Fundamentals of Manufacturing Processes

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Lecture – 41

Material Removal Processes: Tool Materials

Hello, I welcome you all in this presentation related with the subject fundamentals of the manufacturing processes and we are talking about the metal removal processes. In the last few presentations I have talked about that during the machining cutting forces are generated and for the machining purpose we need to supply the power to the machine tool. So, the power is consumed during the machining and most of the power consumed in the machining is converted into the heat which in turn causes a rise in temperature of the tool as well as of the work piece.

So, because of the rise in temperature of the work tool, temperature of the tool, tool during the machining as well as generation of the high cutting forces, the tool failure is caused by three modes of the failures one is like fracture, another is like the blunting or the deformation of the cutting edge deformation; and this occurs due to the high temperature and which will be leading to the softening of the tool material and third is the wear, gradual wear of the tool.

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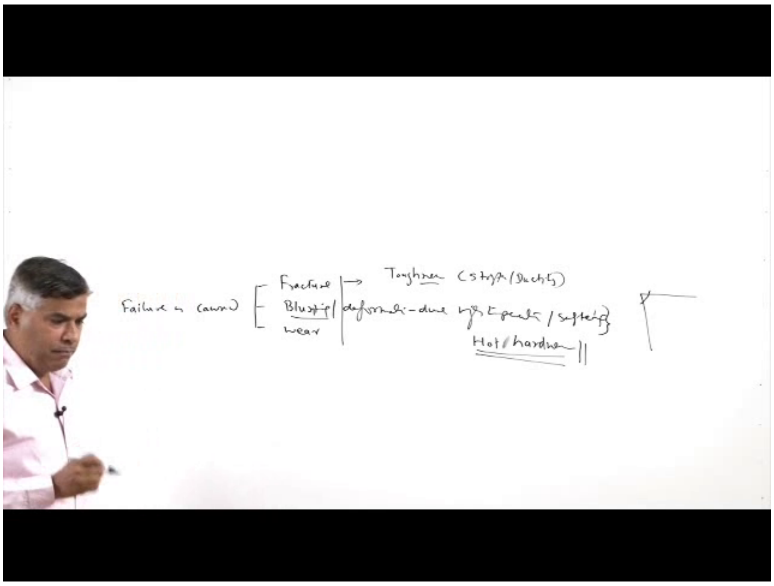

So, since these are the three factors which usually caused the failure of the tool. So, if we have to make a tool of particular material than will be looking for these characteristics these properties. So, to avoid the fracture or to avoid the fracture of the tool it is important that tool material has the desired toughness which is a combination of the strength and ductility. So, it helps to absorb the load, it helps to absorb the impacts and so, avoid any kind of the sudden fracture of the cutting edge. So, if the cutting edge or the tool material is tough then the fracture catastrophic fracture of the cutting edge can be avoided.

Similarly, another important property to resist the softening so that deformation at high temperature of the cutting edge can be avoided which will be leading to the blunting for this purpose, it is important the tool has the desired hot hardness, desired hot hardness or hardness at elevated temperature. So, hot hardness is nothing just to the hardness of the material at the elevated temperature and this hardness must be high enough in order to avoid the softening, in order to reduce the extent of softening, so that the failure or the tool by the deformation and blunting of the cutting edge can be avoided.

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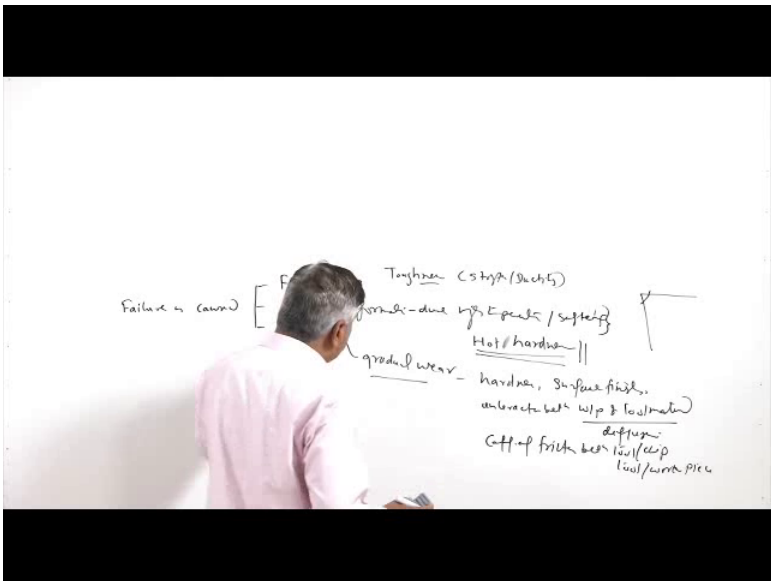

Then the gradual wear of the failure of the tool by the gradual wear actually it also depends upon the hardness, but apart from the hardness like the surface finish, surface finishes one of the aspect then the interaction between that work piece and the tool materials also causes the wear. Then this basically it involves the diffusion of the elements then the kind of the coefficient of friction or the friction between the tool and the chip or tool and work piece are also affect the wear of the tool.

So, in order to have the good wear resistance, primary requirement is that tool material must be hard enough and apart from this it should have the good surface finish, should not interact the tool material, should not interact with the work piece material or the chips during the machining. So, considering the requirement these three requirements to avoid the failures it is required that the cutting tool material has the three important properties that is the hardness hot hardness toughness and the hardness to resist the wear so indirectly we can say good wear resistance.

But apart from these three properties which are required for the functional purposes it should also have like desired fabric ability or manufacture ability. So, that it can be shaped or the desired shape can be given it should be available easily the material of the tools should be available easily as well as it should be economical. These are the other characteristics, but the 3 functional properties which governed the life of the tool as well as performance are the toughness, hot hardness and the wear resistance.

So, considering these properties the range of the tool materials have been developed over a period of time and if we see this one then we need to see the what are the materials which are available along with the hardness.

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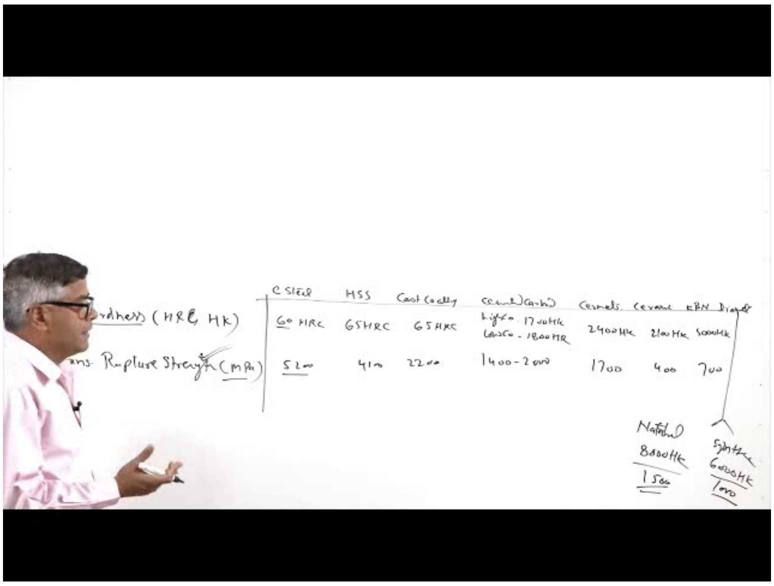

Since the in case of the brittle materials of course, hardness can be measured depending upon the hardness of the work material different methods are used like Rockwell hardness on the B scale, C scale or A scale, nope hardness or brinell hardness for the low hardness materials.

Similarly the transverse rupture a strength, transverse rupture a strength is the another parameter which is used to indicate the toughness of the material which are hard and the brittle. So, this is expressed in terms of the MPa while for the hardness we have four of the hard materials like a common a skills are like HRC Rockwell hardness on a scale C as well as the nope hardness which is represented as HK, these are the two common parameters which are used for indicating the hardness.

So, if we consider the common materials which are used as a tool material then these properties we can have some idea about the properties of the common tool material. So, one is like carbon a steel, another is high speed steel, then cost cobalt alloys then cemented carbides, then cermets ceramics then CBN diamond. So, these are the common materials which are used as tool materials.

So, the kind of properties that these materials offer include like for the carbon a steels the hardness is around the 60 HRC while for the high speed a steel is 65 HRC for cost cobalt or alloys also it is 65 HRC for cemented carbides depending upon the cobalt content for high cobalt content the hardness is 1700 HK that is nope hardness since the cobalt is low hardness material. So, when the low cobalt is low the we get somewhat higher hardness of 1800 HK then we have the cermets, cermets offer the hardness of 2400 HK ceramics of the 2100 HK the CBN offers the hardness of the 5000 HK while the diamond means the there are two categories of the diamond one is the natural diamond and another is synthetic diamond.

So, synthetic diamond offers the hardness of the 6000 HK a natural diamond offers the hardness of like 8000 HK. So, these are hardest material is the natural diamond while somewhat lower hardness is for the synthetic diamond and then in the nope hardness likes for CBN it is 5000 HK.

So, the low hardness is the carbon steel and the high hardness here and then these are in the increasing order of the hardness the ceramics, CBNs and the cermets. And now if we look for their rupture is strength in terms of the MPa mega Pascal then 5200 means the lower hardness higher the rupture is strength is the general trend, but it may not always be true for a the entire range of the cutting tool materials. Like 5200 MPa for the carbon a steel, then 4100 MPa for high speed a steel, 2200 is for the cost cobalt alloys and then it is a 1400 for the cemented carbide and for cermets it is 2400, for cermets it is 1700, then it is this is 1400 to 2000 mpa depending upon the the cobalt content for a high cobalt content the rupture is strength is high the 2000 mpa for low cobalt it is low like 1400 mpa. For cermets its 1700 for alumina or like ceramics it is 4400 only and for the CBN it is 700, for the natural diamond and for the dam a pc d and polycrystalline diamond or synthetic diamond it is 1000 mpa and it is 1500 for natural diamond.

So, the rupture is strength is one which will be decide, which will be determining, which will be indicating the toughness and so the ability of the tool material to withstand against the cutting forces while the hardness will be indicating the ability to reduce the wear as well as ability to retain the size and shape. But of course, these are the hardness values at the room temperature more important is to consider the hardness of these materials at elevated temperature.

So, if we see this list the low hardness material like carbon a steels these will not be able to sustain the cutting conditions for long because cutting conditions are very harsh in terms of the stresses as well as in the in terms of the temperature. So, considering these aspects the low hardness materials cannot be used under the high cutting a speed conditions because they will be leading to the faster failure of the tool. So, higher is the hardness greater leaving the cutting a speed which will be the passive which will be possible; however, there should not be any kind of interactions or a reaction between the work piece and tool material and if this kind of reaction takes place then of course, we need to avoid such kind of combinations where the work material can interact with the tool material and adversely affect the life of the tool.

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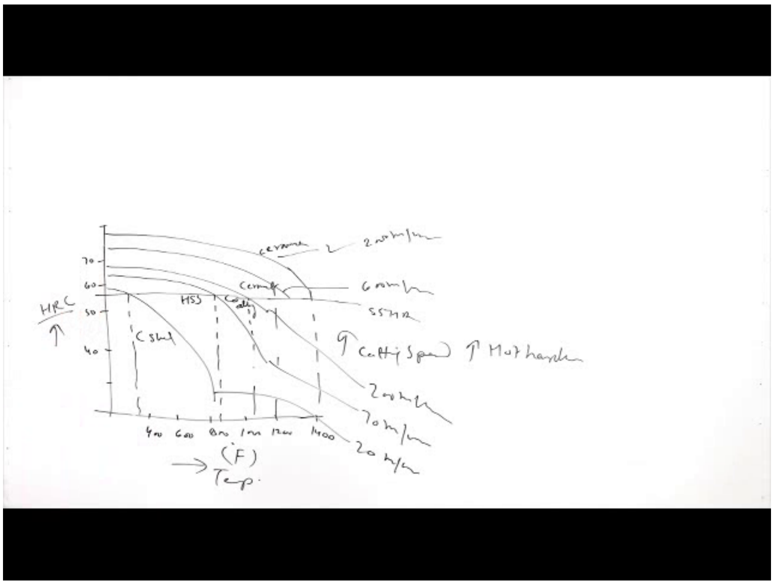

Just to have idea about the, we know that with the increase in temperature hardness of the material decreases. So, this decrease in the hardness will adversely be affecting to the life of the tool. So, it is important that suitable tool material is selected for a given set of the conditions. So, that it can retain its hardness above the specified safe limit. So, if we assume like then like 40 50 60 70 this is the hardness in it on the HRC is scale and this is the temperature here like 400, 600, 800, 1000, 1200 and 1400 this is temperature in the increasing temperature in terms of the Fahrenheit.

So, what happens for the case of the carbon a steel it drops down very rapidly like this, this is the case for the carbon a steel while for the high speed is steel it also drops, but not that rapidly like say this is for the HSS then cast cobalt alloys it maintains for the cast cobalt alloys and then for the ceramits further higher without much drop and for the ceramics further higher without much draft. So, this is for ceramits and this is for ceramics.

So, what we can see here for the ceramics ceramits there is no and for there is no major drop in the hardness values with the increase in temperature. So, these can retain their hardness fairly high value and if we assume that the minimum required hardness for the tool material for working with a particular work piece is say this 55 HRC then. So, this carbon steel cannot work beyond this for this temperature high speed is steel cannot work beyond this temperature of the 850 Fahrenheit. So, means we need to work at the lower a speeds when we are using carbon a steel or the high speed e steals while much higher a speeds can be afore the cast cobalt alloys cermets and others can afford much higher value of the temperature without losing their hardness.

So, this is the this is important in governing the cutting a speed higher is the cutting a speed increases if the material shows higher hot hardness and that is why ceramics can work at much higher a speeds like say 2000 meter per minute, while the cermets may be say 600 meter per minute, while the cast cobalt around 200 meter per minute, maximum 70 meter per minute for and this is very low as like 20 meter per minute. These are the kind of speeds which are possible during the machining of a steal. So, higher is the hot hardness gate will be the allowable speed which can be achieved through these tool materials.

Now, we will come to the different options which we are available. So, these are the tool materials which are available which offers the different hardnesses and the transverse rupture is strength which is indicating the toughness. So, considering their hardness and the transverse ruptured is strength they are used suitably for the different kind of the conditions.

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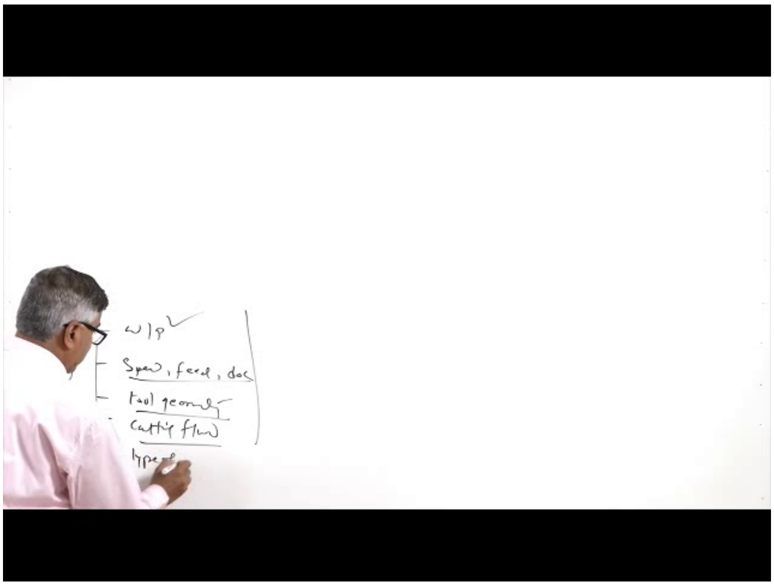

These conditions include, these conditions are of the two or three types one is like the it considers the work piece material it considers a speed feed and depth of cut, it also considers the it also considers the tool means affects the tool geometry to be used and the then the use of the cutting fluid.

So, these are the factors which will be governing the selection of the suitable tool material, tool material selection is influenced by the work piece the cutting is speed feed and depth upward cut be used tool geometry cutting fluid and the kind of type of cutting, type of cutting operation. Like the cutting is continuous or interrupted like you know like in the milling the interrupted cutting takes place while the turning and boring continuous cutting takes place. So, they even the hard and brittle materials tool materials can work under the continuous conditions, but if the interrupted cutting material needs to be tough.

So, for the interrupted cutting conditions it will not be good to use very hard and brittle materials, similarly the tool geometry cutting fluids cutting a speed feed depth of cut all these influence the selection of the suitable or tool material. Now will go little bit in the details of the tool materials and so the various tool materials like a steels, so a carbon steel is one these are normally used for very low hardness materials.

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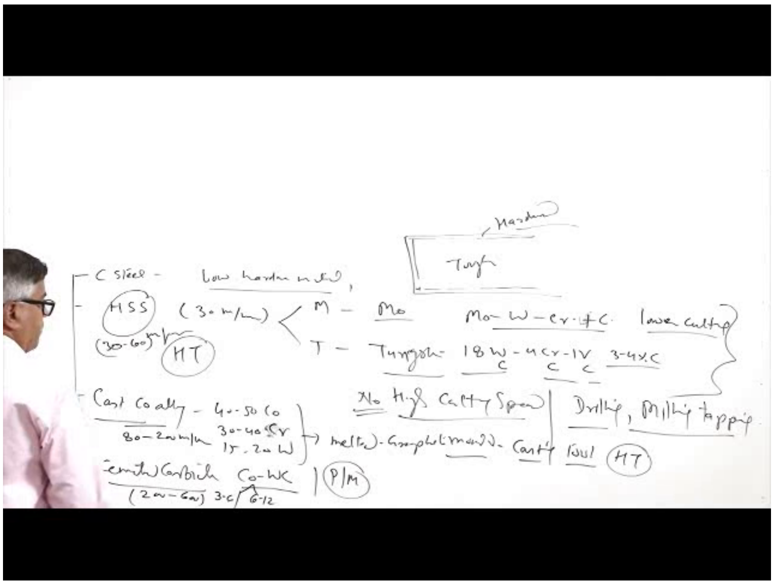

Nowadays these are not used, but a still your may used for making the hand tools like the files or the saws which will be used manually, but the more commonly it is used for a common more commonly used tool material is the high speed steel and in the high speed steel because when it was developed at that time it allowed working, it allowed working with the likes a 30 meter per minute cutting speed which was much higher than what was being offered at the time by the carbon a steel that is why it was termed as high speed steel.

And there are two variants in the high speed a steel one is the M series and another is the T series - M series were basically contained these this is the molybdenum based series and this is the tungsten based series wherein one of the most commonly used the high speed steel of the T series is the 18 percent tungsten, 4 percent chromium, 1 percent vanadium and about the 3 to 4 percent of the carbon.

So, all these are strong carbide formers. So, these forms tungsten carbide chromium carbide vanadium carbide which are very hard and very stable and we stable means they do not softened at an elevated temperature and that is why they offer the good hot hardness. But since the tungsten is costly so the people have tried to replace the tungsten with the molybdenum so that the cost can be reduced.

So, in that case the molybdenum plus some percentage of that tangle tungsten then chromium then vanadium plus of course carbon is added these are a cheaper, but they allow lower cutting is speeds then what is possible with the T series high speed a steels. These are the tool materials which are softened at elevated temperature and that is why these are not used for very high, not for high cutting is speeds and that is why these are normally used for the low cutting speeds operations like drilling making the tools for the drilling, milling, tapping. So, these are the common tools where either cutting is interrupted or the cutting speed is low so not much of the heat is generated which will be causing the rise in temperature and which will be leading to the adverse effect on the tool life.

Another one is the cost cobalt alloy cost cobalt alloy; basically it comprises 40 to 50 percent of the cobalt then 30 to 40 percent of the tungsten sorry chromium and 15 to 20 percent of the tungsten. This mixture is melted and then in the graphite mould graphite mould it is poured so that by casting route that tool is made. So, it does not require any heat treatment to achieve the desired hardness, but in case of the high speed a steel are the heat treatment is needed in order to achieve the desired are the hardness of the 65 HRC. So, that the surface of the HSS can be hardened while the inner portion of the tool remains tough while the surface is hardened through the suitable heat treatment. So, this is what is about the cost cobalt alloy.

Cost cobalt alloys are found somewhat compared to the cemented carbide, if we talk of the cemented carbide tools cemented carbide tools are basically the cobalt tungsten carbide these are the two main constituents where in the cobalt concentration may vary 3 to 6 percent in the low cobalt category and in high cobalt category maybe 3 to 12 percent. So, accordingly we get the higher hardness or the lower hardness cobalt is used as a binder while the tungsten carbide particles will be there as a reinforcing agent and these are produced through the powder metallurgy route were in the elements in powder form are compacted and sintered to get this shape in the desired form of the in such so that they can be used for the cutting purpose. If we see with regard to the properties the cast cobalt alloys actually fall in between of the cemented carbide and the high speed steel.

So, accordingly the hardness and the toughness of the and the cutting a speed of the cast cobalt alloy falls basically between the high speed a steel and the cemented carbide tools. So, cast cobalt alloy normal cutting speed is around say 80 to the 200 meter per minute while 200 to 600 means on the higher side is used for the cemented carbide while 30 to 60 is for the high speed steel in terms of the cutting speed meter per minute.

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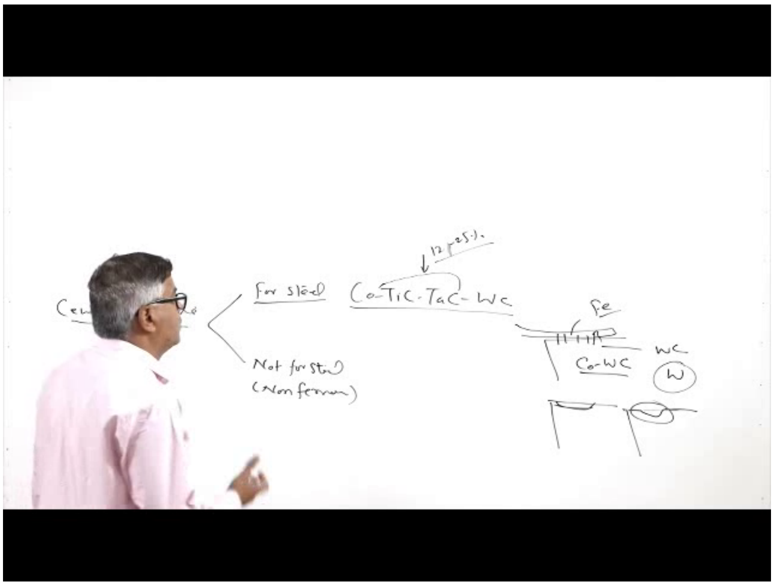

Now, we will talk little bit more in details of the cemented carbide tools. So, in the cemented carbide tools basically there are two broad categories one which are used for the steels and those which are for not for a steels or they are used for like say the non ferrous metals. So, the cemented carbide tools are basically for the steels and for the non for steels not for this steels categories these are two broad categories, so those which are used for the a steels are modified with the titanium carbide and tantalum carbide plus tungsten carbide cobalt used is used as a binder. And the percentage of this titanium and tantalum carbide is around 12 to 25 percent, while also these when these are used it reduces the wear of the cut cutting carbide tool insert or cemented carbide tool insert especially in case of the during the machining of the steel.

So, if we use a straight tungsten carbide cobalt base cemented carbide tool which is a like cobalt and tungsten carbide during the machining actually the machining of a steels a steel which is having iron. So, iron actually interacts with the carbon in the carbide of the tungsten particles. So, this interaction leads to the instability of the WC, the carbon is lost and it is left with the tungsten only. So, the surface near surface layers basically get become depleted of the tungsten carbide particles. So, they lose their hardness and so this region is subjected to the very sharp were and that is why crater is formed near the cutting edge in this form.

So, the tongue straight cobalt tungsten carbide type of the cemented carbide tools when used during the machining of the steels it results in crater wear due to the diffusion of the carbon or with the iron or the steel leads to the loss of the carbon from the rack face of the tool which in turn promotes the crater wear. That is why the straight tungsten carbide seam in estate understand carbide cobalt inserts are not used for machining of the steels, but these needs to be modified with the, so when the modified was TiC and TaC modified version of the co WC inserts are used it offers the good tool life. While for the non ferrous metals we can use the straight WC and the cobalt tungsten carbide cobalt type of the tungsten carbide cobalt type of the cemented carbide tools.

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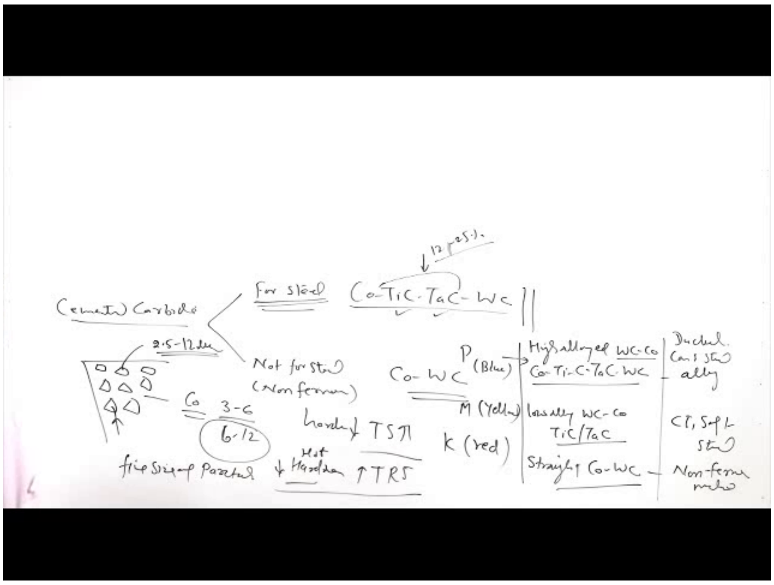

So, a little bit more in details there can be different categories like high alloyed WC Co insert these are used for machining of the ductile metals cost a steels as well as cast is steels ductile metals and alloy a steels. So, these are basically cobalt TiC TaC WC high in concentration of these TiC and TaC while the low alloyed WC Co insert or like were in the concentration of the TiC and TaC is somewhat less these are used for machining of the cast iron as well as these are also used for machining of the these are used for the machining of the cast iron as well as somewhat soft bits of the a steels.

This is a represented by in the letter P and it is coded by the blue color high alloyed then cemented carbide inserts, while the M code is used for the low alloyed resistant carbide a cemented carbide inserts and it is coded with the yellow color. While the K letter is used for; and a cobalt base inserts which are used for the non ferrous metals coded with the red color these are basically a straight cobalt tungsten carbide inserts and these are used for the non ferrous metals.

So, here like say if we see the typical cemented carbide insert then you will see these are the carbide particles fitted with the cobalt matrix, cobalt matrix can be 3 to 6 percent or 6 to 12 percent. When the cobalt is high we will see that hardness is less and that strength and transverse a strength is transverse a strength rupture a strength is high, but the size of these particles also a is important the fine size of the particles means the carbide particles reduces the hot hardness reduces the hot hardness, but increases the transverse rupture a strength.

So, this is how the properties vary and these particles are generally are used in the size range of the 2.5 to 12 micrometer. So, these are very fine in size and these are used for making the cemented carbide inserts through the powder metallurgy root. There are 3 more common tool materials which are also used in the metal cutting these are the cermets basically cermets although cobalt and the tungsten carbide is also cermets, but in the cutting technology these are not used as a typical cermets these are not termed as a typical cermets tool materials.

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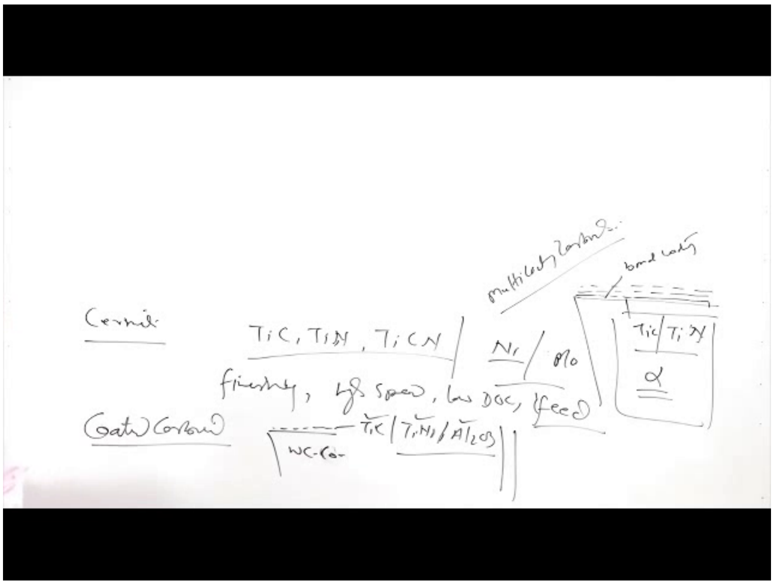

So, for the cermets basically TiC TiN titanium carbide, titanium nitride and titanium carbon I tried are the commonly used by cermets now for making the tool materials and these are, these materials in the powder form are mixed with either cobalt as a matrix or nickel as a matrix sorry the nickel as a matrix or the molybdenum as a matrix. So, these are the reinforcing agents and the matrix is either of the nickel or of the cobalt.

Since they have very low rupture strength and a very high hot hardness. So, these are primarily used for the finishing purpose and when you working with the high cutting speed low depth of cut and the low feed. So, these are the federal conditions when cermets can be used then we have the coated carbide tools coated carbide tools are basically the cemented carbide tools means these are like WC n cobalt base cobalt type of the strait tools which are usually coated coatings are made either of the TiC or TiN or means titanium nitride or it can be coated with the alumina also. But to have, so when we coat in these provides the good stability at elevated temperature as well as good were resistance so they can be worked at much higher cutting speeds.

But in order to avoid in order to avoid any kind of that chipping off or of the spoiling or the separation of the coating from the from the tool material and normally the bond code is given bond coating is provided of the either TiC or the TiN because these two materials have very alpha value r thermal expansion coefficient similar to that of the cemented carbide tool.

So, there is no mismatch in terms of the alpha value and that is why it form it results in a very good bonding with the substrate that is the cemented carbide tool. And over this we can deposit number of the other coatings as per the requirements for developing the multi coated carbide tools. So, they will be performing much better as compared to that the simple state plane carbide tools, because of this coating, coating helps in making the cemented carbide tools to work at a much higher speed with the much better feed and the depth of cut especially for the finishing purpose, also these can be used for the machining using a moderate level of the feed and the depth of cut.

Other two materials which are there in like ceramics.

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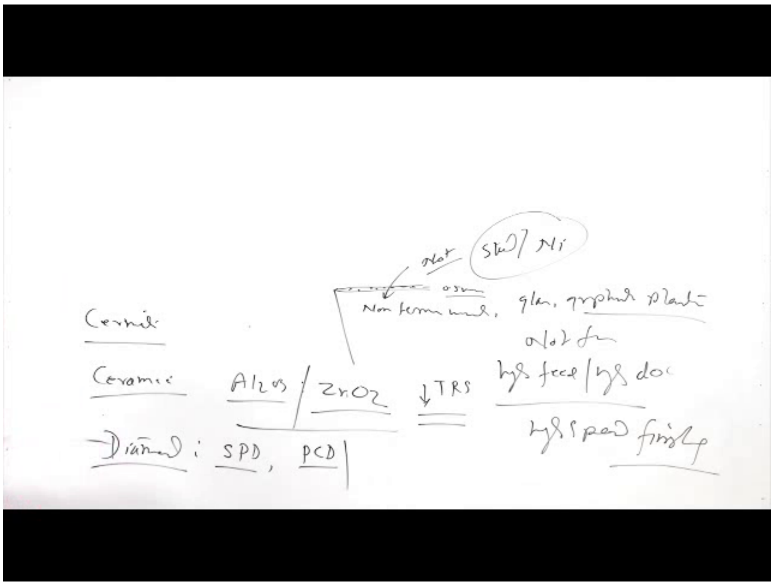

Ceramic basically this is alumina based where alumina particles an find a powder, powder form are contacted and then sintered to make the tool through the powder metallurgy route sometimes with the alumina zirconium oxide is also added so that the properties can be enhanced further. Because of their low transverse rupture strength these are not used for high feed not for the high feed or high depth of cut high doc, but definitely these are used for the high speeds especially for the finishing operations not for the making much of the cutting.

Then another one is the diamond, diamond is basically like a sintered polycrystalline diamond or these are also known as PCD polycrystalline diamond or sintered polycrystalline diamond these are the two things which are normally used these are normally used for the for developing the coatings of about 0.5 mm and since these are very good in terms of the hardness as well as the ability to be distant out of the high temperature, these coatings of the PCD can be effectively used for machining of the non ferrous metals. So, like the glass graphite plastics etcetera can be easily at very high speed machine, but these are not used for diamond coated tools are either the diamond inserts are not used for machining of the a steels as well as the nickel bezel alloy because the carbon has affinity with a steel as well as the nickel alloy.

So, by the diffusion the coating loses the carbon because the diamond is a basically one form of the carbon, so the loss of the carbon to the steel and the nickel alloys these the tool life is adversely affected during the machining of the super alloys nickel alloys and thy steels using the PCD or the sintered polycrystalline diamond. That is why these are not used for machining of a steels iron or the super alloys.

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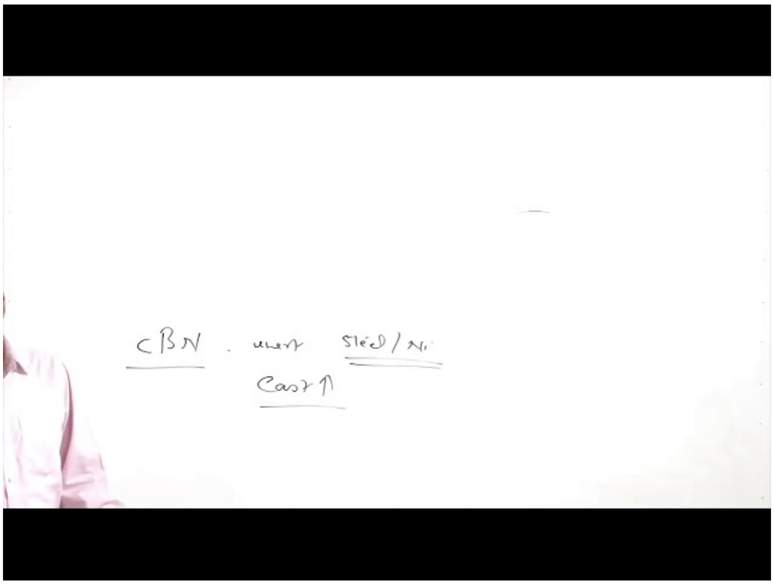

On the other hand the CBN that cubic boron nitride also offers very good hardness and therefore, CBN cubic boron nitride becomes especially inert to the a steel as well as nickel alloys and that is why this is a very good option to replace the diamond as a cutting tool material and, but the cost of the CBN is very high that is why it is economically justified only when this is a economically justified only when the volume of the production is too high or we need to work at high cutting a speeds. So, that now we can afford the cubing boron nitride effectively.

Now, I will summarize this presentation here in this presentation I have talked about the kind of material properties which are required to make the tool so that it can perform effectively apart from what are the various options available in terms of the tool materials and under what conditions they can perform.

Thank you for your attention.