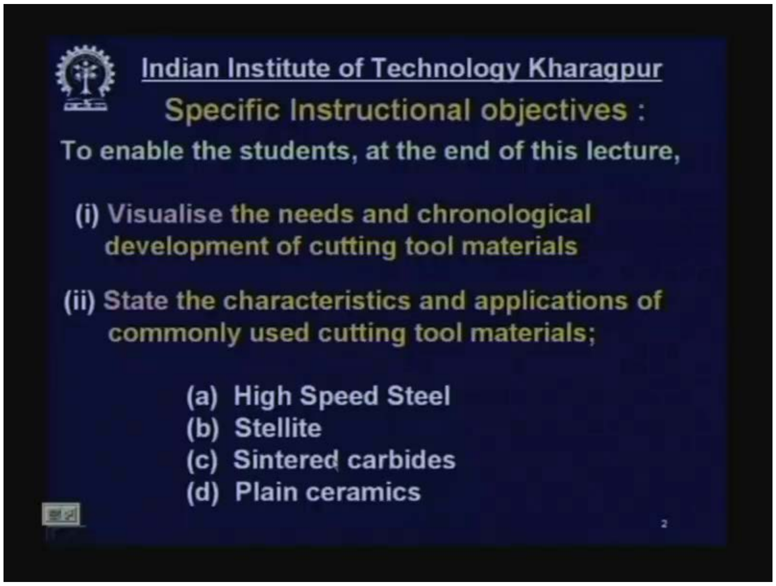
Manufacturing Processes II
Prof. A. B Chattopadhyay
Department of Mechanical Engineering
Indian Institute of Technology, Kharagpur

Lecture No.15
Conventional Cutting Tool Maths

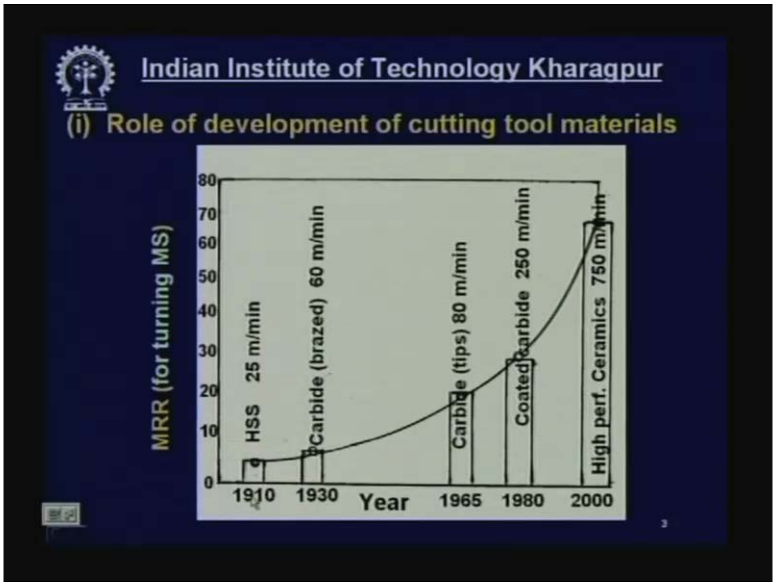
Good afternoon. All of you are welcome to the Course Manufacturing Processes II. We are continuing Module-3 which is machinability and today's lecture number 3.3 and topic is Conventional Cutting Tool Materials. Now what is the content of the lecture today that is Specific Instructional Objectives?

(Refer Slide Time: 01:25)



Visualization of the needs and chronological development of cutting tool materials and also this will enable the students to state the characteristics and applications characteristics and applications of commonly used cutting tools materials. Now in the field of cutting tools materials, lot of development has taken place. So today we shall cover shall cover only the conventional cutting tools which are commonly used you know in all over the world and next lecture we will cover the advanced cutting tools materials. So today's cutting tools materials will be that we covered high speed steel, stellite, sintered carbides and plain ceramics. Now you can see here what can be the role of development of cutting tool materials on productivity of machining.

(Refer Slide Time: 02:12)



Here is a plot. This shows the metal removal rate or productivity in machining say mild steel with year say from 1910 to 2000 and beyond that here you see the productivity has increased almost exponentially from 1910 to 2000. So very rapid improvements are taken place from recent past. Now in 1910, it was high speed steel which could machine material only at 25 meter per minute. You know that the productivity is a function of cutting velocity and feed mainly cutting velocity. More velocity means more productivity. In 1930, advent of cemented carbides made brazing allowed cutting velocity to 60 meter per minute. In 1965, up to 80 meter per minute. Now all of sudden in 1980, the cutting velocity went up to 250 meter per minute through advent of coated carbides and 2000 high performance ceramics that enabled reach 750 meter per minute which is really tremendous cutting velocity and which produces very high productivity. Now here you can see the chronological development of the cutting tool materials:

(Refer Slide Time: 03:40)

There is saying that where there is a will there is a way and where there is a will there is need there will be will and where there is a will there will be development or creation. Now here we have made a chart you can see, year wise chronological need developed and development of the cutting tool to face the need. For example, in 1905, in 1905 the tool material high speed steel was introduced by FW Tailor. It is really great break through in the history of cutting tool material development that time the other cutting tool material could machine hardly at say 10 to 5 to 10 meter per minute but high speed steel enabled machining say material like mild steel very common material up to 13 meter per minute.

What are the major constituents or the composition of high speed steel? High speed steel is termed as 18 4 ,1 18 percent tungsten 4 percent chromium 1 percent vanadium and carbon 0.7 percent rest iron ferrum. Now this automobile industry came up in large way around 1910 which demanded some more improved cutting tool materials which can machine materials faster than high speed steel. Yes a material namely stellite was developed in around 1913 and the stellite is a cast alloy. It is produced by casting simply. But this is composed of cobalt, chromium, tungsten and similar materials. This will be discussed in appropriate time. Now you see the World War I; now the great World War I and World War II happen to be the sources or the mile stones for development of science and technology.

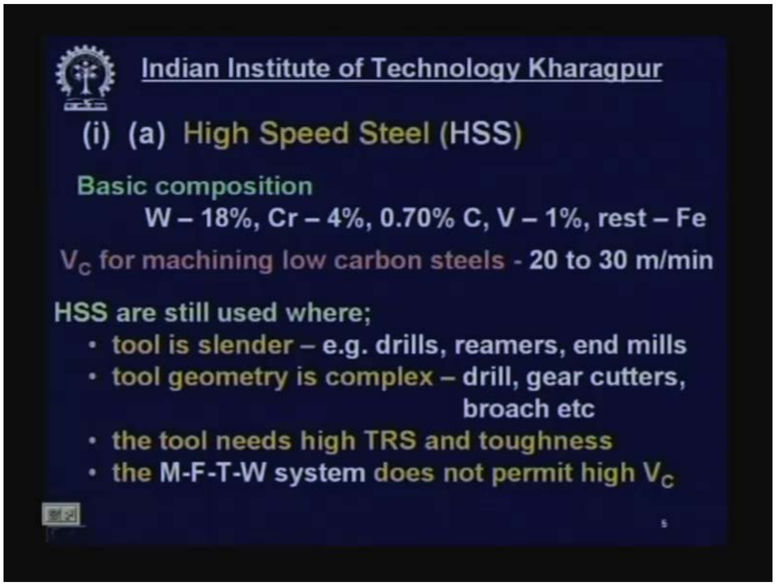
The great improvements in science and technology have taken place during the World War II especially in second World War in all respects around 1920 high speed steel was improved drastically by addition of vanadium 2 to 4 percent which provided more heat resistance and wear resistance than cobalt hot strength and hot hardness which was added 5 to 12 percent in tungsten and cobalt tungsten and chromium, etcetera in an high speed this is not cobalt this is chromium. Now aircraft, there is boom in air craft industries in 1930, there is a tremendous demand for machining materials at higher speed and that time there was a great break through another break through in the history of science and technology of cutting tools and noble tool material namely cemented carbide was developed in the around 1930 and it is claimed that it has it has been developed either in Germany or Russia or Union Soviet Union or USA but there is a doubt really where it was invented might be that it develop simultaneously in all this three the advanced countries. Cemented carbide but that time it was confined to only machining of cast iron than due to the Second World War around 1940 and above the carbide for steels where developed.

The cemented carbide that was developed in 1930 was suitable for cast iron machining cast iron which normally produces short chips, the chip tool contact length is very small. The duration is very short. So temperature was not very high, but in machining steel, lot of temperature is developed because of continuous contact between continuously flowing chip with the rake surface. This temperature is detrimental for the tool very much which you know softens the tool and aggravates the rate of growth of wear. In 1940, a special type of carbide called composite carbide has been developed for machining steels at reasonably good speed. In 1950, around there is a need from chemical, petrochemical and nuclear industries as well as polymer industries to have better cutting tool material and what were the developments? High speed steel with high vanadium, molybdenum, cobalt and carbon.

This created a very good quality of high speed steel enabling machining at speed more than 50 meter per minute compared to 30 meter per minute when it was introduced. At the same time in 1950 plain ceramics like alumina or silicon nitride were developed and synthetic diamond. So diamond a single crystal diamond was found to work very well in some machining activities and the synthetic diamond was also developed in around 1950 for some application. 1960 is another breakthrough because that time jet engines, space programs, and all these things demanded a very fast machining tool and which can machine varieties of machine materials and that time ceramics and cermets were developed various types. 1970 that is another small breakthrough the carbide tools, cemented carbide tools were coated by various materials, powder metallurgical process high speed steel.

The quality of high speed steel was enhanced by manufacturing by powder metallurgical process and then simultaneously polycrystalline diamond is another kind of diamond tool has been developed for wide application. Now in 1980, defense and super alloys like titanium alloy and nickel base alloys which are very difficult to machine by conventional cutting tool materials. So special cutting tool materials had to be developed you know and that is really advanced cutting tool materials these are like cubic boron nitride coated high speed steel and sialon. This kind of advanced cutting tool materials came into being in 1980. 1986 here also remarkable time were high performance ceramics because ceramic cutting tools are unique, but it has got certain weakness also and so overcoming the weakness some high performance ceramic cutting tools has been developed to machine at very very high speed. In 1990 onward just in time, that is very quick production very quick production implicit time had to be done on some exotic materials. So, very special and capable cutting tool materials were demanded and the people were successful to develop and use diamond coated carbide. The cemented carbides now it has been coated with diamond thin film of diamond. Now let us see the high speed steel.

(Refer Slide Time: 10:41)



High speed steel: This is so named high speed steel because when it was introduced this high speed steel could machine the material like mild steel at the highest speed up to 50 30 meter per minute that time in 1905 this this tool material could machine at a highest speed that is why it is called high speed steel. But now, presently among all the cutting tool materials high speed steel is possibly the lowest cutting speed type of tool material it can be used as the lowest cutting speed. But for the honor of the inventor of high speed steel that time it is still named as high speed steel because it made a breakthrough. But at present, it is not machining at that high speed possibly it is machining material like that is the lowest possible speed.

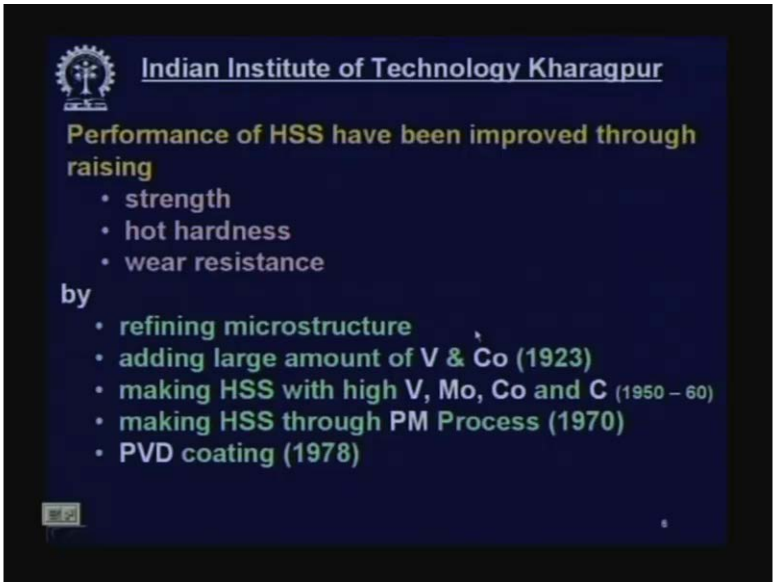
Now what are the basic compositions of high speed steel? Tungsten 18 percent, chromium 4 percent then carbon 0.7 percent, vanadium 1 percent rest iron. Now tungsten and chromium were added in to iron for improvement in hardness and hot hardness, wear resistance, abrasion resistance then vanadium for further wear resistance and hot hardness but the cutting velocity for machining low carbon steels was 20 to 30 meter per minute that means even with such good composition high speed steel could machine materials like mild steel only from 20 to 30 meter per minute which is really very very low in the scale of today. But though high speed steels were invented and introduced long back around 1905 with a limited quality. But interesting part of this is this primitive tool high speed steel are steel utilized nowadays and this will continue over another 50 years may be why? Why high speed steel being so primitive being capable to machine only at 20 to 30 meter per minute are steel utilized when high performance ceramic diamond and other modern cutting tools have been developed. There are reasons where are they? They are used at very useful when where the tool is slender.

When the cutting tool is slender say like a rod, then it is subject to lot of bending and vibration. So this kind of tool will be subject to lot of tensile stress and bending stress. So modern cutting tool materials cannot sustain that kind of stresses or bending moment or vibration like the drills, long slender drills, reamers, end mill cutters of small diameter or say even mediums of diameter, medium size diameter they have still made of mostly made of high speed steel. But some of them are made by carbide also but mostly high speed steel. Now high speed steel are also used were tool geometry is very complex. So complex that it is very difficult to manufacture such kind of cutting tools were the carbides and ceramics cannot be used for the purpose because carbide ceramics are difficult to process like machining and other things. But high speed steel can be machined just like any other steel.

So the complex geometry type of cutting tools like drills with the double force gear cutters like hobs or gear shaping cutters, milling cutters, the broach, broaching tools etcetera are still mostly made of high speed steel. The farm tools are made of high speed steel the tool needs high tens transverse roughness strength or bending strength and toughness say when there is a say intermittent cutting or interrupted cutting shock loaded cutting than there will be lot of vibration and shock loads which cannot be tolerated by the modern cutting tool materials like carbides and ceramics which are basically brittle so under such situations say in interrupted cutting and shock initiated cutting high speed steel tools are very appropriate.

Another case were the machine tools, fixture tool and work system does not permit high velocity, may be the machine fixture tool work system is not strong and rigid enough because of many reasons may be small, may be old, may be and if a cheaper type or some problems in such cases the velocity cannot be raised very high and when the velocity cannot be increased than high speed steel is the best cutting tool material. Now here you can see the high speed steel was introduced i told you around 1905 but and it is still getting used but do not think that by this time it has not been improved lot of improvements have taken place in the properties and qualities performance of high speed steel by the last century. What were the improvements?

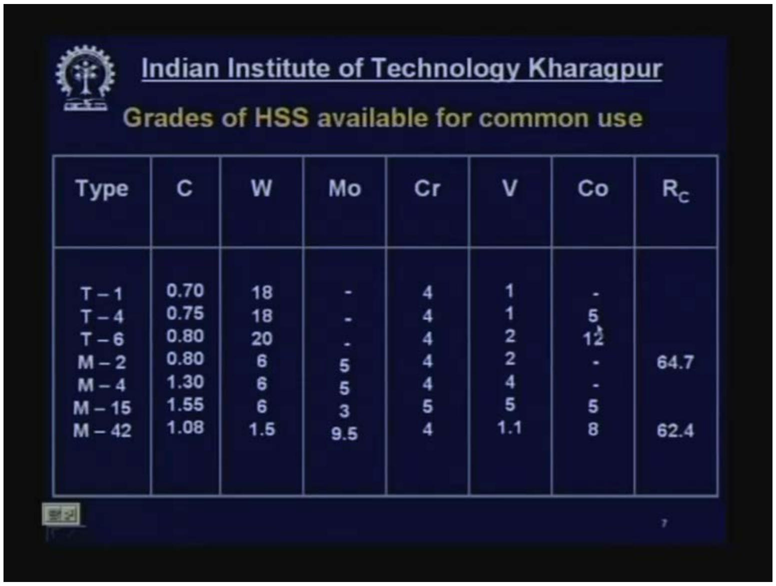
(Refer Slide Time: 15:58)



Performance of high speed steel had been improved through raising strength, mechanical strength like tensile strength, bending strength, etcetera hot hardness, wear resistance for improvement in tool life and allowing this tool to be used at higher speed. How these properties can be induced? By refining the microstructure which also improves the properties, mechanical and physical properties, adding large amount of vanadium and cobalt say around 5 to 12 percent vanadium for wear resistance and heat resistance. What for cobalt for hot hardness so that the hardness of high speed steel is retained even at high temperature around say 400 or 500 centigrade as such high speed steel can withstand temperature up to 600 degree centigrade so and corresponding velocity is around 30 meter per minute but by adding vanadium and cobalt. It can withstand hard temperature hence higher cutting velocity.

Making high speed steel, with high vanadium, molybdenum, cobalt and carbon. This really created a very good grade of high speed steel which can be used for very complex type of cutting tools making high speed steel through powder metallurgical process since 1970. Now if the high speed steel which is normally produced by say rolling, now this is produced by powder metallurgical process and that enabled to get very fine microstructure and hence properties and last in 1978 or 80, this high speed steel tools have been coated by physical vapor deposition technique and the coating material is normally say titanium nitride, titanium carbonitride, aluminum titanium nitride, and so on. So still research is going on to improve the performance and quality of high speed steel. Now the grades of high speed steel available for common use.

(Refer Slide Time: 17:58)


Indian Institute of Technology Kharagpur

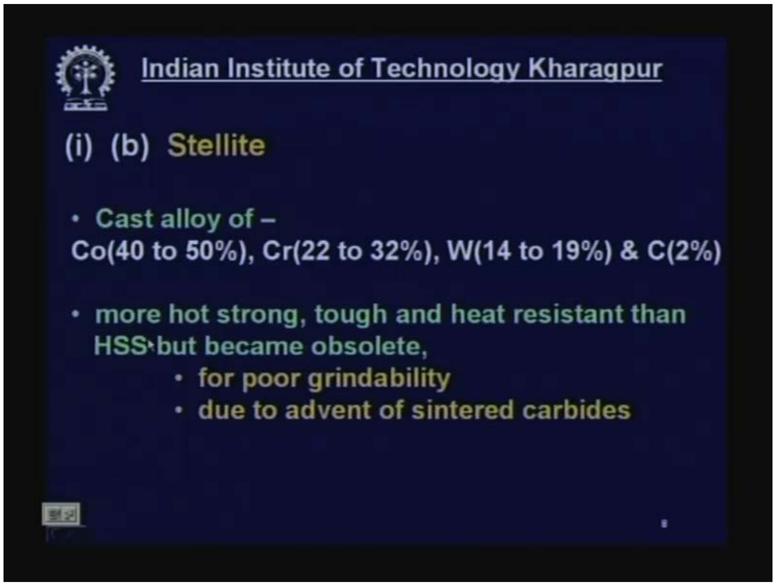
Grades of HSS available for common use

Type	C	W	Mo	Cr	V	Co	R_C
T – 1	0.70	18	-	4	1	-	
T – 4	0.75	18	-	4	1	5	
T – 6	0.80	20	-	4	2	12	
M – 2	0.80	6	5	4	2	-	64.7
M – 4	1.30	6	5	4	4	-	
M – 15	1.55	6	3	5	5	5	
M – 42	1.08	1.5	9.5	4	1.1	8	62.4

You have seen that through the century, lots of changes have taken place in the composition, properties and applications of the high speed steel. Now they have been graded for different applications. For example: T 1 T 4 T 6 these are few. There are few more I have given only few which are more useful. Commonly used T 1 T 4 T 6 they are basically having carbon percentage 0.7 to 0.8 much lower. But main alloying element is tungsten. Chromium is for hardness and wear resistance vanadium very low amount 1 1 or 2 percent. Cobalt may be 5 later 5 to12 percent cobalt have been added to enhance hot hardness and hot strength of high speed steel. Later on, during the Second World War there is a tremendous shortage of tungsten. So there was a request substitute of tungsten and it was found molybdenum could be partially a substitute of tungsten it is cheaper also.

So a combination tungsten 6 percent and molybdenum together was almost equivalent to eighteen percent tungsten. There is another grade called M grade which is which possess molybdenum, chromium same amount vanadium with a large amount and cobalt is at 5 percent 8 percent. Now this molybdenum enhanced the hardness, enhanced the toughness but at the cost of hardness, hardness has been slightly reduced but toughness have substantially improved by molybdenum. So, presently two kinds of high speed steels that are basically available say in material wise basic material one is tungsten base, other one tungsten and molybdenum combined base. In addition to that, lot of you knows coating and all these things are done. Come to the next tool stellite:

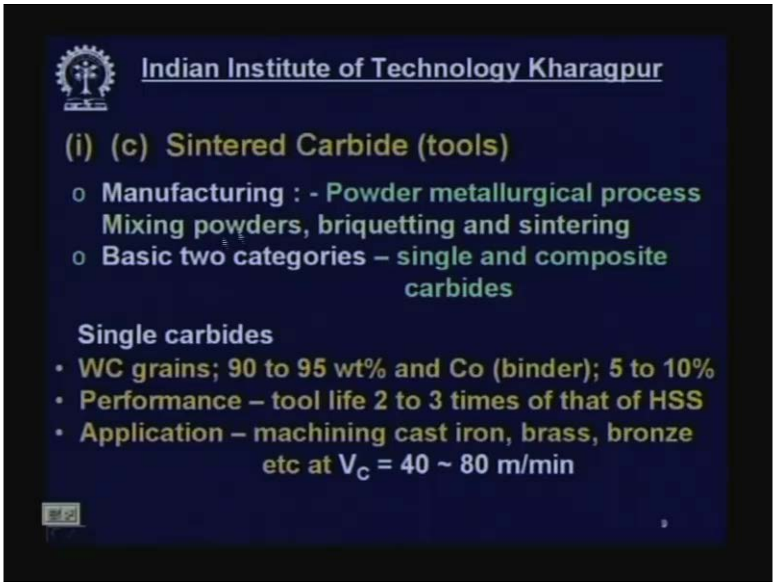
(Refer Slide Time: 19:53)



This tool stellite is a noble material was developed in 1913, may be 1914 and this is cast it is produced by casting, not powder metallurgical process or other process. But it does not contain any iron. It is composed of cobalt 40 to 50 percent, chromium 22 to 32 percent 32 percent, tungsten 14 to 19 percent, and carbon up to 2 percent. All these materials taken together had been melted and cast in to the form of tool bits which are then brazed on tool shank and used for cutting. Now this was definitely better than high speed steel at this moment so far as productivity is concerned. It could be used at a higher speed or for a longer time. Here you see that this stellite is a cast alloy of this one compared to high speed steel stellite is more hot strong that is retain strength at high temperature toughened tough that is can stand shock and vibration, heat resistant then high speed steel.

But even such good tool material became absolute within 15 years, within 10 to 15 years why? For two reasons: For poor grindability, unlike high speed steel, stellite was very difficult to re sharpen and re sharpen after wear and tear the cutting tool need to be re sharpened of the cutting edges by grinding process. But grindability of stellite is so poor that re sharpening was very very difficult and the cost was gradually increasing. So this problem was faced by the people and they were tolerating for some reason. But as soon as a very noble tool material cemented carbide came in to being than this use of stellite have been totally stopped. Now this sintered cemented carbide.

(Refer Slide Time: 21:52)



Sintered Carbide also called cemented carbide tools this is came in around 1930. This is really a very great breakthrough in the history of cutting tool material in last decade. This is powder metallurgical process produced in inserts or bits by manufactured powder metallurgical process. So what are there? Mixing powders of tungsten carbide cobalt and some additive the powders are properly mixed and then there is a bracketing or compacting in a dye and dye with the help of punch and it was fired or what is called sintering at suitable temperature and soaking time may be around 1200 degree centigrade for half an hour. Now there are basically two categories of cemented carbides. This power metallurgical produced carbide tools. One is called single carbide, other one is called double or multiple or together called composite carbide.

Now what is single carbide? Single carbide has got only tungsten carbide and cobalt. Tungsten carbide grains of size say about 1 to 20 micron once you know mixed with cobalt powder and then it was sintered cobalt being softened and it really used as binder. So cobalt gives strength and toughness and tungsten carbide grains give wear resistance and heat resistance. Tungsten carbide grains and the cobalt was used 5 to 10 percent tungsten carbide 90 to 95 percent. So the binder was 5 to 10 percent only. Now the performance tool life became 2 to 3 times of that of high speed steel. So productivity enhanced by more than say 250 percent than machining steels. Now what are the applications? It has got very very wide application. What are those? Machining cast iron, brass, bronze etcetera at velocity 40 to 80 meter per minute.

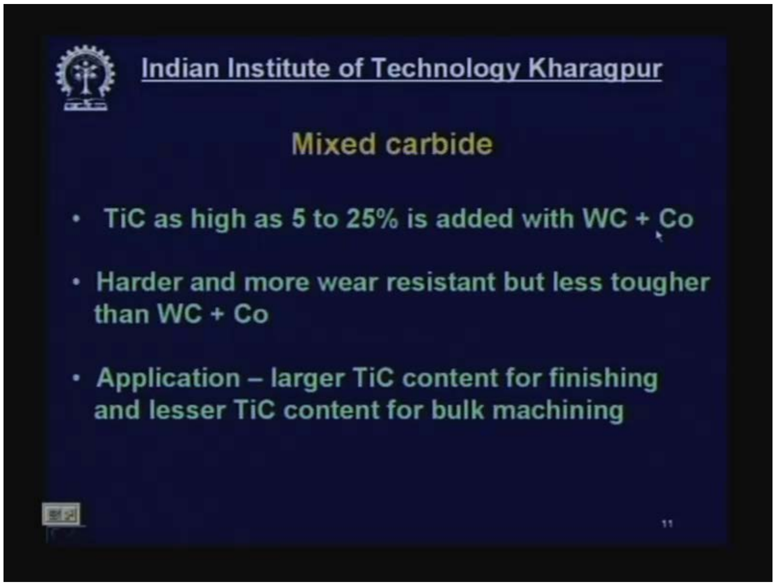
Now here one thing to be noted though it was a very noble material made a break great breakthrough. But this was suitable for materials which produce short chips, short and discontinuous chips which do not stay or slight over the tool surface and does not make much temperature. But when this tool was attempted to be used in machining steel, ductile material continuous chips were formed and that made bulk content continuously over the rake surface. As a result, lot of heat was generated and this high temperature because of high heat caused lot of problems in this cutting tool. Mainly at such high cutting temperature the cutting tool started wearing very fast because of adhesion and diffusion of the cobalt from the tool to the steel or chip and carbon also. So this single carbide was very good for say short chip forming materials like cast iron, brass, bronze etcetera but not for steel. Then Composite Carbide:

(Refer Slide Time: 25:07)

This is really a breakthrough, another break through within break through, and this was suitable for steels. What is the composition compared to single carbide? Here you see that tungsten Carbide content has been reduced from 70 to 70 to 80 percent. Cobalt has been reduced from 4 to 8 percent and what is the rest? Rest is a gamma phase is a mix of 8 to 12 percent weight percent of titanium carbide, tantalum carbide, titanium nitride, hafnium nitride, hafnium carbide and similar materials say this kind of materials are more. Now why these materials are added? Because, these materials like Titanium Carbide, Tantalum Carbide, Titanium Nitride etcetera are more heat and diffusion resistant than tungsten Carbide. So while machining steel, this element these materials Titanium Carbide, Titanium Nitride which are very stable chemically stable, heat resistant and diffusion resistant. They prevented this. They are not prevented; they reduce the rate of growth of diffusion wear and addition wear which was the main problem in machining steels.

So this material has been excellent for machining the steels will produce continuous chips and high temperature compared to single carbide this high this double carbides again are less tough so they are not suitable for impact or interrupted machining but more resistance to crater wear by adhesion and diffusion. So this is very good for steel. Application- machining steels at velocity from 50 to 120 meter per minute. For soft steels like mild steel 120 meter per minute for little stronger steels or harder steels say around 50 meter per minute but this can be used for intermittent cutting also light intermittent cutting. Now there is another grade, mixed carbide.

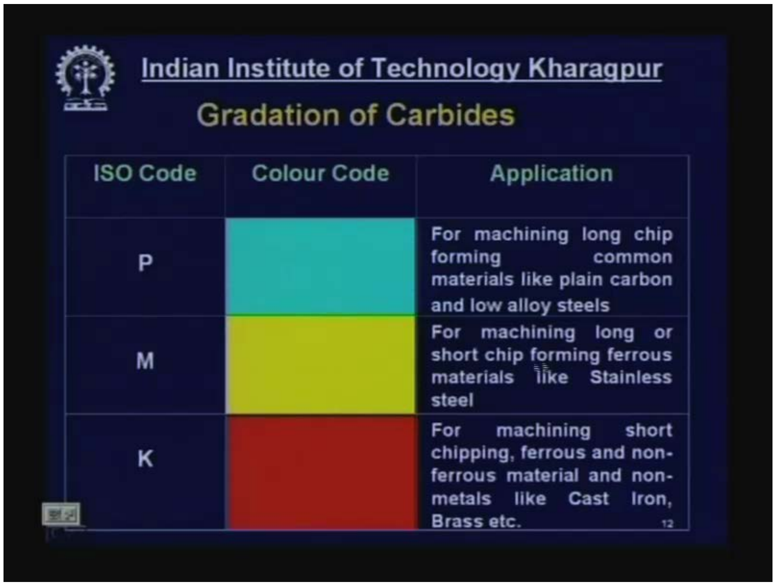
(Refer Slide Time: 26:57)



It is already stated that materials like Titanium Carbide, Titanium Nitride, Titanium Carbonitride are very stable because of high negative energy of formation and they are heat and wear resistive. They reduce or they resist the diffusion adhesion wear, built of edge up formation. So a mixed type of carbide has been produced by mixing Titanium Carbide of 5 to 25 percent in to tungsten carbide and cobalt that is single carbide. So this will add the hardness and wear resistance but at the cost of toughness. So titanium carbide will add wear resistance and hardness okay but the toughness will slightly fall. Now what the applications? Larger Titanium content about 25 percent for finishing. Now what are the characteristics of finishing?

Finishing work is normally done at high speed. So, there is high temperature. At high temperature Titanium Carbide is very good. It is more heat resistive and stable at high temperature. At high speed and temperature diffusion wear and similar thing takes place. So Titanium Carbide source suits. This finishing work the form of the cutting edge is very important for quality and Titanium Carbide helps retain the geometry and sharpness of the cutting tool by reducing the wear and tear of the cutting tool. On the other hand, lesser amount of Titanium Carbide may be 5 to 10 percent content is used for bulk machining were the cutting force is large but cutting velocity that is temperature is low. So there Titanium Carbide is not that much required. Now come to gradation of carbides.

(Refer Slide Time: 28:45)



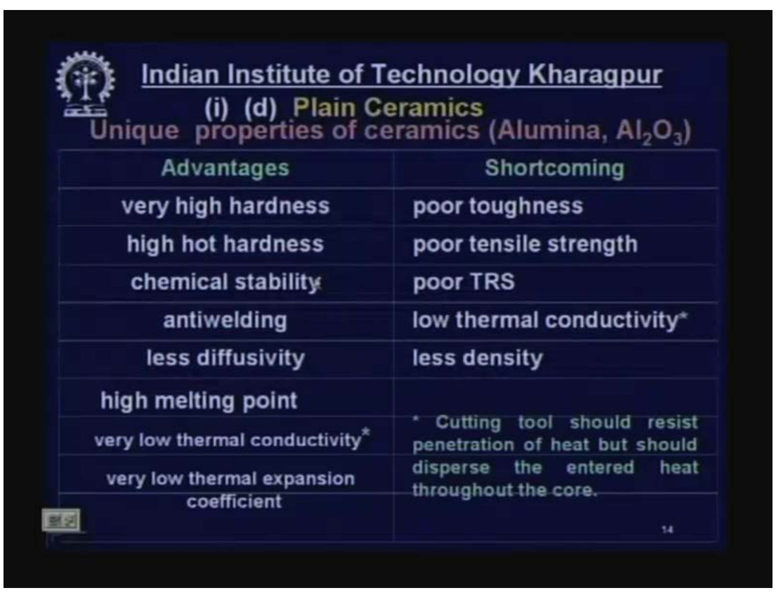
As we have heard that different types of carbides are available have been developed, have been made available, targeting suitability of machining for different work materials. Now according to ISO all the carbide tools, this powder metallurgical produced cemented carbide tools have been graded in to three forms. P M K grade; P the color code is green M sorry yellow and K red. What does it mean? P stands for machining ductile materials. For machining, long chip forming common materials, like plain carbon steel and low alloy steels. So material should be ductile but soft. M M sorry K. Now let us say K for machining short chipping ferrous and nonferrous materials and nonmetal.

These are basically single carbide with a little less additive and this is suitable for cast iron and similar materials. Sorry, now M 1 is suitable for machining ductile materials but harder materials or machining long or short chip forming ferrous materials, these are suitable for stainless steel, austenitic steel, nickel steel and similar materials. Remember within P, it is further graded by some number say P 5 P 10 P 20 P 30 P 40. Smaller number means, it is harder and larger number means tougher. So with increase in toughness, the number increases. Similarly M K also graded K 5 K 10 K 20 K 30 K 40 and so on. K 5, 10 means those are harder and K 40 is very tough. Now this shows some typical carbide tools.

(Refer Slide Time: 30:56)

This can be square, this can be triangular, this can be hollow, this can be solid, it can be different shape like this and the patterns that you see here those are made for built up sorry not built up for this patterns are given for giving an addition strength, edge strength and this chip breaking effect and all other things and compound rake, negative rake, positive rake together for this purposes. Now come to plain ceramics:

(Refer Slide Time: 31:27)

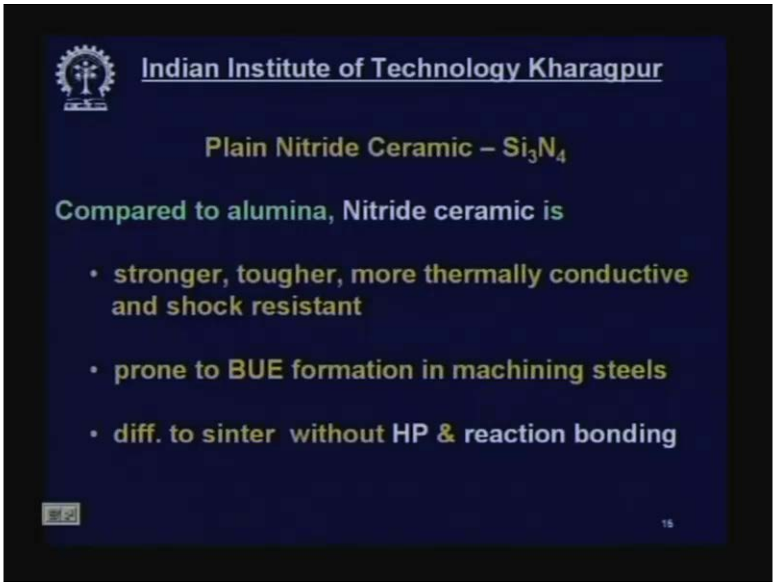


Now ceramic is heat resistive and refractory material. So when we talk about ceramic as a cutting tool material, we mainly refer alumina and Silicon Nitride. More popularly alumina. Plain ceramics are only ceramics. Now why alumina or Silicon Nitride have been targeted? Why they have been looked in to because, these two materials have got unique property, some unique properties which are essential for cutting tool materials. For example, for example say the plain ceramic like alumina like alumina advantages properties are very high hardness that is abrasion resistant. So it will reduce wear abrasion wear, high hot hardness. So form stability, this will hold the strength and harness of the material tool material even at high temperature. So it will not undergo plastic deformation easily. Chemical stability; so this will not react unfavorably or undesirably with the tool material or the environment to that extent. Anti-welding; so this is inert to welding and less diffusivity so this is very good character because of less diffusivity, diffusion wear this can be used at high speed at high temperature. High melting point; so you can go for very high speed, very low thermal conductivity, and very low thermal expansion coefficients of stress. Internal stress will be less because of low thermal expansion coefficients.

Now very low thermal conductivity or thermal insulation is good or bad is a very debatable question. It can be good quality. It can be weakness also. Let us examine the short comings or limitations of ceramics. Poor toughness that is brittleness. These tools are brittle so cannot withstand high tensile stress, bending stress and vibration jerk, poor tensile strength it cannot withstand, poor transverse rupture strength. It cannot withstand bending, low thermal conductivity. Now here you see, low thermal conductivity is taken an advantage and low thermal conductivity as taken as a limitation why because what is required by a cutting tool? The cutting tool should such that when the heat will try to enter from the chip to the tool, the tool should try to resist incoming of heat as far as possible that is at the surface, tool should be thermally nonconductive or less conductive. Inspite of that, certain amount of heat will enter in to the tool but as soon as it enters, the tool material should allow it to disperse through high thermal conductivity.

So we need cutting tool should resist penetration of heat at the entry but should disperse the entered heat throughout them core by high thermal conductivity. So it is very peculiar. The tool material same tool material needs thermal insulation at the surface and thermal conductivity at the inside. So it is dual character which will be later on you will find have been solved by coated curve coated tool by coating. Now the plain nitride plain nitride cutting tools:

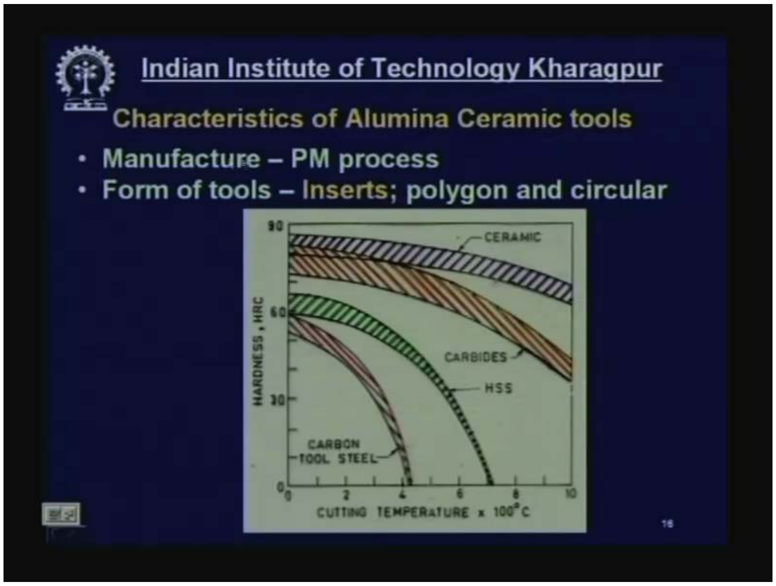
(Refer Slide Time: 34:47)



Silicon Nitride; now I talked about alumina Al_2o_3, now silicon nitride Si_3N_4. How is it different from alumina? It is also very good potential ceramic for cutting tool. Compared to alumina, nitride ceramics are stronger in tension and compression, tougher, high fracture resistance. More thermally conductive. So heat will be dispersed and shock resistant. So it can withstand vibration and jerk. So it can be used such tool can be used in in to light interrupted cutting or were there a vibration in the machine tool, this tool material is good much better than alumina. But, this nitride is prone to built-up-edge formation in machining steel. So it is partially soluble in steels and because of continuous contact, there will be a rubbing and heat generation. So built up edge will form at the interface which will cause lot of problems in machining.

Besides that, this Silicon Nitride tools are difficult to sinter. So the manufacturing process, manufacturing of Silicon Nitride is more difficult than alumina processing but this can be done only by hot pressing and reaction bonding and both of them are really costlier process. So these are the advantages and disadvantages of silicon nitride tools over alumina. So both are potential, so both have got merits and demerits. So these merits and demerits, merits of silicon nitride and alumina need to be exploited in appropriate way in appropriate applications. Now here you see the Characteristics of alumina Ceramic tools. Another characteristics:

(Refer Slide Time: 36:44)



Manufacture already told, it is powder metallurgical process. Alumina powders say 1 to 10 micron size may be a little bigger also micron size pure alumina will be or it be a before use, it should be ball milled to appropriate size particle size and then this will be compacted in suitable dye with the help of punch. May be hot pressed or cold pressed and then this will be sintered at high temperature may be at around 1550 to 1650 degree centigrade even up to 1700 degree centigrade it can. Form of tools- in what form of tools form it is available? Only inserts; square, triangular or other say polygon inserts and circular like button type. This diagram shows the unique character of ceramics say alumina, one side is hardness of the tool material versus the cutting temperature. Now the cutting temperature you know it goes up to 400 to say may go up to 1000 degree centigrade it can go.

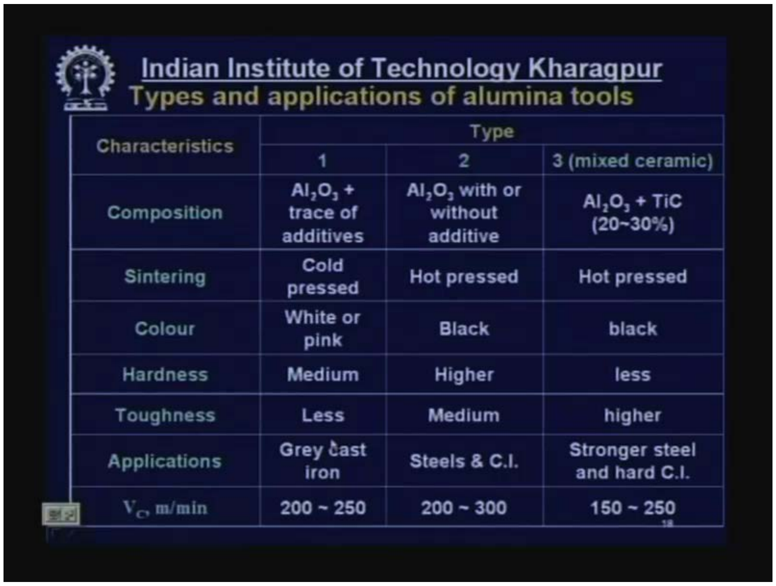
Say 20 40 60 80 1000 like that. Now here you see that the carbon tool steel that was used before high speed steel the hardness what was good enough at ambient temperature but fell down rapidly with increase in cutting temperature and with increase in cutting velocity, temperature will definitely rise. So this tool was not suitable for machining at high speed. So it could be use hardly up to 10 meter per minute in machining steel ordinary steel. Next came high speed steel, you see the jump improvement. So for same cutting temperature the hardness of high speed steel is retained ambient temperature of this the difference in hardness is not much.

But the hardness of high speed steel remains higher much higher than high carbon steel, but beyond 600 degree centigrade, the hardness falls so much that it cannot be used anymore. So the cutting edge becomes dull. What about carbides cemented carbides? Here the hardness is quite large and it drove slowly drove slowly with rise in temperature. So up to 800 degree centigrade or 700 degree centigrade these tools can be very comfortably used. What about ceramic? Say alumina ceramic plain alumina ceramic. At ambient temperature, hardness is more or less same compared to carbide but its hot hardness at high temperature the hardness is retained in the ceramic much better compared to the carbides for which same material mild steel can be machined at higher speed by ceramic tool than carbides because high speed means high temperature. Now here you see you some typical ceramic tools inserts:

(Refer Slide Time: 39:52)

The whites are the white grid and there is one black here and some of them are pink. Sometime the pink colors are also there but what is what is the shape? Square, rhombus triangular, hollow solid and there are different button, circular, solid circular and hollow circular. There are various types are there but you see that unlike carbide tools and ceramic tools there is no pattern like this because it is difficult to produce the pattern and then it will if you produce the pattern or positive break then the tool strength will fall because it is more brittle than carbides this high speed steel. That is the limitation of ceramic tools. Now what are the different types of ceramic tools available in the market?

(Refer Slide Time: 40:44)


Indian Institute of Technology Kharagpur

Types and applications of alumina tools

Characteristics	Type 1	Type 2	Type 3 (mixed ceramic)
Composition	Al_2O_3 + trace of additives	Al_2O_3 with or without additive	Al_2O_3 + TiC (20~30%)
Sintering	Cold pressed	Hot pressed	Hot pressed
Colour	White or pink	Black	black
Hardness	Medium	Higher	less
Toughness	Less	Medium	higher
Applications	Grey cast iron	Steels & C.I.	Stronger steel and hard C.I.
V_C, m/min	200 ~ 250	200 ~ 300	150 ~ 250

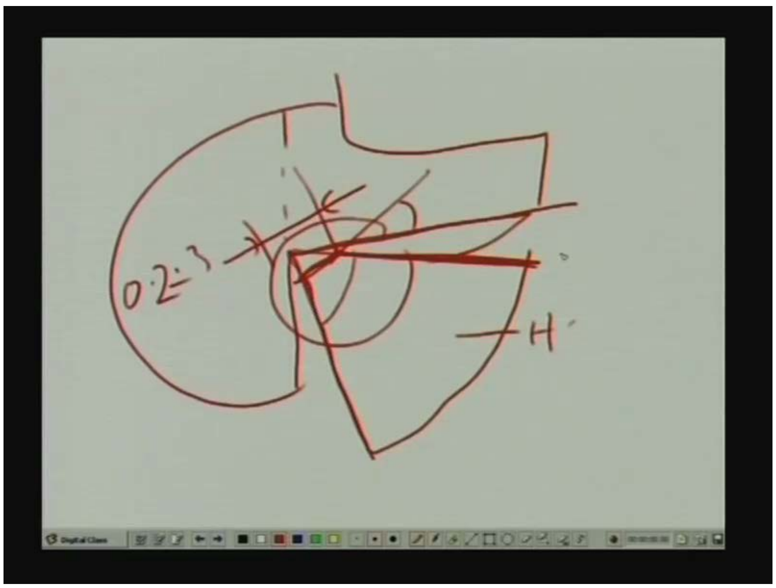
Plain ceramics; we are taking about plain ceramics. See types and application of alumina tools, alumina ceramic tools presently available. So I am not talking about this high performance ceramic or advanced ceramic which will be taken over next lecture. But what are the plain ceramics those are used in the market available? Type 1, Type 2 and Type 3. There are three types. Type 1- the composition is alumina and little amount of some additives may be say chromium oxide and some other materials very small amount. It is the produced sintering process is cold pressed. So under normal condition I mean temperature it is pressed so cost is not high.

What is the color of this type 1? Pink, white or pink hardness medium medium means around say 1500 becomes hardness becomes toughness really low less application gray cast iron which is soft but it produces slight you know vibration because of discontinue of the chip and this alumina can take that amount and cutting velocity is only 200 within 200 to 250 meter per minute. Now compared to high speed steel, even carbide you can see that the cutting velocity has been 200 250 compared to 80 to 120 meter per minute for carbides and 30 to 40 50 for high speed steel. Now what is the next one? This is really harder grade but less toughness.

Next one is alumina with or without additive. There is no additive. So it is supposed to be white but because of hot pressing sintering by hot pressing that is during compaction sintering is done together simultaneously. So pressing is done at high temperature. Sintering and pressing together so the color becomes black. Hardness very good because of hot working, toughness that is also medium improves because of microstructure. Application for steels and cast iron that means it can withstand higher temperature and large force it can withstand. Third one which is another one this is the mixed ceramic is mixed with tungsten carbide or titanium carbide which imparts toughness in alumina. So alumina plus titanium carbide what amount? 20 to 30 percent titanium carbide.

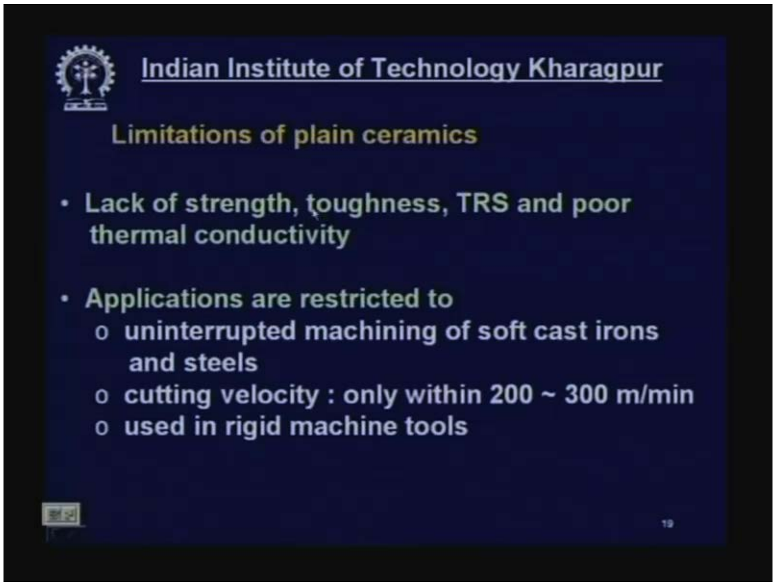
Sometime titanium nitride titanium titanium carbonitride or mixes of these materials are added in to alumina basically for improving toughness hot pressed hot press. So it is costly process the color is also black. The toughness, hardness is low because toughness is high. Toughness is very high because of the titanium carbide. Applications- stronger steels and hard cast iron were the material is harder and there is chance of fluctuation in the force than large amount titanium carbide has to be added. But because of less hardness less hardness the cutting velocity would be only 150 to 250 meter per minute. So these are the three grades basically. Within this 3 categories, there are number of types in size, shape, composition processing treatment post processing treatment and finishing by mechanical grinding. All these things are there but one thing that the ceramic tools are really brittle.

(Refer Slide Time: 44:25)



So in ceramic tools this is the carbide tools normally, the tool sharp cutting edge and this is the chip formed. Now this edge is very sharp normally. If it is high speed steel the stress will be stressed and temperature will be concentrated at this region all right and there will be but if it is high speed steel or even carbide this sharpness can be retained it will work but if it is a say ceramic cutting tool than this has to be negative rake. So this is going to wide wedge angle or at least the sharp edge will be beveled like this. So partly this will be positive break and at the end this will be negative break. So the edges of the ceramic tool should be beveled. Of course this width will be not much may be say 0.2 millimeter to 0.3 millimeter and the angle will be around 30 to 40 degree only all right. So this is one thing to be remembered either this has to be used with the negative break or compound break, negative followed by positive break. Now what are the limitations of plain ceramics?

(Refer Slide Time: 45:43)



As I told you that ceramic tools are very good in many respects say hot hardness, anti-welding, anti-diffusion, chemical stability, low cost is another factor low cost but it has got problems. Some problems like lack of strength. Now when I say strength not compressive strength it is bending strength and tensile strength. Bending strength, transverse rupture strength is also low and toughness fracture toughness is really very low because this material is as such brittle. So they has been handled carefully and the thermal conductivity of such material is also low. So the heat that is produced remains confined in the surface. So lot of temperature is generated and that can create a problem initiated by temperature or thermal shocks kind of thing.

Now what are the applications? Applications are because of the problems or limitations of ceramic tools as such, applications are restricted to uninterrupted machining of soft cast irons and steels. Now interrupted machining like milling that needs you know material should be tough or fracture toughness because if the material is brittle and the tool is subjected to say vibration than it will break in to pieces. So this has to be since it is brittle it cannot be used in interrupted machining like milling or shaping. It should be used in continuous machining like turning, boring and similar process of boring, drilling, end milling like that not other milling and this also cannot take large force. If you machine with a large depth of cut and large ah feed than it cannot withstand.

So force has also to be limited that means it can machine cast iron gray cast iron not very hard gray cast iron soft gray cast iron and also steels. These are very good for steels. These ceramic tools because steels produce high temperature and tend to cause lot of diffusion and adhesion wear which really causes problems in carbide tools. But ceramic tools are inert anti-diffusive, anti-adhesive. So for machining steels the ceramics are excellent. Now the cutting velocity cutting velocity though it is very high say 200 to 300 meter per minute, it is quite high compared to that liable for cemented carbide tools that is carbide tools and high speed steel 200 300. You remember that in high speed steel, the cutting velocity for machining material like steel mild steel is hardly 30 to 50 meter per minute with cutting fluid.

In carbides, machining steel could be 80 to 120 meter per minute but in ceramic 200 to 300 meter per minute. So as such that is very good, good improvement, good jump. But the point is that the velocity cannot be cannot be more than that or less than that if that is more than that than there will be lot of vibration because of high RPM and the tool will break because of brittleness and if you take at low speed than also problem arises at low speed machining machining is unstable. Unstable and at a high speed it becomes stable.
Stability means the cutting process is smooth force remains constant chip tool interaction remains steady but in unsteady machining chip tool interaction because of friction fluctuates built up edge is formed and the force is fluctuated under the fluctuating force such brittle tool material are not good.

Now used in rigid machine tools, that is another limitations strong limitation against you know ceramic tools. In one one end ceramic tools had to be used only at low only within a small range may be high speed but the range should be very low. May be 200 to 250 maximum may be 300 meter per minute. So at low speed it cannot machined but during machining in industry for different configuration of size and variation in size dimension and material of the work piece for same RPM, the cutting velocity fluctuates varies from zone to zone of the work piece.

At certain point the diameter is high at certain point the diameter is low because of the variation in the diameter the same RPM, the cutting velocity fluctuates but this will not be suitable for cutting tools like ceramic and the ceramic tool will need the machine tool which has to be rigid and ragged all right. If the machine is not very rigid and ragged because of compliance, this will vibrate and this will fail by breakage. So this has to be used very carefully all the time. These are the problem till 1970. After 1970, you know new kind of ceramic tools have been developed called high performance ceramic, which has overcome this limitations of shortage of strength, toughness, transverse of the strength and fracture toughness even thermal conductivity could have been improved. So all this things high performance ceramic and then all this things we will discuss in the next class.

Thank you