**Manufacturing Processes II**
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**Lecture No.27**
**Grinding Principle, Application**

Welcome to this lecture session on grinding principle and application

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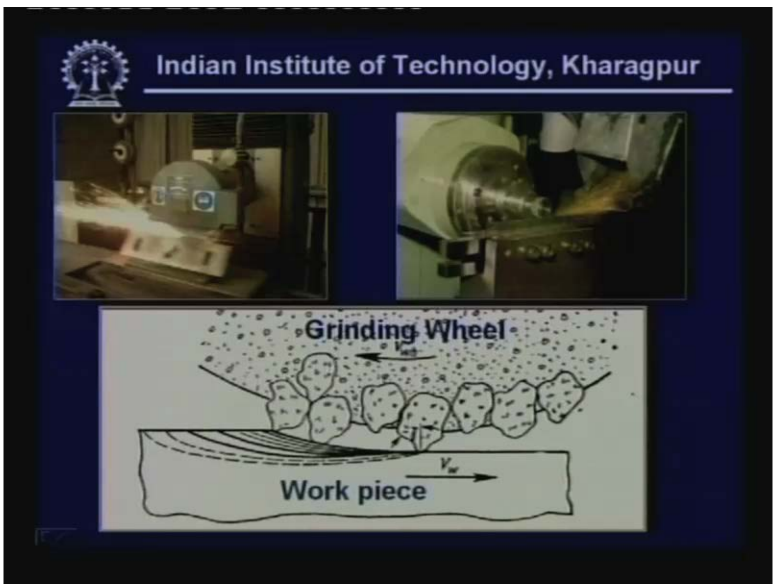

Grinding can be considered as a multipoint cutting operation very similar to any machining operation. In this case, abrasive grits in large number suitably bounded with a binding agent and in the form of a wheel actually does the function of a grinding. Here we can see this grits which are the abrasive particles bounded in this cementing medium and it is removing the work material in the form of fine layers in the step-by-step boat. So this wheel is imparted with certain velocity and at the same time the work piece also moved or advanced towards the grit and as a result of that we have the cutting action. So these are the two examples of grinding where the material is being removed from the surface it is a surface grinding and this is also another example of surface grinding involving small wheel.

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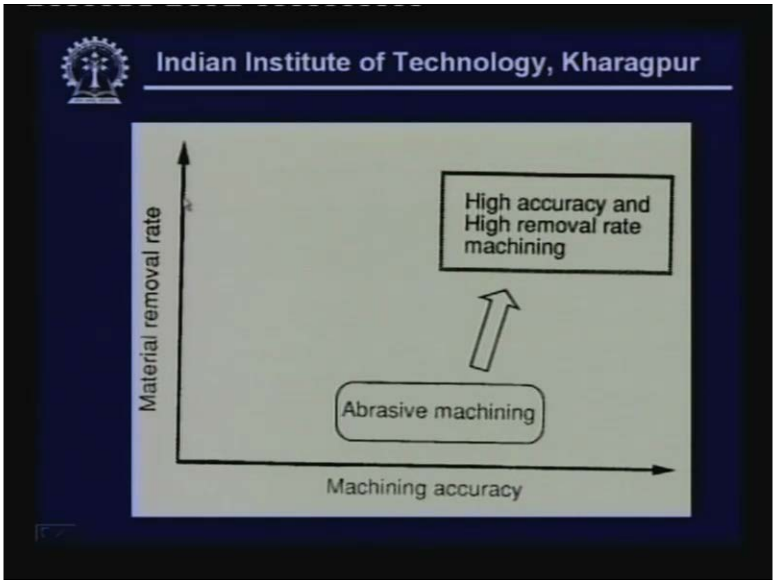


Now if we look to the basic objective of machining on one side we like to have material removal rate and on the other side the machining accuracy. So there are various processes which can give material removal rate or machining accuracy. Now so far as grinding is concerned we have different types of application of grinding according to that old concept.

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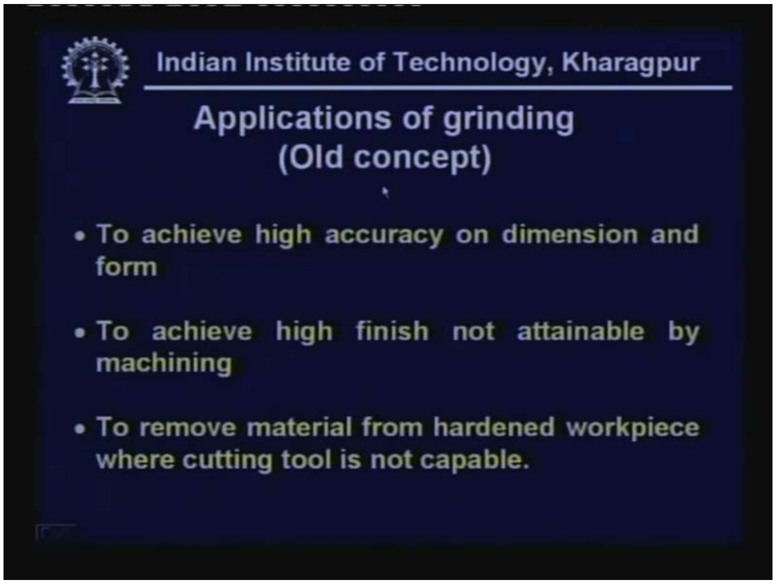


If we go back to this diagram, we can see that the basic purpose according to this concept is to achieve machining accuracy, good finish which are not achievable by just ordinary machining, by some cutting tool and there grinding has to be used and also there are cases where the work material is extremely hard and it is not possible for the single point cutting tool to have the cutting action on this hardened material or inherently hard material.

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So in those cases, grinding is the only option. But, according to the new concept, what we can see here that it should be possible to have high stock removal in just single pass conventional grinding needs multi pass operation. But what people like to achieve is single pass operation thus transforming grinding to an abrasive machining or what we can call abrasive milling.

Then the second objective; According to this recent concept is to also to extend this abrasive milling not only to hardened material but also to unhardened and ductile material. That means this abrasive wheels should encompass both hardened material and soft ductile material. Then, the third one which is also very important high stock material removal under lubricant free environment. So according to this new concept the grinding operation of the process can be elevated to abrasive machining it is suppose to fulfill these two application or these two purposes.

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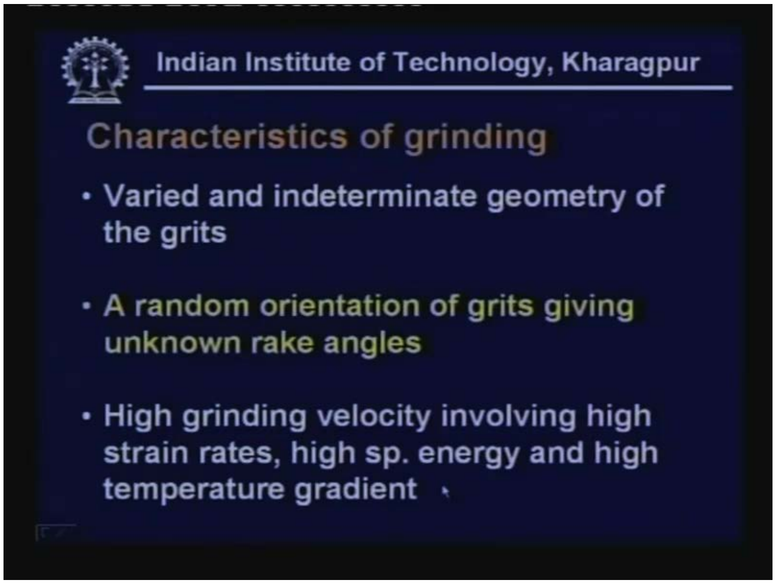


How do we characterize this grinding? How does it differ from conventional machining? 1. What can be immediately recognized very high velocity of this grinding wheel compared to any cutting tool which is being used for usual machining application. Then another thing which is also immediately can be recognized variation in the geometry, basic geometry of this cutting points, which are nothing but those abrasive grains. These are working like the multipoint cutting tools. That means this is not fixed when where as in any cutting tool this is well defined. So, there is also random orientation of the grits giving unknown tool geometry or rake angle and as we have already mentioned it needs high velocity. That means strain rate is also high. Specific energy is also high, which leads to high grinding temperature gradients. So,these in summary the basic characteristics of this grinding or abrasive machining.

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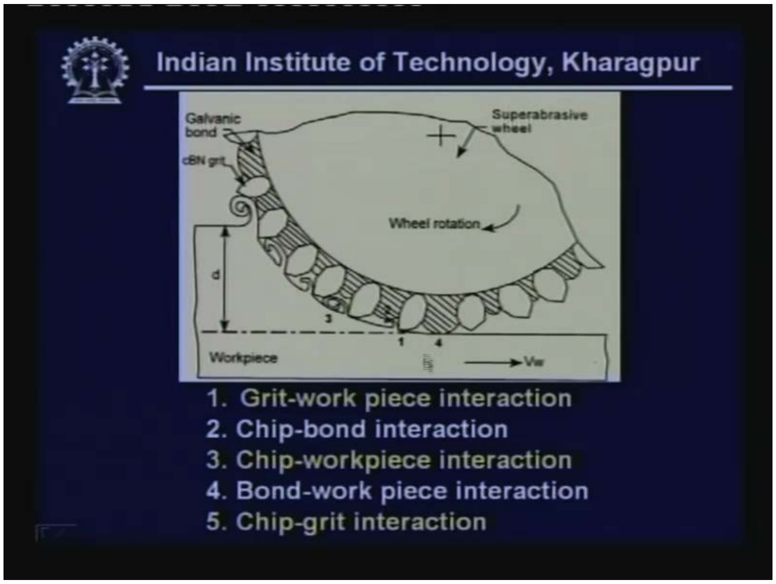


Now let us have the closer look, how this grinding wheel is actually functioning? This is the wheel configuration where each grit is serving like a cutting tool and this is imparted with a velocity that means the main cutting velocity here we have the feed velocity V w. Now, if we look here if we consider this particular grit immediately we can see it is engaged in chip formation. So the number one interaction is the Grit-work piece interaction. Actually it is the interaction between the wheel and the work piece but we can split up the bulk interaction into individual interaction. So, the number one is Grit-work piece interaction leading tool formation of the chip.

Then we can see further to this chip bond interaction.This chip is rubbing over this bond material which is just the cementing agent for holding this grit. Number three what we can see that this chip which is going to be a pretty long chip and we have a limited space. So, it will immediately fold back and it will start rubbing over this work piece and that we called Chip-work piece interaction, we have the fourth one too. If the bond level is high, then this bond also can directly engage in rubbing over this work piece which is very undesirable but as placed we can see such kind of thing cannot be avoided.

The fifth one which also comes with this one grit work piece interaction like chip grit interaction it is very similar to the chip in a machining say for turning. The chip is actually sliding over the rake surface and it is very similar to what we say in that number fifth one chip grit interaction. Now with all these five interactions ultimately, the grinding action can be continued over this entire work piece and as a result, we have certain amount of material removal, we get the exact dimension, require finish through this removal of chip but individually this can be splitted in to 5 interactions.

Now obviously, during this grinding we have to spend energy. There will be generation of force. There will be generation of temperature. There will certain level of specific energy. Now what should be our strategy? If we can look in to 5 interactions immediately, one can recognize the very importance of the interaction number one that means the Grit- work interaction. And this interaction actually causes removal of that chip that means this is the most useful interaction leading tool chip formation.

Now what about the rest four? This rest four are all undesirable interaction which also require energy and also force will develop. So according to that strategy, the best option will be to enhance this number one that means we should choose or create a condition in order that we can maximize this Grit-work piece interaction and minimize all this remaining four two to five all these things should be minimized. So that, we can have the best possible utilization of the energy available for this grinding action.

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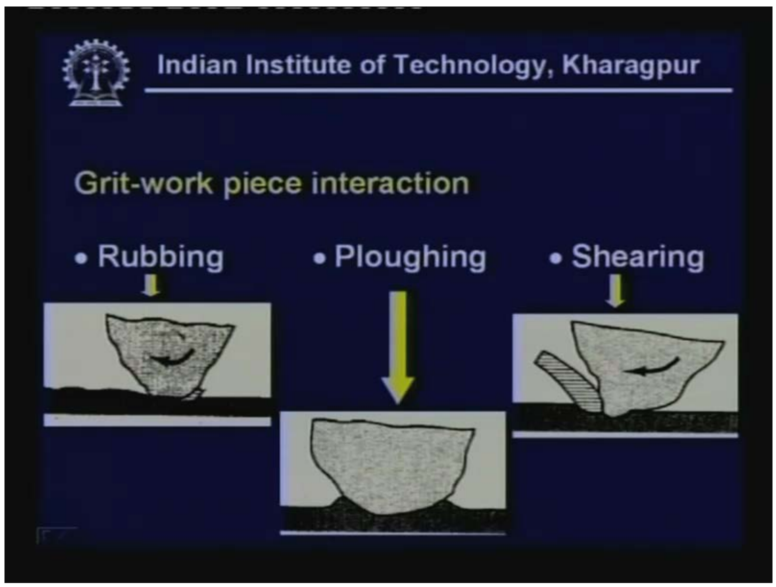


Now if we look further to this, if we concentrate our attention to this Grit-work interaction resulting in formation of the chip, atleast in this grit action which can be subdivided into three: number one is rubbing this can be promoted by the basic geometry of the grit as we have already mentioned that this grit geometry is not properly defined or controlled. There could be an unfortunate eventuality that grit has only sliding action. Then we have also ploughing, what is mean by ploughing? It forms a groove. It cuts a groove but this groove is cut without any removal of the material. We can see immediately from this diagram that this material is pushed laterally and a groove is formed but chip this material is not removed in the form of chip.

Now so far as grinding is concerned, these two are undesirable interaction inside this grit and chip interaction. Now what is most desirable this third one. Removal of chip by shearing. If I consider all these three, then by the shear mode we really have the material removal and proper utilization of the energy and perhaps we need much less energy for removal of the material through this grinding process. But anyway we can say that the grit has to pass through these three stages: 1.Sliding followed by ploughing and ultimately shearing. It is the efficiency of the grit and those conditions that determines whether the grit is actually engaged in major part of its action for shearing or ploughing or sliding and that will decide how much will be the reliable of force what will be the level of rise of temperature, what will be the requirement of specific energy?

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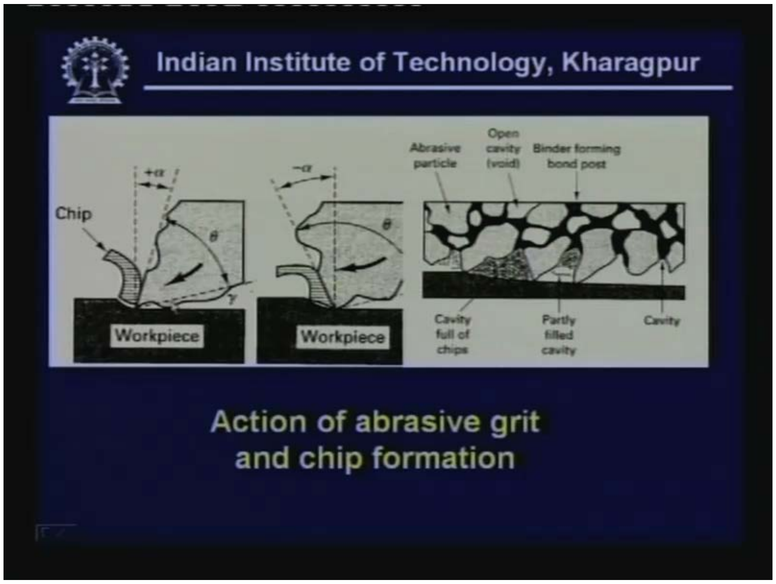


We can have a look into this basic grit geometry. In this basic grit geometry we can see here a positive rake a positive rake and also we can see another grit, with a negative rake. Obviously this positive rake is most desirable which can reduce chip reduction coefficient, thickness of the chip after grinding, less deformation, less energy spend and also low rise of temperature. So that means, this is most favored but in grinding, we cannot control the basic geometry of the grits which is random in nature. So we have no option but also to accept this one but with the clear understanding here rise of force temperature will be quite high compare to what we can see here.

Now we like to also have our attention to this grinding zone, just it cannot be ignored. What is very different which makes this grinding different from the cutting action of a single point tool? Here actually, chip is engaged in the grit is engaged in chip formation which we can see. This grit is actually creating this chip through this cutting action. Now where this chip should go? This chip cannot leave this place, it is confined where it is confined. Between these two grits the one the grit which has already done some grinding. The one which is presently engaged, then you have bond material on this top and the work-piece this contact area.

That means the chip material which is being continuously produced that is confined here and the scale, what is the chip can be accommodated within this storage volume available. Before the grit comes here and the chip is thrown out that will decide also the performance of the grinding wheel. What we mean to say here, that it is just not the strength of the grit, its thermal stability or hot hardness or its sharpness or the favorable rake geometry. It also to be considered the chip storage with what is the chip can be stored within this space before the grit comes out of this contact zone and this chip is thrown out that will also determine the final outcome or the ultimate performance of the grinding wheel. We can have the best possible bond or the best possible grit but because of this shortage of space, this wheel can also have premature withdraw or premature loss of life.

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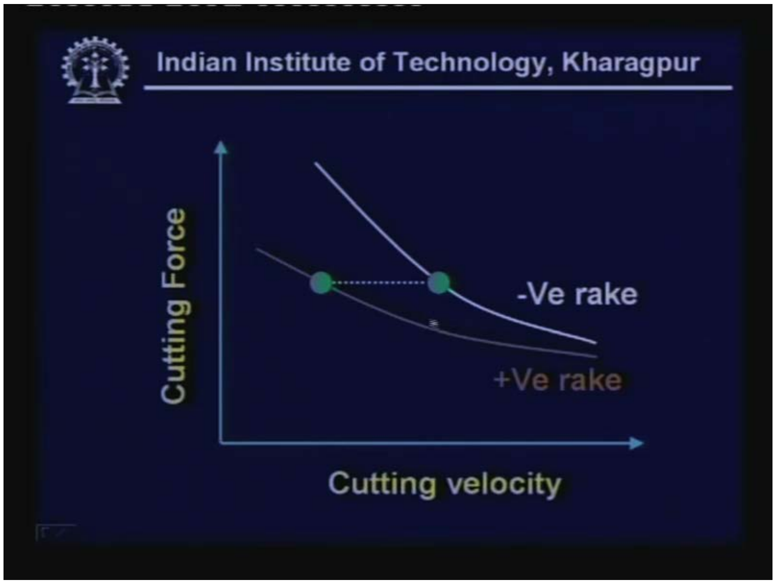


Now this is one important graph showing the need of very high cutting velocity in case of grinding. If we look how this grinding is conducted, one can immediately recognize the very importance of high speed. This speed we normally do not use in case of cutting or machining. Why it is so? To illustrate this point, we can have a look here. If we have a look cutting force versus cutting velocity, this is a normal trend of cutting force versus cutting velocity that means the force comes down with increase of cutting velocity. So that is one point in favor of cutting velocity.

Now we have two curves; one this one shows for a tool with positive rake angle and the upper one with negative rake. Now for one cutting speed, we can see the tool with negative rake generates high cutting force. Now what happens? In case of grinding, we have just now seen that most of the grits can have negative grit geometry that means very very odd situation. Now to neutralize to offset this odd situation, to our advantage or to our favor what we have to do? We have to increase the cutting velocity so that even with this negative rake, we can reduce the cutting force to our advantage and to achieve that one we have to go for accessibly high speed. And at the same time we can also see that the effect of positive rake or negative rake that narrows as we increase the speed. So, if we consider these two points for the same level of cutting force. If we choose one grit with a positive rake we can work with this velocity, but if we have another grit with a high negative rake angle, we have no option but to go for a higher cutting speed so that we can keep the force level at the same magnitude. So this is one reason why we should always hope for high velocity in case of grinding.

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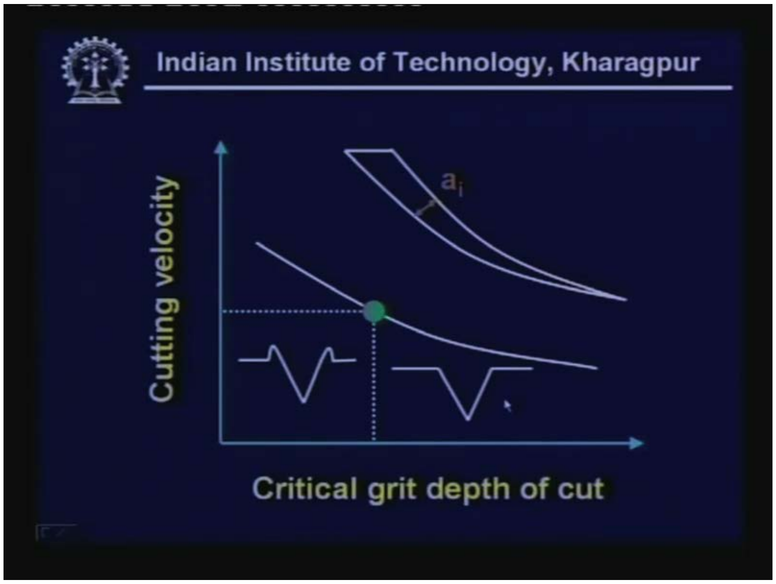


Now we have another thing cutting velocity has another role also. It is just not reduction of the cutting force offsetting. This disadvantage to our advantage by augmenting the velocity but also another thing as we have seen that, this is the chip produced during grinding. Now the chip the grit starts its action and lifts here the grinding action is terminated here. Now during this movement, from this starting point to the end, chip has to the grit has to go through three phases: sliding, ploughing and ultimately shearing. What is our desire that grit should start? Shearing, from the very beginning of grinding and this particular curve shows atleast we need a certain level of grit penetration to have this shearing.

What we can see here that the velocity versus critical depth of cut, what is mean by critical depth of cut? It is a requirement form grinding that means if we like to have just shearing with a sharp point, there will not be any flare up of the material. It is like a cutting sharp groove. Now on this side what we see we see a v groove but also we have material piled up through this lateral displacement the material is physically displaced on the two sides. And it is a best example of ploughing that means material is being pushed on two sides while making this groove.

Now what we can see that the requirement of critical depth of cut that becomes lesser and lesser as we go to higher velocity. For example if this is our chosen velocity then if i why reach this point that point corresponds to this is the minimum depth of grit grit penetration that is necessary to have such groove cut that means to have this shearing action we need minimum this grit depth of cut. If we have something less than this, we end up with such situation we cannot avoid this material piled up on this. If we like to have critical depth of cut still less suppose here then we have to reach to this graph and find out that velocity has to be augmented. So from this diagram showing a correlation between cutting velocity and critical depth of cut, we can immediately see that the critical depth of cut can be reduced requirement can be reduced by simply augmenting the cutting velocity.

Actually what happens here the inner mechanism is like this. We know a hardened in a hardened material. Penetration will be easier; there will be less ploughing action. So immediately the grit goes immediately goes into the shearing mode. So, the sliding and the ploughing will be less compare to the shearing action of the grit. So hardness of the work piece definitely playing an important role in deciding what is the requirement. So, what we are doing here? What is done just by increasing the speed, we get some improvement in the dynamic hardness. We can call it a dynamic hardness, which can be induced during the high speed operation. As if the wheel give some impact with that high velocity and there by its penetration becomes easier, it goes straight to that shearing action without spending much of its time for sliding or ploughing.

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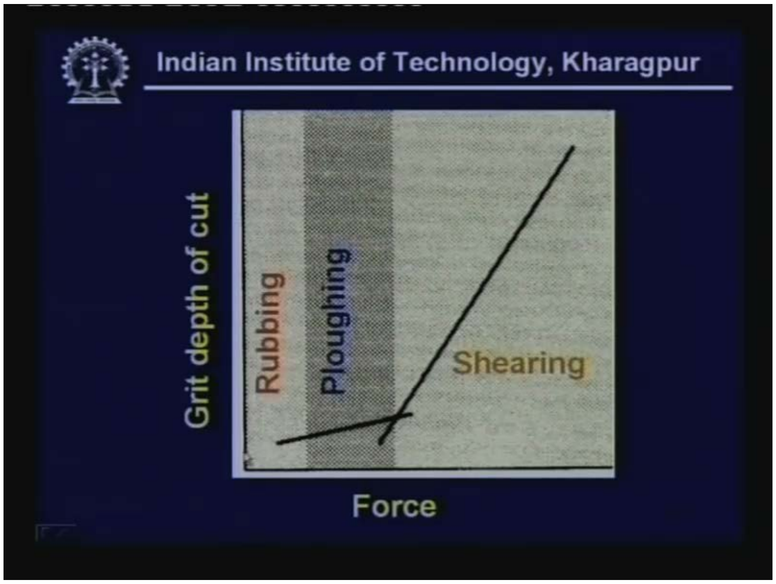


We can see immediately the effect of grit, depth of cut versus force on this rubber ploughing and shearing. Here it is grit depth of cut. Now, as we have already discussed rubbing, ploughing is the initial stage that occurs and there for little increase in grit depth of cut, the force is disproportionately high. We can see little increase in depth of cut and we have large increase of the force. But, when it goes to shear mode we can see that, force is la increase of force is not that high with the increase of grit depth of cut. So, this shows that why the specific energy or force will be quite high specific force or specific energy, why it should be high when we work with a lower grit depth of cut.

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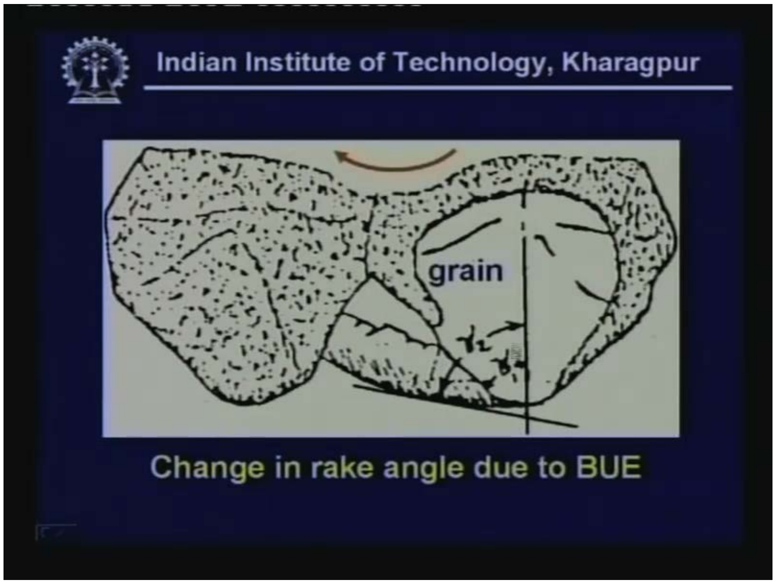


This is another illustration which also shows that during grinding the situation may also change. Now how it is change may take place. Let us have a look here, that originally this was the shape of the grit and this gamma one that shows the original rake angle which is of course quite negative and it has a high negative value. This is understandable, considering the configuration of the grit but the problem may be compounded. How if we have unfortunately some material piled up which was original in the form of chip and it adhere or stick to this grit.

Now we can see if we consider this tangent and this normal line, then we can see with gamma 1 now it has become to gamma 2 and the value of gamma 2 is quite high. It is obvious that this is higher compared to this one that means, through this sticking this effective rake angle has increased and this increased has taken place in a negative sense. That means such kind of grit is expected to increase the force. So augment of the force which is not at all favorable, not at all desirable. It happens because of the undesirable change in the grit geometry, during grinding because of this material built up at the tip of the grit. There are certain materials where such situation we may have to come across.

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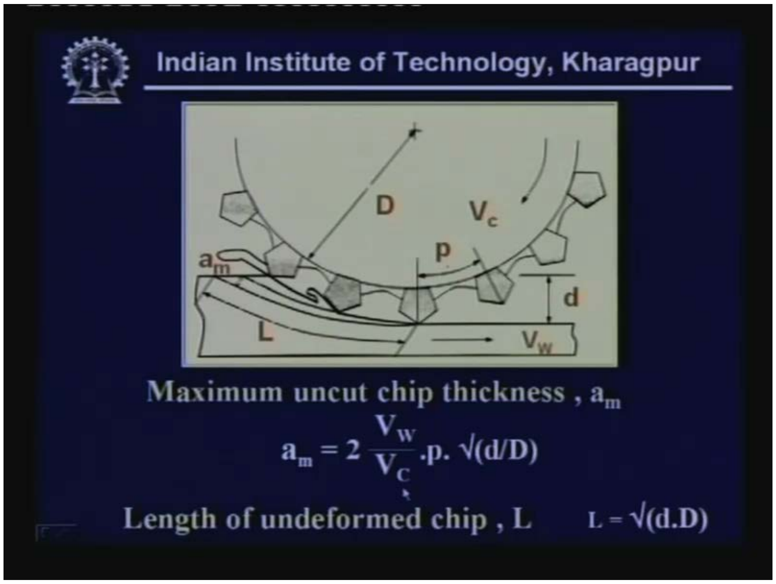


So we are going in to another aspect of grinding, as we have maintained that it is just not grit action on the work material leading to chip formation. It is also how the chip can be accommodated within this chip storage space. If we look in to these two grits, then we have this bond material and this is the border of the work piece .So this is actually the available chip storage space. This chip storage space will provide the necessary store house for accommodating this chip.

Now here two things are very important: the uncut chip thickness, this is the uncut chip thickness, which starts with zero and assume the highest value when the grit is about to leave the work piece. Now this is one thing which is equated by this relation and here the table speed wheel speed the grit spacing wheel depth of cut and the wheel diameter they are playing they their role and we can immediately see the role of this V c. If we increase this V c quite high, then we can reduce the value of 'a m' immediately the load on each grit can be reduce substantially and that helps in improving the performance of the individual grit. There is another parameter length of the undeformed chip which actually is a function, direct function of the wheel, depth of cut and diameter of the wheel. If we increase either of these three two, then this contact length will increase and length of the uncut chip will also increase. So these are the two parameters important which should be considered during grinding.

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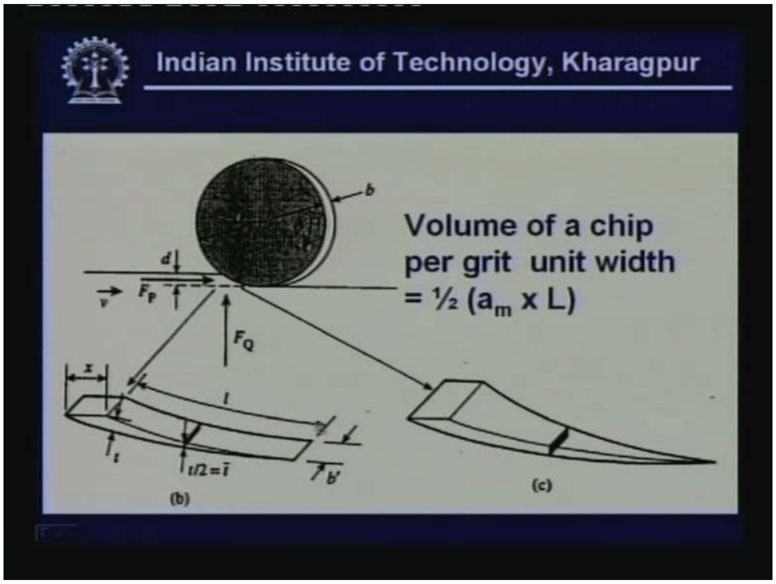


Now here the volume of the chip to be considered because this volume of chip removed by grit each grit that has to be accommodated into that chip storage space and this volume with some simplification we can equate correlate by half into chip maximum chip thickness into this length of the undeformed chip. Here, we have two possibilities either we have a grit like a would looks like a pyramidal section or grit which has like a chisel edge both can have such geometry and accordingly the shape of the chip may little differ but more or less we can consider this as the chip volume to be handled by the chip storage space.

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Now here we are coming we are considering one very important aspect of grinding that chip accommodation problem in grinding and that some times it has an overriding influence in determining the performance of grinding compared to the quality of the grit or the quality of the bond. Now we can draw one analogy of this chip accommodation of the grinding with that of a broaching tool. It is a very good analogy.

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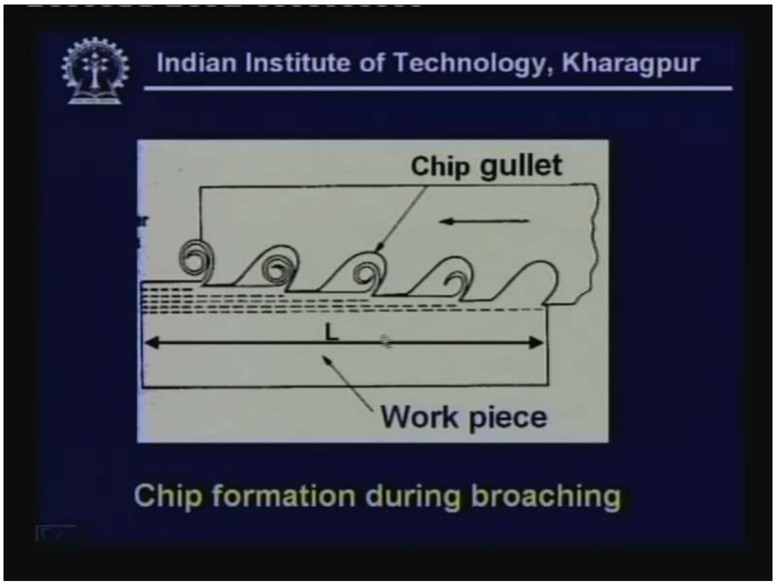


Suppose this is a broaching tool and each cutting edge of the tooth is participating in removing successive layer as illustrated in this figure. Now this is the length of the work and as each this edge is yet to start action and it has just completed action and the rest three are in their intermediate position, if we see this particular tool. Here we can see, this is the available space. Now this length cannot be accommodated just in a very simple manner. This chip has to fold back and this folding back will take place like a coiled spring with some radius and it is with what is the chip can be accommodated that decide that force. It is just not the force arising out of the chip formation, but also chip force is arising out of all other interaction that means if this chip is little constraint or compressed or squeezed then the total force may increase and exactly that happens in case of grinding.

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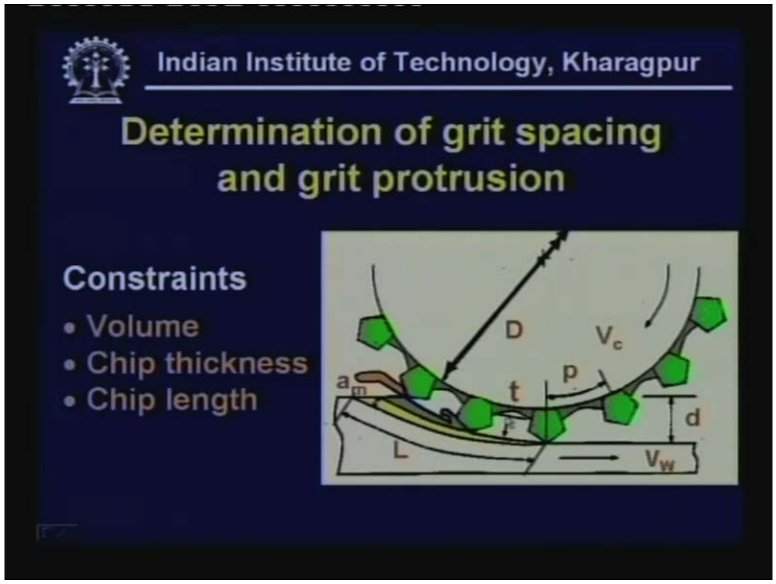


If we look here that, these are the grit material we have this chip volume storage volume which is used for storing this chip. Now here this grit has just completed the grinding action. This one is in intermediate position and the third one is yet to start. So, this yellow color shows the volume of the chip which has to be removed. Now during its path its movement from this point to this one, this volume has to be accommodated here. So, atleast what we can say this volume should be equal or greater than this volume of the chip. So while designing this wheel, one has to consider the chips storage space considering the volume of the material being removed by each grit and which is a function of this thickness of the uncut layer and this contact length which has been illustrated here. So this is one of the constraints.

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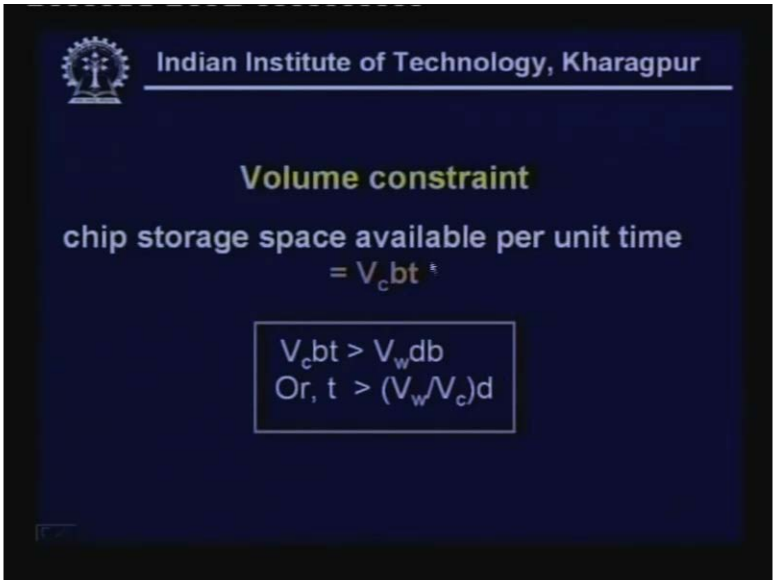


So this is the equation. We can see that if we consider the chip protrusion and width of each grit, then the volume of storage space available per unit time is equal to is given by this expression. And what is the material removal rate per minute that is equal to the table speed in to the depth of cut in to the width of cut. So from this, we arrive at this relation which is given by V w by V c in to d and so the crystal protrusion which is one of the components which give this chip storage space. This should be atleast greater than this value.

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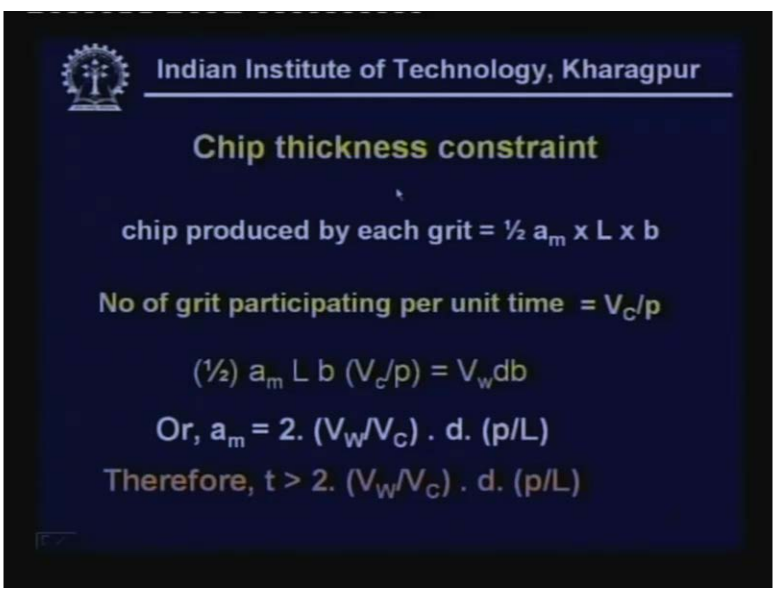

Now we go the second constraints. What is that? Chip thickness constraint that means chip thickness should not be such that it is going to interfere with the bond. In simple term, the chip thickness should not be more than the crystal protrusion. If we consider this then definitely an equation can be framed which is given by the volume of the chip removed by individual grit. Then we have to also find out how many crystals are participating in this chip removal per unit time? This can be simply determined by dividing the velocity, grinding velocity, by the grit spacing. So, this is the number of crystals which are participating in grinding action per unit time.

So this is the left hand side of the equation which can be equated by this material removal rate which is given which is a function of the table speed, the wheel depth for cut and width of the cut and from there we arrive at that this ‘am’ is equal to this. Now putting this value here we can find out that, this t should be as we have already said that the crystal protrusion must be greater than this ‘a m’. So that there will not be any interference of this uncut layer with the bond material. So atleast this crystal protrusion should be greater than this magnitude which is given by this expression. Now we go to the last constraint which is chip length constraint.

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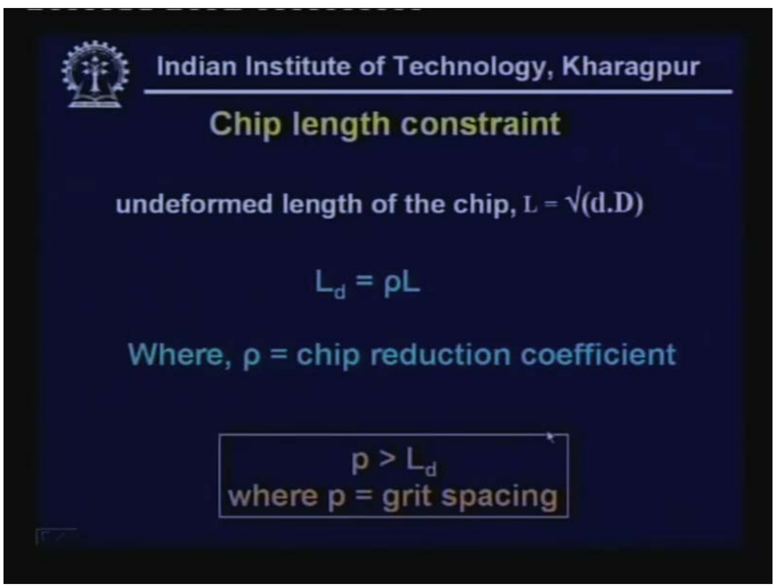


It is obvious that the entire length of the chip after deformation should be accommodated in the inter grit spacing. Now here if L is the length of the undeformed chip, then it will be little short end after deformation and which can be obtained by this expression where this ‘rho’ is the chip reduction coefficient. So it is obvious that grit spacing should be greater than this length of the chip after deformation. If this is not the case, then the chip will have chip have to, this chip material has to fold back like a coiled spring which has been just illustrated in case of broaching and then a stage may come there will be to much of squeezing which may lead to escalation of the total grinding force. So this is the condition. So after considering all these three constraints, one can be able to design the wheel spacing and grit protrusion and only then the grit are expected to do their grinding action in the best possible way.

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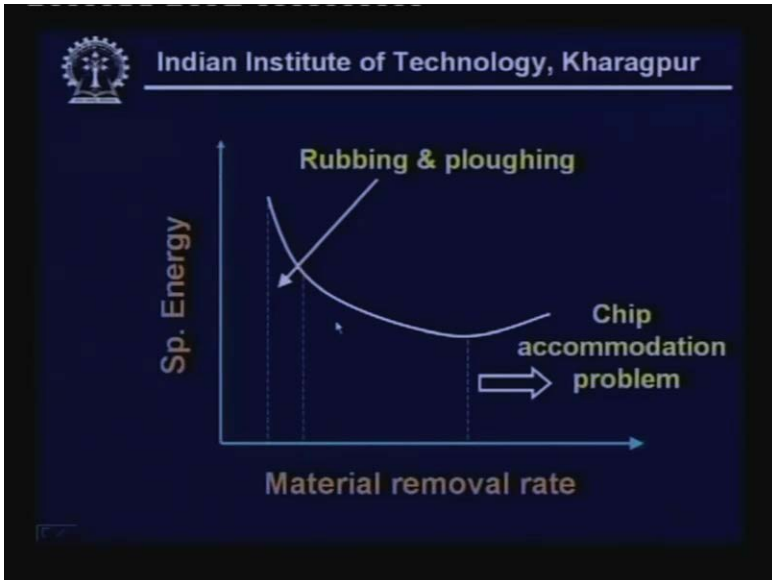


Now, this is one very important curve so far as grinding is concerned. We can immediately see that specific energy that is an index of grinding capability. So, this is the value or a figure which decides how good is the grinding or it is unfavorable situation. So it is the amount of energy required for removal of unit volume of the material. We see that at the very beginning since the grinding grit starts with rubbing and ploughing. As it starts removing the material, this value is quite high. Now as it goes to the shear zone, then we have lessening, lowering of the specific energy. So, by increasing the material removal rate, we can reduce the specific energy. But this is only one aspect of this consideration, but we can see also that if we go for increase of material removal rate without other consideration then also we may end up with steep rise of increase of specific energy.

Now what is the reason? This part comes from the geometry of the crystal, basic geometry of the crystal, its penetratability into the work piece. Then the ductility of the material, loop stiffness of the grinding system, all these thing decide the rubbing stage, ploughing stage and ultimately shearing stage but once it reached a saturated value. If we go for further material removal rate, we may reach a stage where this material cannot be accommodated by the given available chip space. And that also can lead to chip accommodation problem which is simply translated into specific energy rise. So we should try to avoid togo to this side.

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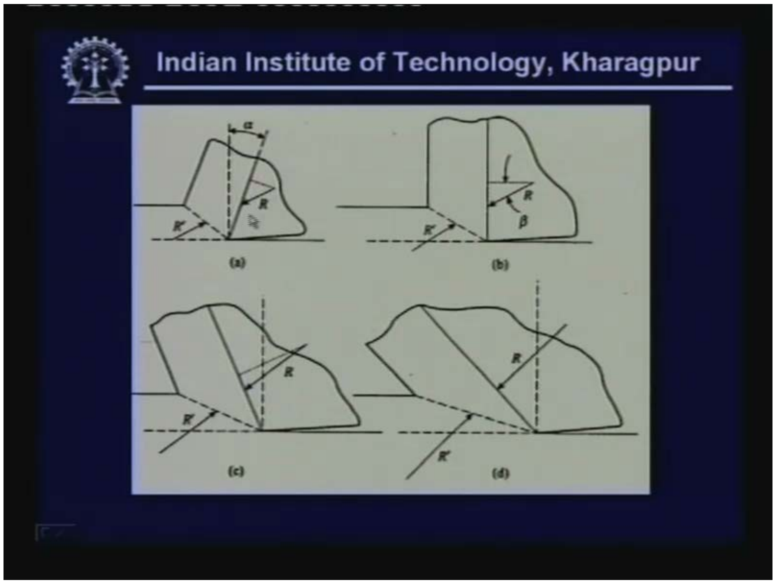


If we like to remove or increase it at all, then redesign of the wheel is necessary. Actually this is a diagram which shows how this rake angle can change the direction of the force, the resultant force and how we can apportion the normal force and the sliding force. If we see a positive rake, then the sliding force is quite high compared to the normal force. Now it is a zero rake. Now we have gone to a negative rake angle. This is the negative rake angle, we have to increase the negative rake angle further. Now if we consider this particular split up a force, this is the tangential force and this is the normal force. Similarly we can also split up normal force and tangential force. We can see the ratio of normal force to tangential force is quite high in this case. This is a peculiarity in grinding that means normally usually we know a high strength material, a hardened material because of its elevated shear strength is supposed to give larger cutting force and larger thrust force. Both should be high compared to a ductile material.

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That means same material when hardened, its yield point is elevated and because of that the cutting force or the thrust component of the force should go up should rise that is understandable but that is not what we can see in this case and that is called the peculiarity of grinding. If I consider just this side of this diagram, this is up grinding, down grinding, just if we consider this side we can see the tangential force. This is the level of force in case of mild steel. It is a soft material and this is a harden steel for mild steel what we can see the tangential force is higher compared to a harden steel where as the normal force the trust force that means, the resistance to penetration that is quit high compared in case of hardened steel compared to mild steel. This is understandable because hardened material offers stiff resistance to penetration. But what about the tangential force? Actually this can be explained by this term.

The grinding means sliding ploughing and cutting but in case of turning it starts with shearing. So the energy required for plough sliding and ploughing this component of the force will be higher in case of mild steel. But may be shearing component will be less for mild steel compared to the harden steel. So if we consider the tangential force which is actually composed of this energy force required for sliding and ploughing and then cutting. If we add all three, then the total summation becomes higher in this case but we consider shearing alone, perhaps this harden steel because of this elevated shear strength should offer high should develop higher cutting force. So this is what is we called the peculiarity in case of grinding.

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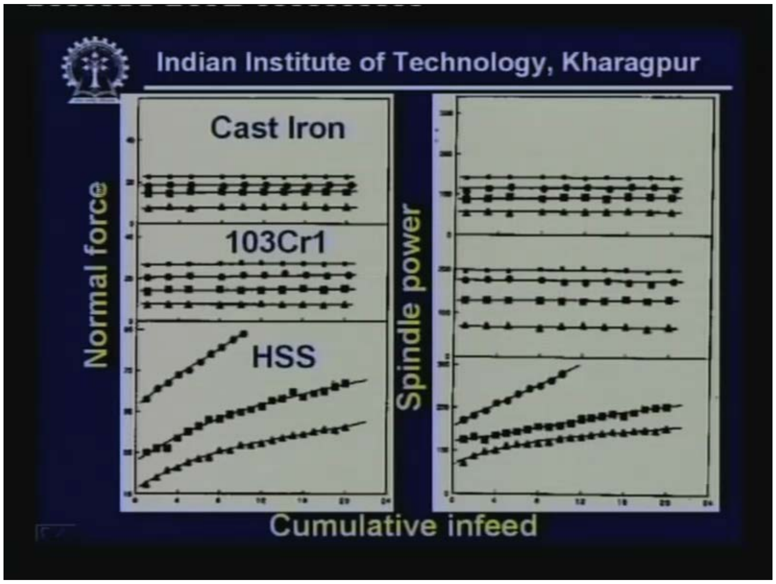


Now we go to some case studies, concerning grinding action by some cBN wheel on cast iron, then bearing steel and high speed steel. What we have shown here? This is actually cumulative in-feed. Here we have the normal force and the spindle power and this is actually the down-feed. If we increase the down feed that means the depth of cut force will simply increase but over this period of grinding, the force is almost steady. Similar is the case with a bearing steel but when it is high speed steel, what we see that this high speed steel gradually causes gradual or progressive increase of force.

The spindle power also follows the same trend. This is because of the gradual wear on this grinding wheel and as a result that causes change in grit geometry and force is progressively raising I. In this case the material characteristics do not cause any appreciable change on the grit geometry that’s why over a long stretch of grinding this force or the spindle power that remains constant. In case of high speed steel, there are certain hard carbides like tungsten carbine, vanadium carbide and chromium carbide that cause wear on the cBN grit and that is responsible for this change in grit geometry and progressive rise of the force. One thing we can look here that, spindle power is quite high compared to that what we can see in case of cast iron. This is one thing one can notice.

There are two reasons; one can be the basic strength of these two materials. This material bearing steel has a higher yield strength compared to cast iron. Obviously if we consider a particular in-feed or down-feed value, there will some difference. But when you a go to the highest in-feed, value about 40 micron there is a large difference. Now this difference is not just because of this difference in strength and the force requirement. We have another reason and this reason comes from the chip accommodation problem.

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If we look in to the types of chip produced during cutting of cast iron and this unhardened bearing steel immediately for we get the answer. This is a low high magnification 4 to 50 microns and this is just 1 millimeter. One can immediately recognize the size of the chip. This is quite long chip and this was a face grinding with a cup wheel. So over that contact length, a large volume of chip can be produced whose length is quite high compared to this. Now this chip volume has to be accommodated over the chip accommodation space which has been already illustrated in the earlier section of this lecture in the diagram and it is obvious that the difficulty will arise in accommodating this large volume of the chip which is like a ribbon. If it is fragmented, accommodation is easier what I mean to say, if we have a given volume then chip accommodation is easier with a short chip or fragmented chip than with a long ribbon like chip and that is actually translated into this high rise of this spindle power.

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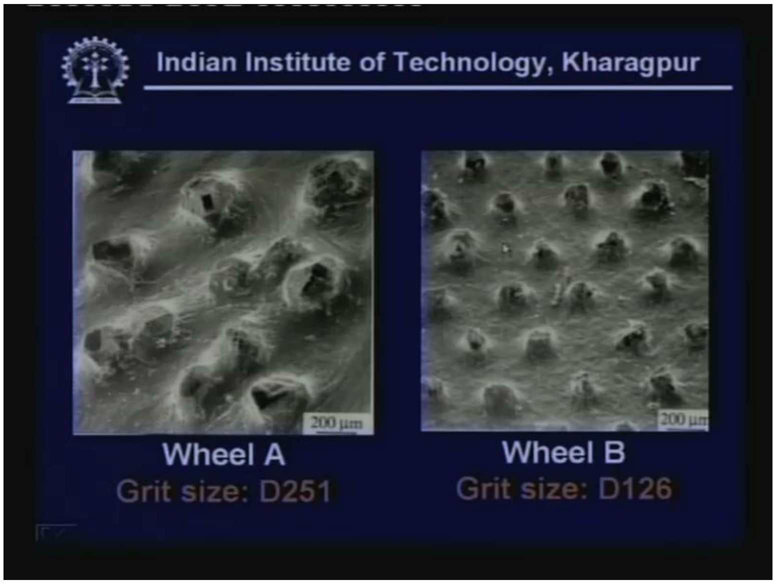


Now we consider two wheels. The difference is here that one wheel is made with larger grit size which gives larger grit protrusion and white spacing the another, with smaller grit size small grit protrusion and smaller grit spacing which is illustrated here. So, these are the two wheels the size it is 250 micron and it is about 126 micron. So, these are the two grits which were used to prepare to single layer wheel and these two wheels were engaged in grinding.

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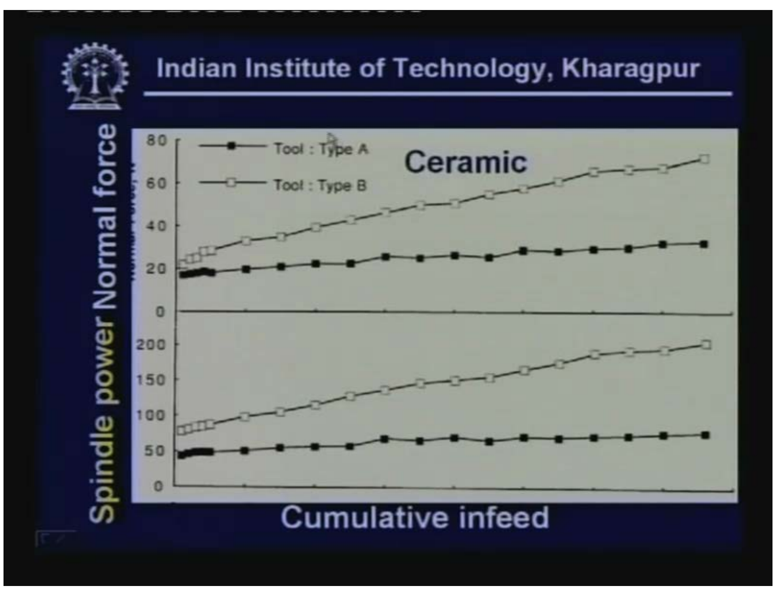

Now this is the performance curve of these two wheels .The wheel type 'A' means which has large crystal protrusion and large spacing. Now it is actual the ceramic material which was ground under dry condition. Two parameters were noted, the normal force in Newton and spindle power spindle power in what, so these are the two things which have been noted here and what we can see that there is a progressive rise of these two forces and a spindle power but the rise is taking place at a higher rate with a smaller wheel with a small grain size compared to the large grain. Now let us go the performance of the wheel in case of cast iron.

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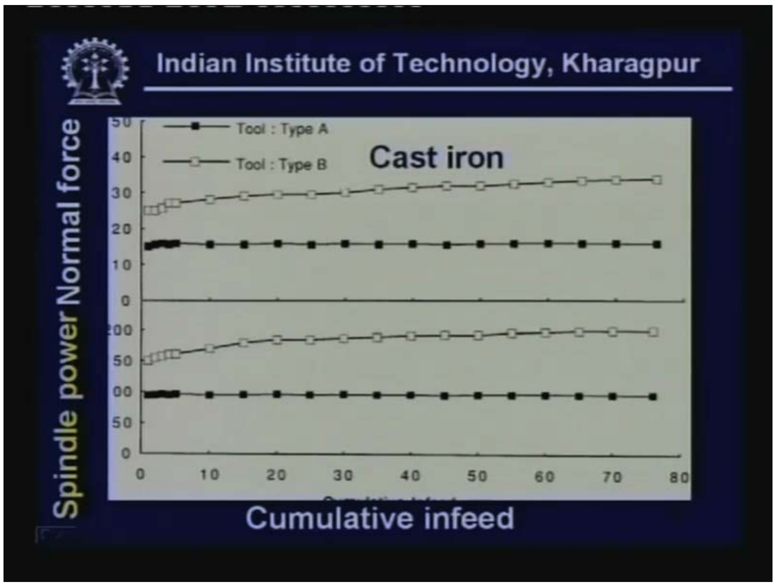


In case of cast iron, what we see that the force is almost steady with this large grit and there is very little rise of force with a small grit size which is in contrast to just what we have seen here that ceramic tool gives a high rise of force compare to cast iron and to get an explanation for this, we have to actually look in to the basic wire mechanism of the grit.

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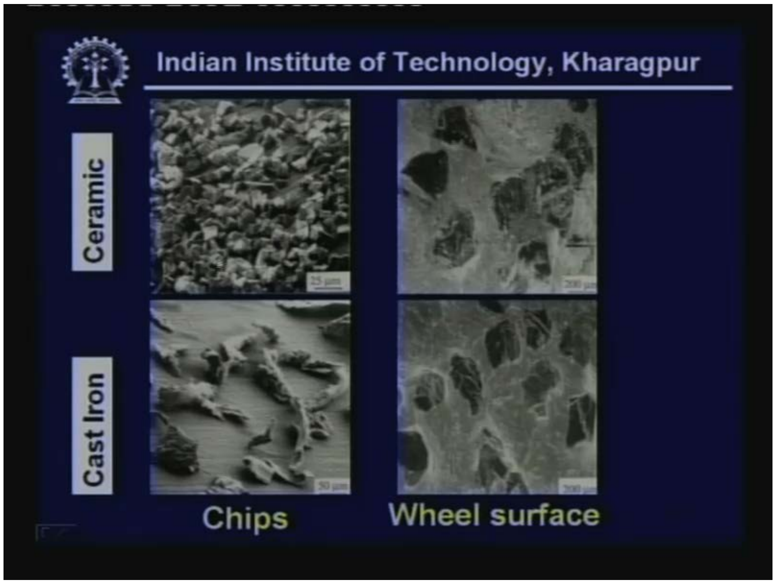


These are the actually type of chips which are produced for cast iron although they are fragmented chip but they were heavily deformed and compared to the ceramic chip which is almost like grit it's a gritty material fragmented it is mostly by fracture but here it is deformation and then fracture. So these are the two basic differences in mechanism of their chip formation and that also makes a difference in the performance of the wheel. Now in case of cast iron we can see that these crystals the photo shows the crystal structure after grinding. We can see multifaceted appearance, it is typical of micro fracturing of the grit but when it is the case of ceramic, the morphology is quite different compared to what we can see here.

It is almost like a polish surface, that means the ceramic material while being ground causes also abrasion heavy abrasion over this diamond surface making it a flat and it wear flat grew gradually over a period of grinding and grit geometry was continuously changing. As a result the gradual rise of force with passage of grinding was inhabitable. But in case of cast iron because of large force this large force actually caused the micro fracturing of the grit and that micro fracturing also maintained the cutting capability of the grit throughout the grinding span and as a result, the grinding performance and grinding force was more or less stable and that gives a steady performance over this period of time. So definitely here the friability of the material that comes in to comes in to play and it has a major role to play.

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Now we go to an illustration what can happen if we do not provide adequate chip space, this is one example where this crystal has a very high level of protrusion but it is highly dense fact. So what happens during grinding of unhardened material, this chip actually got entrapped. The length could not be accommodated that means it is not that protrusion will serve the purpose along with the protrusion we have to also provide a reasonable grit space to allow easy movement of that long chip and this is what we can understand from this illustration.

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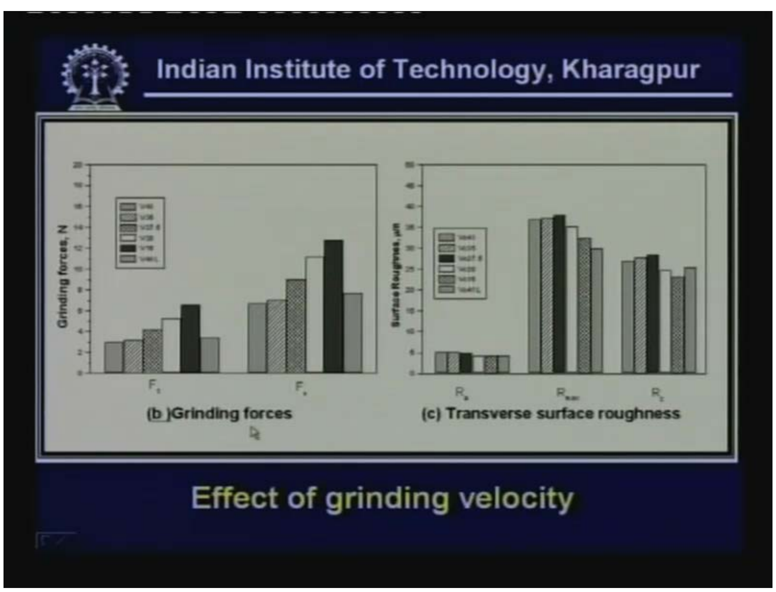

So this is one example how this grinding force may change with cutting velocity at higher velocity, we are lead lesser grinding force and also transverse roughness. This is almost independent of the velocity. This is grinding force versus the table speed.

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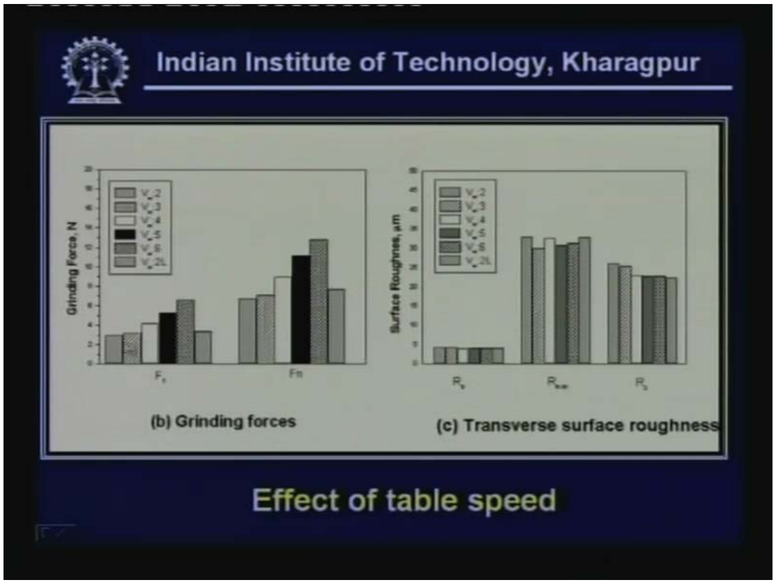


Here we can see as we increase the table speed there is progressive rise of the grinding force, but the table speed does not affect the transverse roughness.

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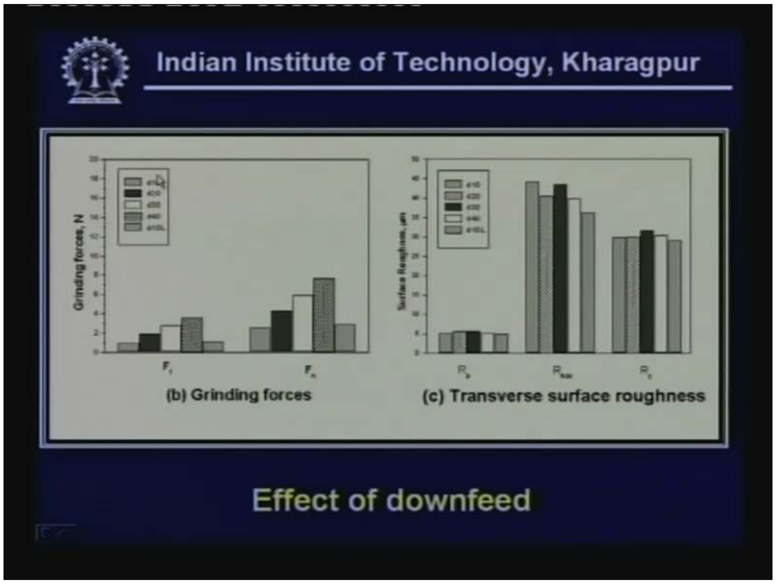

We go to this next illustration which shows variation of this in-feed or down-feed and the grinding force. Here also the force is progressively increased, but surface roughness is not that affected by this depth of cut.

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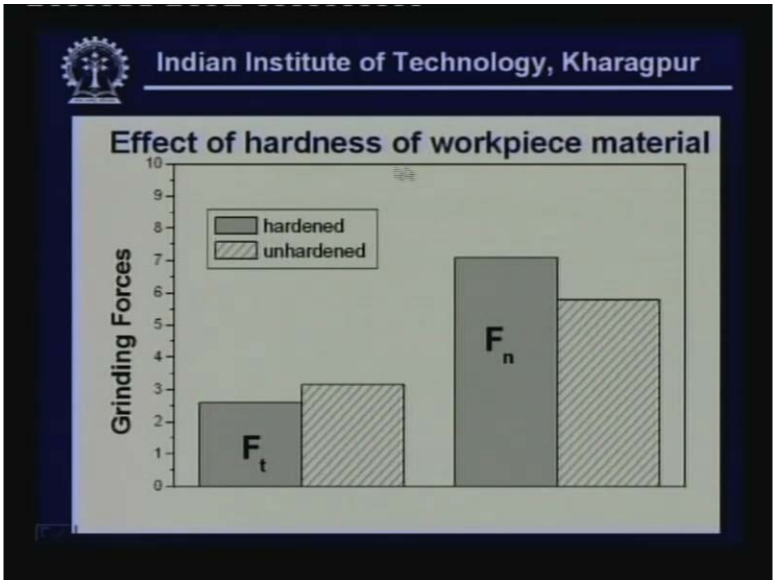


This is already has been explained that hardened material gives larger normal force where as unhardened material gives larger tangential force. This is actually the grinding ratio which is also very very important if we consider the performance of the grinding wheel.

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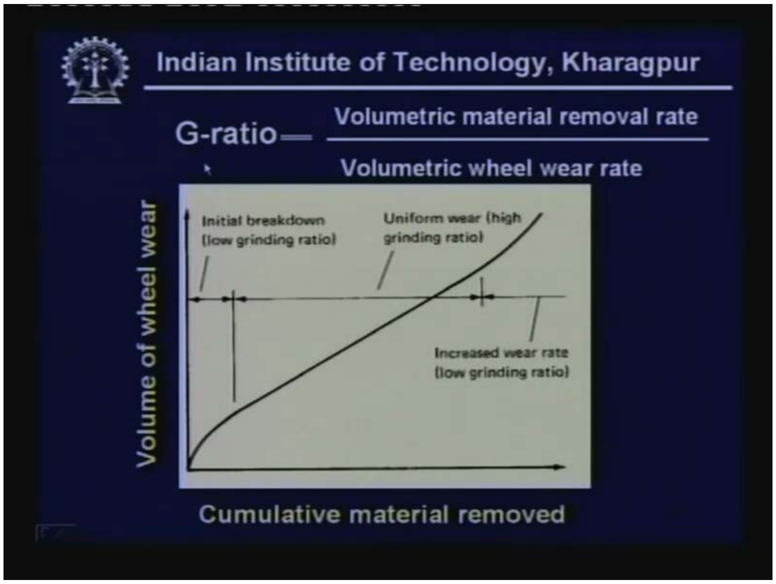

Actually what happens this is the volume of wheel wear and that is the cumulative material removal rate. Now when we consider the material removal rate by the ratio that high ratio means better performance of the wheel and obviously that ratio has to be improved if we like to improve the performance of the wheel.

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Now wheel wear actually caused by three mechanism. This is attritious wear that means dulling of the surface which can be because of mechanical reason that means if the work material is extremely hard, it can cause mechanical abrasion causing some blunting of the grit. If it is chemical action of the work material against the grit material, even a soft material can cause flattening on the grit surface just by through some chemical reaction. We have also wear by fracture. Because of the grinding force, the wheel grit may also undergo some fracture and this fracture may takes place in the micro level or it can takes place in the macro level depending upon the friability of the grinding wheel and also the level of the grinding force.

The last one is the bulk loss of the material it is grit pull out. If the grinding force is too high or the bond between the grit and the binding agent is very poor then loss of grit also can takes place. So wheel wear is controlled by these three mechanism. Now we go the question answer.

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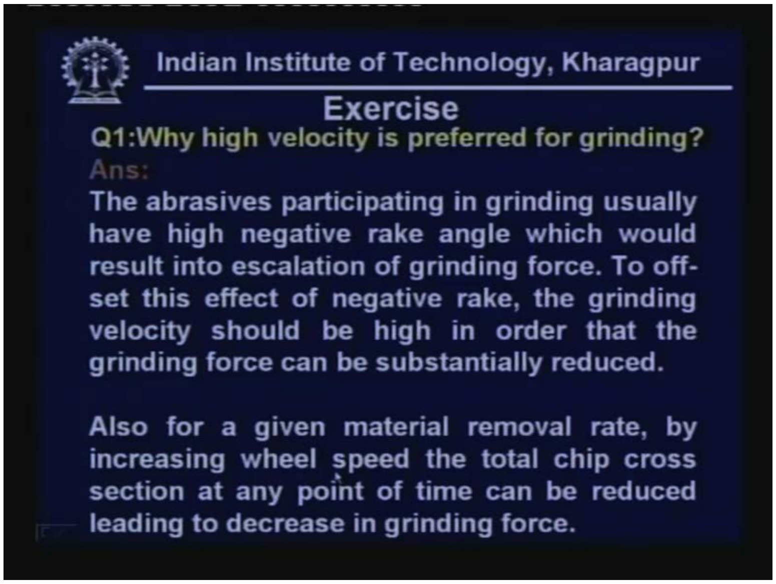


Why high velocity is preferred for grinding. This high velocity is preferred for grinding for two reasons: One to offset the effect of this negative rake. There if we can go for grinding, we can if we go for high negative high speed we can offset this negative rake. Another one that chip section can be also reduced by this high velocity. Specific energy should reduce with increase of material removal rate, but then it can increase because of the chip accommodation problem also.

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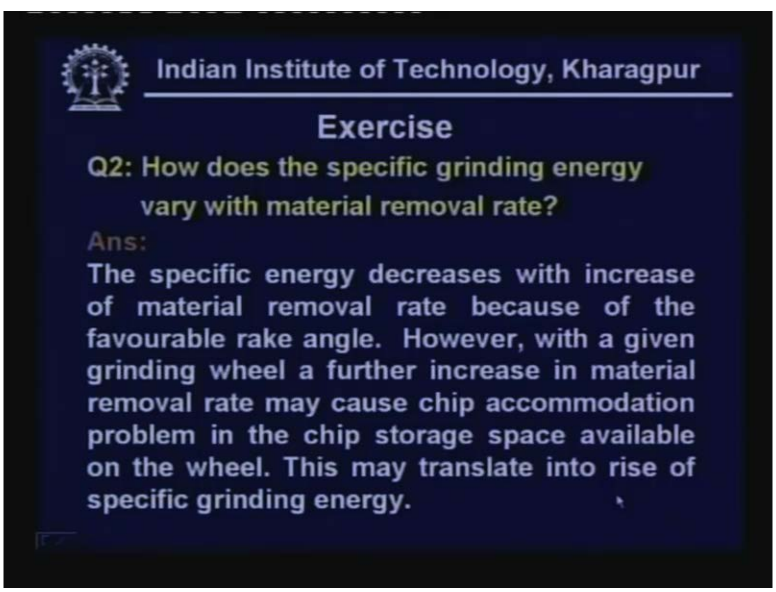

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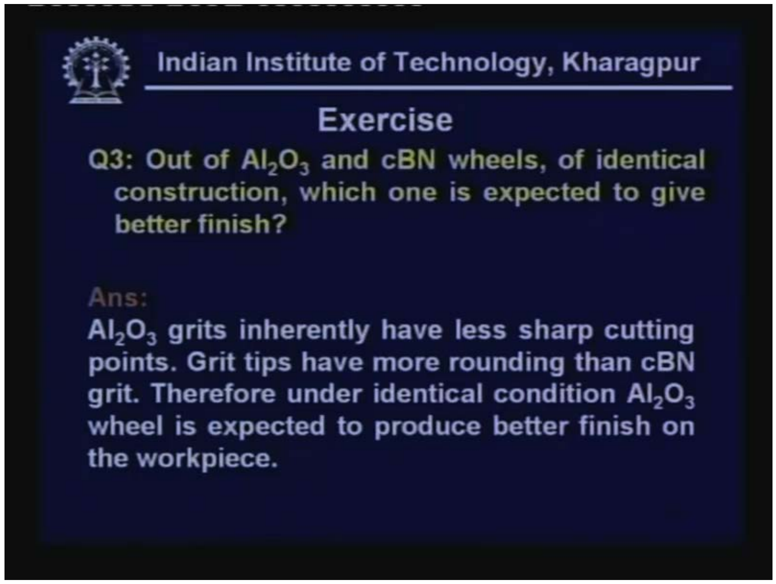


For identical wheel condition, aluminum oxide wheel has blunted grit or less sharp grit and that's why compare to cBN it is expect to to get give good finish.

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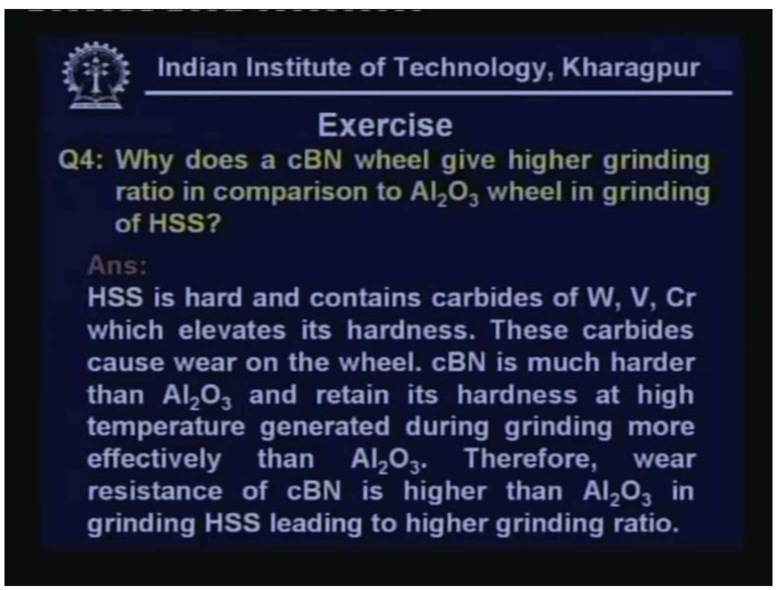


And when it is high speed steel then this hardened constituents of the work material can cause greater wear on the aluminum oxide because it is less hard than cBN.

Thank you for your attention.