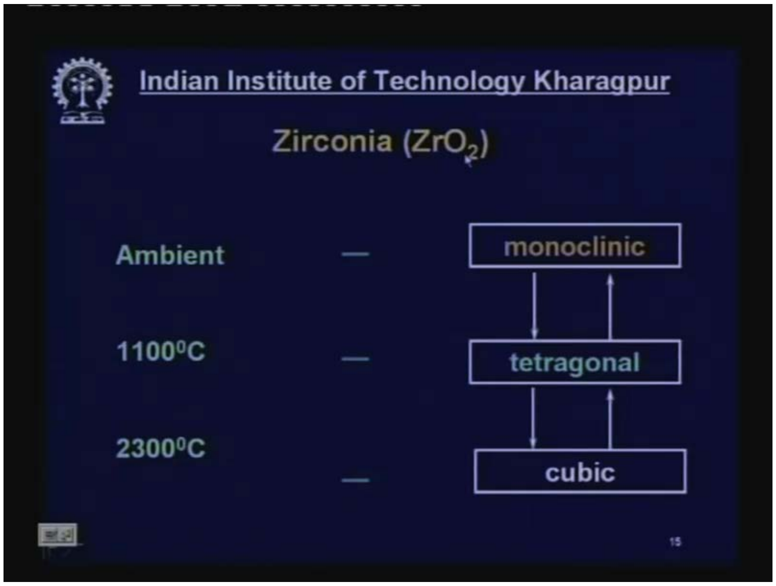

Now zirconia zirconia as I told when added into mixed with alumina it enhances the strength and toughness. How what is the characteristic of zirconia zirconia exists in three forms at ambient temperature monoclinic at 1100 centigrade tetragonal and two thousand three hundred centigrade about cubic. Now the properties when it converts from tetragonal to monoclinic, it expands and in a mix induces compressive strength. Now by dubbing with certain material this tetragonal form face of zirconia is brought at the ambient temperature. Now this metastable tetragonal particles are compressed or pressed or stressed during machining this state to metastable tetragonal particles which have been frozen by dubbing into the ambient ceramic tool. At ambient temperature during machining those particles will be stressed when this will be stressed this will expand and shape. This expansion or transmission tough will cause lot of induction or compressive stress. See the example, suppose there is a crack.

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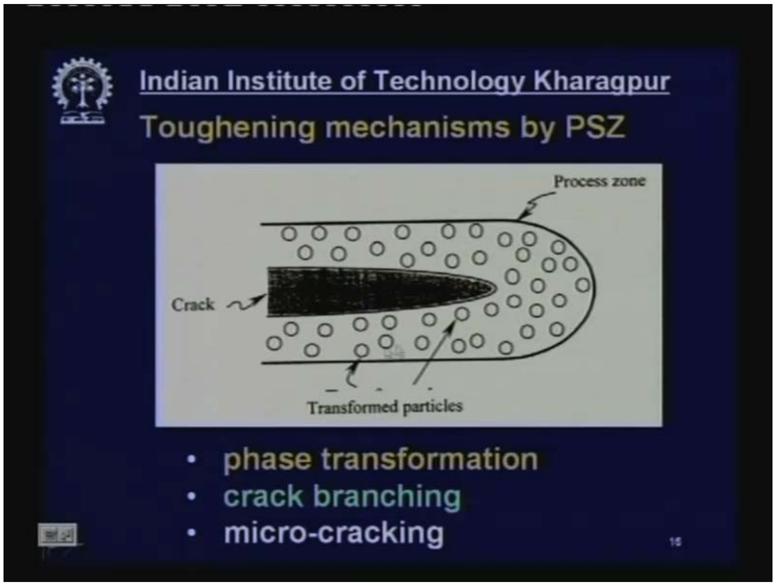

Propagating in a matrix of alumina powders and these are zirconia say partially or fully stabilized zirconia and they are stabilized by some action. Now what happens when this crack propagate there is a stress field with in this stress field whenever this zirconia particles will be stressed they will expand and due to the expansion they will induced compressive stress that compressive stress will nullify reduced tensile stress or nullify it or induced compressive strength and you know compressive strength is very favorable that improves toughness tensile stress is detrimental. Now what is the toughening mechanism by partially stabilized zirconia face transformation that is conversion from tetragonal to monoclinic crack, branching the crack will branch. So the strength of the crack will be decrease and micro cracking and there will be feather micro cracking around the expanded zirconia particles. So this will also weaken the main crack to propagate. Now reinforcement by ceramics:

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Reinforcement of ceramics by Silicon Carbide whiskers: I already told what is Silicon Carbide whisker. You know the Silicon Carbide is a very very hard, stable and wear resistance material okay. Now thin rods of such material have been made. They are called whiskers and as I told the diameter around say 2 to 6 micron diameter 1 micron and cross section approximate hexagonal. These rods are mixed and dispersed in alumina matrix and this reinforces. This induces strengthen toughness how toughening mechanisms are crack bridging fiber pull out and crack deflection. Some you can see the diagrams.

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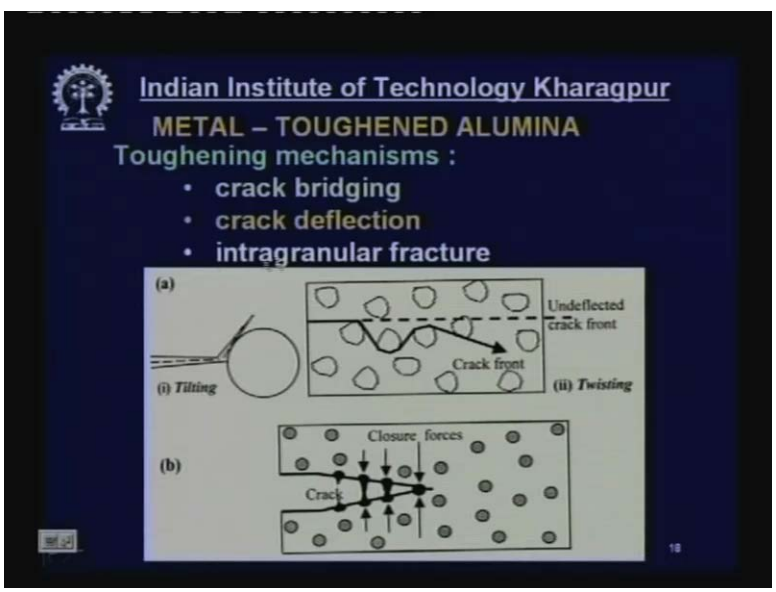

This is crack bridging. So the crack will be bridged by the harden particles the silicon carbide rods or whiskers. The fibers will be pulled out and while pulling out will absorber certain amount of energy and reduced the crack propagation energy and crack deflection and which will also weakened the crack propagation and improve toughness. Now METAL-TOUGHENED ALUMINA; toughening alumina by addition of metals. Now I told that in there are many applications other than cutting tools were this ceramic or similar ceramic have been toughened by addition of metal powder. Say metal face like iron molybdenum nickel chromium and so on. Those have already some application but in case of cutting tool, those metals are not been that successful but metal like silver work excellent. So about say 5 to 20 percent by weight.

Silver Oxide was mixed with alumina then well sintering this silver oxide was decomposed oxygen went out and silver remain dispersed with in the alumina matrix and that dispersion of silver find particles thought out the alumina matrix enhance toughness and strength. What are the mechanisms? Crack bridging; now this diagram shows crack bridging. Now suppose the crack is propagation here and these are the soft say silver particles. So they have to be stressed. They will be stressed and try to hold up crack or as the crack thereby the crack propagation will be either arrested or its strength will be reduced. Crack deflection; this shows the crack deflection. Crack is propagating, now it is made to deflect in number of directions by which the cracks strength is reduced and crack deflation here also the show the example of crack deflation is bound to move wider path so this strength will fall. So crack propagation will be arrested ultimately and finally intergranular fracture. Sometime the fracture takes place through the grains of alumina if some silver particles are added into that. Here this shows these are next actual cutting tool made by ceramic added with silver.

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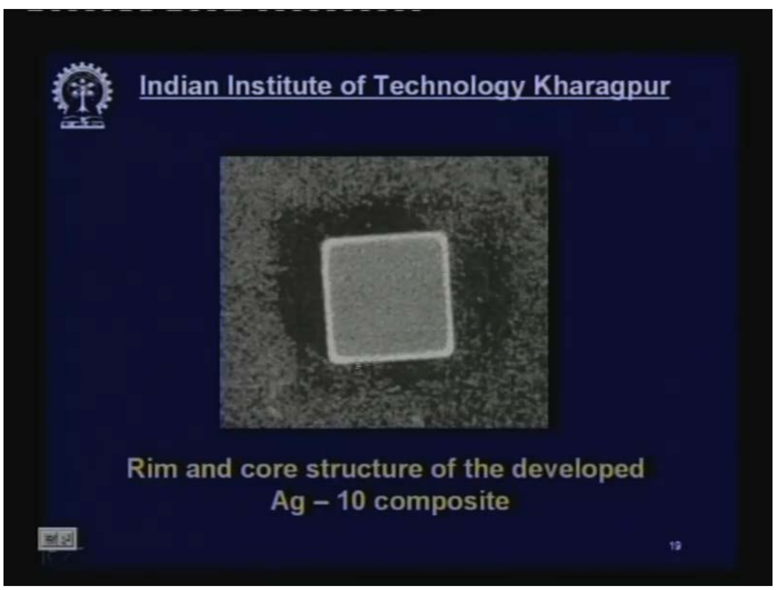

Inside you see at outer periphery it is white, because it is pure alumina and this there is no silver. Almost there is no silver but at the inside there is a black color because of presence of silver. These are very good you know this upper surface works as a coating where insinuation is desired more abrasion may also desired and heat resistance that will be given by the pure alumina. But at the core because of the presence of silver we will get lot of toughness and strength bulk hard bulk strength and toughness.

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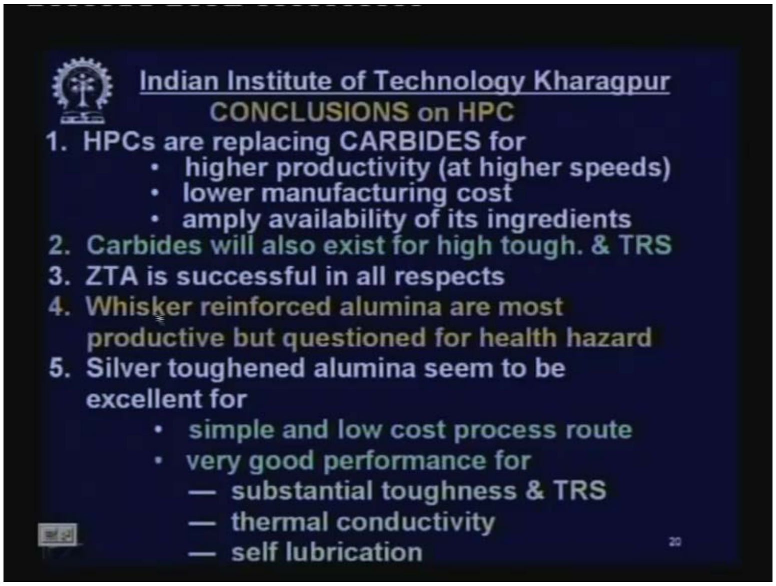

Now the conclusion on high performance ceramic: We have we have heard several high performance ceramics, silicon nitride based and alumina based. Now let us have a quick look into the high performance ceramics. High performance ceramics are replacing carbides very rapidly all over the world for higher productivity because it can work at a higher speed, higher velocity at higher speed, lower manufacturing cost. Yes, the ingredients are cheaper and the manufacturing process is also simpler than carbides and coated carbides. Amply availability of its ingredients. Now the ingredients of tungsten carbide that is tungsten and cobalt are very strategic materials. These two materials are not available in most of the countries in very few countries tungsten and cobalt is available.

So the whole machining World has to depend upon the import of such materials from thought countries. So it is a very risk but in ceramic cutting tools the ingredients like say alumina, silicon nitride or zirconia are available in plenty and these are of low cost carbides will also exist for high. Now hyper ceramics will not totally remove carbides because cemented carbides will also exist like high speed steel for high toughness and transverse of the strength. Zirconia toughened alumina is successful in all respects. It has got no problem and it is a most successful amongst all the high performance ceramic considering this a manufacturing cost manufacturing process handing operation then process roots application range and availability of ingredients safety. In all respects zirconia toughened alumina appear to be the best and widely used whisker reinforced alumina are most productive because this is very very hard and tough simultaneously but some questioned have been raised about health hazard.

It has been observed or it has been said or you know reported by some people that there is a chance of having some hazard like cancer problem and all this things. If this whiskers are not carefully or you know properly handled during manufacture as well as use. But this problem will be shortly overcome and whisker based alumina tools will become an excellent cutting tool and will used all over the world of course it is expensive. Now silver toughened alumina seems to be excellent. Now look silver toughened alumina which has not yet been that you know practiced all over the world. They are still under research and optimization or commecialization but it has got tremendous potential. Silver toughened alumina seems to the excellent for simple and low cost process route. There is no need of environmental control and it working temperature etcetera are not that high very good performance for substantial toughness and TRS transverse subsistence.

So strength and toughness have been substantial improved thermally conductive thermal conductivity. So thermal shock resistance will improve and self-lubrication it is another thing which is imparted of possible imparted by silver because the silver dispersed silver will gradually ooze out through the pores and gradually reach at chip tool interface and when this silver part of this silver particles reach even in the small volume and the chip tool interface it functions as solid lubricant. That way it will reduce the fraction and the consequences of fraction. This is how the silver toughened alumina will become an excellent cutting tool. It will be commercialized shortly.

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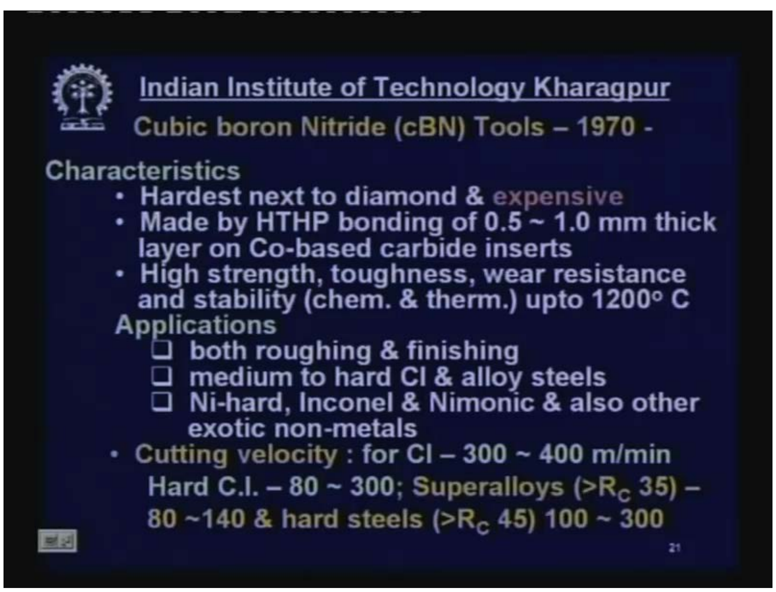

Now there are two more super materials. One is Cubic boron nitride and other one is diamond. What is Cubic boron nitride? These tool were introduced in 1970, Cubic boron nitride of structure cubic. Now what is the characteristic for which is it is so potential cubic boron nitride is a hardest next to diamond that is a point. That means extremely hard and hence abrasion resistance found stability will be high but obviously it is expensive like diamond almost like diamond. Now how these tools are made? Made by high temperature high pressure bonding of 0.5 to 1 millimeter thick cubic boron nitride you know cubic boron nitride will be produced in thin strips of 0.5 to 1 millimeter thick by temperature, high pressure and then this layer will be bonded on cobalt based carbide inserts.

So at the core it will be carbide and at the top it will be a layer of 0.5 millimeter 1 millimeter thick cubic boron nitride is extremely hard and stable. High strength really extremely high strength, high toughness, wear resistance and stability. So all this essentially most important properties required for cutting tools are available in cubic boron nitride. It is very much chemically and thermally stable and up to 1200 degree centigrade. So it is thermal and chemical stability to such a high extent enables machining at very favorable condition. There will be no wear and tear within a short time and finish and accuracy will be excellent. Not only finish the thermal, the surface integrity will be very good. There is no residual stress, no burning and nothing. What are the applications? It is such a tool which can be applied for both roughening and finishing simultaneously same tool you give large depth of cut so bulk material removal finishing will be available in one stroke. Medium to hard cost iron and alloy steels can be machined Ni-hard you know Ni-hard.

These are very difficult to machine work hardenable material Ni-hard Inconel Nimonic these are nickel based super alloys etcetera with exotic materials are very difficult to machine by other cutting tools but by cBN we can cut it easily and it cBN can cut also other exotic non-metals. Now cutting velocity, because cutting velocity is index of productivity. This cutting tool cBN noble tool can handle on one side wide range on work material and including the very hard materials and at the same time can work at high speed you see cutting velocity for cast iron ordinary soft medium cast iron 300 to 400 meter per minute with excellent finish and accuracy, hard cast iron 80 to 300 meter per minute, super alloys like Nimomic, Inconel, titanium alloys were the Rc Rockwell hardness is above 35 can be easily machine by this cBN wheel and these are very difficult to machine by other tools and this super alloys can be machine at quite reservedly high speed 80 to 140 meter per minute and hard steels or hardened steels up to 45 Rc harden materials can be machine up to 300 meter per minute and this enables dry machining or hard machining hard turning or drawing machining with minimum requirement or no requirement of cutting fluid. So pollution will be much controlled.

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Now the Diamond Tools: Diamond tools now before that say Cubic boron Nitride has got tremendous property, wide applicability on one hand. It can be used I am repeating for very high productivity. It can be used for very good finish, surface finish and surface integrity it can cover wide range of work material steels which are very difficult to machine hard steels by other tool materials. They can be easily machined and perfectly machined by cBN and all this and hard turning which is the modern technology coming up. Hard turning or dry turning are coming up that is possible by this tool material, exotic materials like nickel based superalloys titanium superalloys which are coming up very rapidly can we machine machine white sufficient speed by cBN but only problem that remains manufacturing is difficult no doubt for that the cost is also high but time is coming that this will be used this will be produced in a very simpler in a better way and ah more inexpensive way and this will cover wide range of machining and the cost will come down hopefully.

Next and last is Diamond Tools. Diamond Tools you know Diamond is the hardest material amongst all the material known diamond is the hardest and we need the cutting tools to be extremely hard to prevent plastic deformation as well as wear. It is highly thermally conductive. So it can stand with stand thermal shocks, then quite tough. So mechanical shocks can also be you know tolerated by such diamond tools it is excellent no doubt but before I going to depth obviously diamond is very very expensive. It is diamond and cBN wheels are most expensive amongst all the cutting tool materials. Now diamond tool are available in three forms: One is single crystal, the single crystal so single grain okay and this can be a natural single grain or it can be synthetic. Now natural if it is a natural it will be very hard and it will which has got very sharp cutting edges. So cutting will be very good but it will be not of perfect geometrical shape is a natural shape. So you cannot use it very widely alright. What are the limitations of this naturally available single crystals cleavage? There are certain layers with in the body with in the grain were along which it slides under the pressure it is got cleavage. So this single crystal will fracture at high temperature and high stress.

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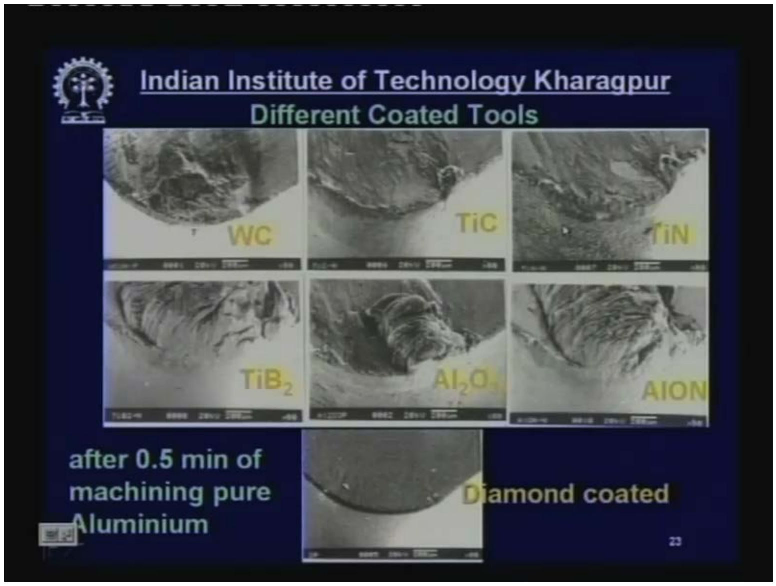

Less tough; it is a very wear resistant and hard. So toughness is less. So it cannot with stand that vibration. This is costly and less available. This natural these are not very available and these are expensive. But recently, this single crystal diamond grains are manufacture synthetically. By high temperature and ultra high temperature and high pressure synthesis process synthetic single grains diamonds are manufactured and poly crystalline also later on. Now another form later on, so this single crystal diamond tools what are the use they are used mainly for wheel dressing of wheels the wheel dressing and thing. Secondly for making very small drills or milling cutters were only one grains is sufficient to fulfill the desired requirement. Then came PCD Poly Crystalline Diamond. Poly Crystalline Diamond; how it is manufactured?

Here a thin strip say diamond fine powders of diamond say sub micron diamond particles different size shape and orientation will be first sintered into thin strips say 0.5 millimeter or around that millimeter and then this thin strips will be bonded and high pressure and temperature on cobalt based tungsten carbide. Why cobalt based? Because cobalt based gives the toughness at the bulk. So the bulk it remains tough at the carbide and at the top is a thin layer of thin strip or poly crystalline diamond and the poly crystalline means there will be no cleavage. Such poly crystalline diamond has found wide application and it is been working excellent and giving some time 100 times more tool life than carbide in certain applications. Now what are the merits? It has got several merits okay. But two important merits are tougher than single diamond and no cleavage because of having no cleavage this will survive much longer very very long tool life and what are the limitations okay. These have got certain limitations. But before I go in to the limitations, what are the applications?

Applications; now before that let us see the limitations less wear resistive. Why less wear resistive? because it is bonded on cobalt based tungsten carbide. So if it is used at very high temperature, then the diamond will react with the cobalt and graphitize. So it should not use at very high speed soaked the a high speed the wear resistance will decrease, size and shape restriction since PCD is a poly crystal diamond is obtained in the form of first made in form of strips, flat strips can easily manufactured but complexive strips cannot be manufactured that easily and economically. So there is a question of size and shape.

If the shape is complex, if size is very large, then this poly crystalline and diamond is not suitable because of the manufacturing process and thick layer the cost will be definitely high. But it has got tremendous application in machining various materials. All say exotic materials namely say slate stones, then marbles, then ceramics, FRP's polymers. All these things no but the problem comes with the steel when PCD comes into contact with iron at high temperature then this is a mutual solubility that diamond gets deserved into iron or it takes iron from this steel and it undergoes graphitization and it softens. So it cannot work. So diamond tools are not at all used should never be used for machining steels that has to be remembered. Now CVD coating sorry.

Now to over come over come the limitations of this PCD poly crystalline diamond, a new technique have been introduced that is CVD coating on carbide tips, ordinary carbide tips probably K grade that is tougher grade will be coated given will be given a coating, a thin coating of crystalline diamond. The coating thickness may be say 6 micron to 10 micron even less some time, but this thin layer of diamond poly crystalline diamond layer imparts lot of wear resistance and improves the performance the cutting tool spectacularly. Now this diamond is coated on carbide tools in number of methods. But one is most favorable is CVD, chemical vapor deposition and this deposition CVD can also be various types you know, hop by hot filament technique, then microwave technique and combustion technique like that. Out of those CVD chemical vapoure deposition technique is very good because here from methane the carbon is derived and deposited on the tungsten carbide substrate in 3 in layer but it takes it is a slow process but what are the merits?

The merits of this CVD coated tool, first of all you see there is no binder. It is a coating tool and giving the coating, there is no binder and even before coating these diamonds on the tungsten carbide the cobalt can be removed by etching. To make free from cobalt to prevent graphitization. So this anchoring or the bond strength is very high. High hardness high hardness only at the surface the coating though thin, it is very very hard and wear resistant. So abrasion will be much less but the central it is tough that will take over the vibrational load. This thin coating of diamond, crystalline diamond is thermally stable. You know it can which can very very high temperature say up to 800 centigrade. So it can machine at high speed and as such there is no problem and the problem of PCD like say size and shape restriction that is difficult to or uneconomic for large size cutting tools is overcome by CVD because in CVD process only 6 or 7,8 micron thick layer is deposited on entire surface of the cutting tool.

So the total amount of diamond required will be much less in case of coating diamond coating. So irrespective of the size, it can be done. Beside that, even in the shape or the configuration of the cutting tool is very complex then there will be no problem because this coating will automatically be deposited on any surface. Now there are certain cutting tools such as say by with very complex shape like form tools drills reamers milling cutters hobs and such kind in such kind of carbide cutting tool ah diamond cannot be you know PCD cannot be possible. So only CVD process is visible. So this is very good for such kind of small at to large size cutting tools of any complex shape. Now here you see one example that what is the application range of this diamond? Accepting iron based material or some of the material like cobalt diamond is excellent. Some time it is the only tool which can be used for machining such kind of exotic material and cBN is another noble tool which not only can machine any exotic material. It can also machine steel which cannot be done by diamond.

So Diamond tools can be machine say non-ferrous metals and alloys, non-metal specially Ceramics, polymers, vapour piece, composites, every thing excepting diamond excepting steels. But there is another problem which we see machining of very soft material like say copper and pure aluminum. This is say for pure aluminum. Aluminum is soft pure aluminum is even softer but machining of aluminum is tremendous by aluminum aluminum alloys. This figure shows this diagram shows you see that after 0.5 minute, the half a minute of machining pure aluminum the condition of the rake surface of the tool when you machine by tungsten carbide lot of aluminum got deposited when titanium carbide coated tool there was lot of deposition and that titanium nitride coated tool there is lot of damage of the tool titanium boride could not reduce. Alumina coating that induced lot of built of edge aluminum oxide ALON phase which is very very stable material and noble material even ALON phase could not prevent such kind of damage or the carbide tools.

You see ALON phase, you know the carbide tool at the top there is an ALON phase that also could not prevent built-up-edge formation and damage of the tool. Even if half a minute all the tool under went such kind of problem were as when the same material was machined at high speed by diamond coated carbide tool. You see the cutting edge remains as good as it was. There is no sign of any built-up-edge, any damage, and any chemical reaction or anywhere within 0.5 minute. So this kind of material aluminum and aluminum alloys like aluminium silicon etcetera can be machined excellently by diamond coated tools. So this is all about but do not think that this is the end of high modern cutting tools or advanced cutting tools. Continuous research is research is going on in the laboratory and in other edges in industry to develop new and near type of cutting tool materials by composition, by process, by post processing, finishing process and by coating process and by composition or and composite structure and all these things. So this will continue and in your life you will find many more novel cutting tool materials whose property will improve, performance will improve, but the cost per piece or the product will gradually come down. So there will be revolution continuing in the field of manufacturing, in the field of cutting tool development and machining.

Thank you.