Mechanics of Machining
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Lecture - 17
Grinding of Metals and Mechanics of Grinding Process

Welcome to the 17th lecture on Mechanics of Machining. Today I am going to discuss about Grinding of Metals and Mechanics of Grinding Process. Grinding is also a machining process, but it is usually implied for finishing. It can also be used to remove the large volume of difficult to cut materials. Suppose some hard material is there, we can actually grind it may not be able to use single point cutting tool of h s s material or carbide material so, we do like that. So, we are going to discuss about mechanics of grinding process.

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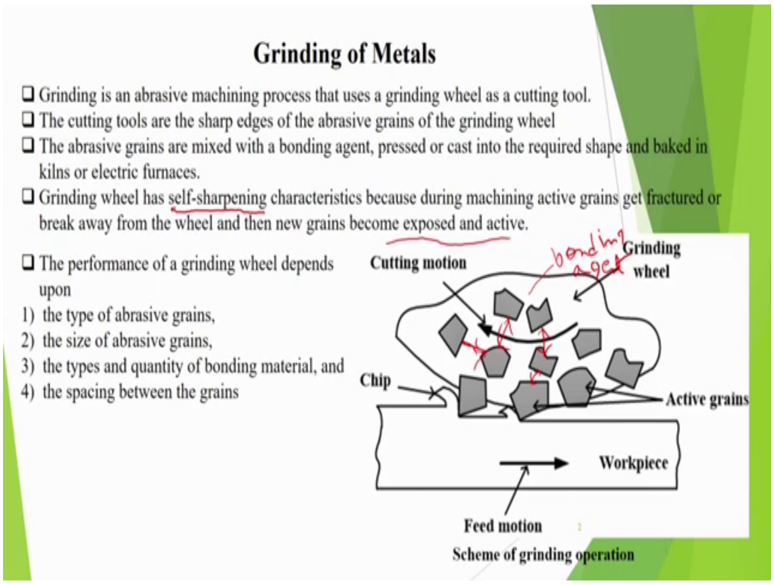

Before that we will discuss about some concepts about grinding of metals. So, grinding is an abrasive machining process that uses a grinding wheel as a cutting tool. It is called abrasive machining process because material is removed by a abrasion, they actually upgrade the surface these small small cutting tools, there can be small small cutting tools are there, basically they are abrasive grains. So, these cutting tools are this sharp edges of the abrasive grains. If you have abrasive grain, it may be having number of sharp edges.

Suppose this is the grinding wheel it is the bond material, in this there are number of abrasives they have been put, and they are having multiple cutting edges. Know, this one this is cutting edge this is also. And what will happen that after at the surface? May be some cutting edges are exposed like here, this edge is exposed this edge is also there, but that is far away. So, these are called active grains. There are grains inside also they are inactive grains. If these grains will be broken and they will be removed, then naturally the new grains will come and they will become active inactive they will become active grain.

So, initially there are some active grain, some passive grains are there, after sometimes those grains which are passive they will become active and this process will go on. And chips are removed suppose you give the feed motion let us say work piece is moving in this direction, then you are giving the feed motion, and material is removed by small small chips like this is one grain and you are removing that. So, this way it process moves on.

Abrasive grains are mixed with a bonding agent. Here there is a bonding agent basically in this you get bonding agent so, bonding agent. So, bonding agent is there and it is pressed or cast in to the required shape and baked in kilns or electric furnaces. Whole thing baking is done grinding wheel manufacturing process. We will not discuss in detail, but this is how it is made. Grinding wheel has self-sharpening characteristics we say grinding wheel has self-sharpening characteristic.

So, we see that this is the thing you have to note it has got, self-sharpening characteristics because during machining active grains get fractured or break away from the wheel and then new grains become exposed and active. So, new grains become exposed and active and this process goes on. Performance of grinding wheel depends upon mainly 4 factors. One is the type of abrasive grains what type of abrasive grains you are using there are different type of abrasives. Like it can be aluminium oxide, it can be silicon carbide.

So, you have to decide which type of abrasive grain has to be used every abrasive grain will have different characteristic. Then what is the size of abrasive grains? We have to decide about the size of abrasive grains. And we decide types and quantity of bonding material. So, types and quantity of what type of bonding material is there, and what is the quantity you know means, what is the quantity means, there may be more bonding material less number of abrasives or vice versa and then spacing between the grains like this one.

So, there is a spacing here, this is this one if more spacing is there; means, open structure or it is dense structure spacing usually need not be uniform also here, you see that somewhat variation is there here is spacing is less. But you know this will be in a an every sense we talk about the spacing between the grains. So, these 4 factors will decide that what type of motion will take place.

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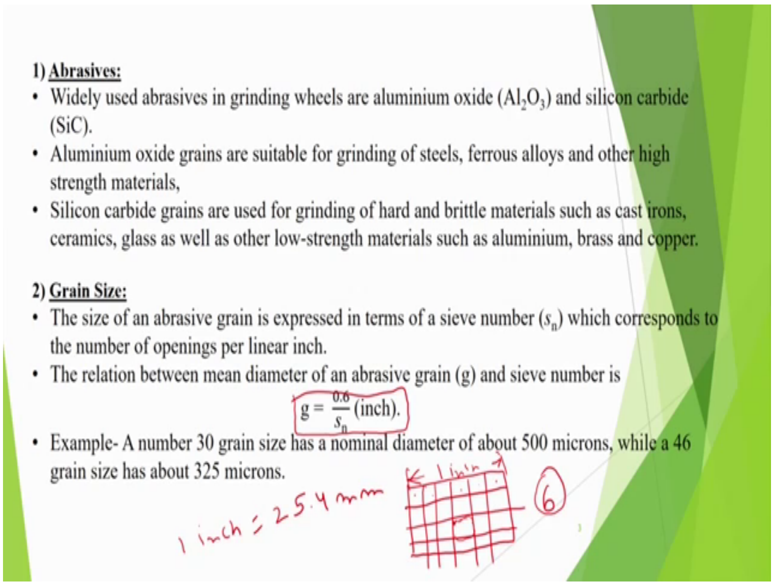

So, let us discuss one by one about abrasive abrasives widely used. Abrasives in grinding wheels are aluminium oxide, that we say Al 2 O 3 and silicon carbide that is SiC. Aluminium oxide grains are suitable for grinding of steels ferrous alloys and other high strength materials. Aluminium oxide grains are suitable; suppose, you want to grind steel you can use aluminium oxide ferrous alloys are there, and some high strength materials can be machined or ground by aluminium oxide.

Silicon carbide grains are used for grinding of hard and brittle material such as cast irons, ceramics, glass as well as other low strength materials, such as aluminium brass and copper. So, silicon carbide grains are used for grinding of hard and brittle materials. Example cast iron, ceramic, glass and it can also be used for machining of aluminium glass and copper.

Now about grain size the size of an abrasive grain is expressed in terms of a sieve number. We basically see that we make various type of sieves. So, from which you this grain can pass ok. So, sieve may be like this ok, that may be suppose I make a rectangular sieve, it may be like this. And this is a typical may be size of the opening. And so, if the size is more then; that means, the number of openings are less ok, number of openings are less. So, if we talk in terms of inch you know 1 inch is equal to 25.4 mm, 1 inch is equal to 25.4 mm, whole system was actually inch etcetera. In our country also we are using inch and now of course, we have switch toward to SI system of unit, but you can know the conversion.

So, 1 inch is equal to 25.4 mm so, earlier suppose sieve number is there they use to define, that how many openings are in 1 inch. Suppose this thing is let us say if this is 1 inch, then in 1 inch, how many openings are there 1, 2, 3, 4, 5, 6. So, we can give that something like sieve number is 6 ok. So, you can very well see that sieve number is inversely proportional to the size of the opening. If the sieve number is more; that means, your size is less. Then what is the size of relation between mean diameter of an abrasive grain? And sieve number is given like that. If suppose mean diameter is g so, is defined as 0.6 divided by s n in inch; that means, this diameter will be in inch.

That means, more the sieve number lesser the diameter. Example is that a number 30 grain size has a nominal diameter of 500 microns, micrometer 1 and while a 46 grain size has about 325 microns ok. So, this type of relation is there. Any way you have to just suppose you can remember this formula g is equal to 0.6 divided by s n per inch.

So, we talk in terms of basically the grains. So, grain size will be that suppose there is a grain size, it can pass through this particular sieve. So, that will be the size of the grain ok, suppose 30 grain size. 30 grain size means, it can pass through the sieve of number 30 ok. It will not pass through the sieve number of 32 (Refer Time: 10:00). It will pass because 30 grain size has big opening and 30, 29 has even bigger opening 28 has got even bigger opening. But 32 has got smaller opening you know it is just reverse. So, you just have to remember these concepts ok. So, we have talked about this one now coming to the bond material and structure.

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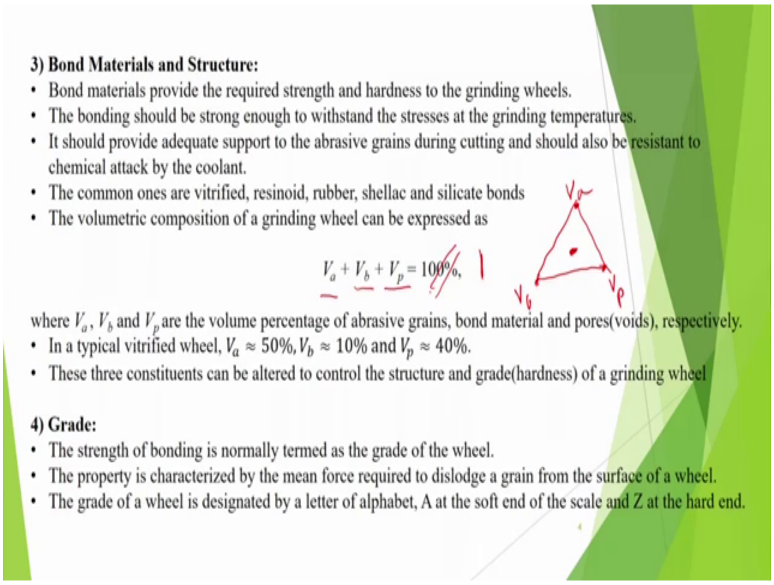

Bond materials provide the required strength and hardness to the grinding wheels, because abrasives are basically loose particles. So, they have to be bonded together. So, these abrasives are bond together. And the bonding should be strong enough to withstand the stresses at the grinding temperature. Because temperature also increases there is lot of heat generation. So, bonding should be strong, otherwise the abrasives will fragment and nothing will be done you cannot do machining.

But it should provide adequate support to the abrasive grains during cutting and should also be resistant to chemical attack by the coolant; because we keep lot of coolant sometimes we give lot of flow of the coolant that is flirt coolant type of thing. So, it should be your bonding material should be resistant to chemical attack. It should not be spoiled by the chemicals.

Common bonds are vitrified you know which is appeared in a special way by wheel hitting etcetera, and then resinoid rubber shellac and silicate bonds, and volumetric composition of a grinding wheel can be expressed as V a is the volume percentage of abrasive grain. Abrasive grains have volume percentage V a. V b is the bond material percentage, and V p is the pores or voids they together constitute 100 percent. So, V a plus V b plus V p is equal to 100 percent and the group.

In a typical vitrified v suppose V a can be 50 percent 50 percents are abrasive. V b is 10 percent and V p is equal to 40 percent. So, most of the material there is a pole; that means, void (Refer Time: 12:21) type thing means rather void type of thing. So, these voids they control this one if V p is more; that means, it is having open type of structure. And if V p is less then it is this one. If we talk not in terms of percentage, we can talk in terms of the fraction also, and in that case this value can be written as 1.

So, we can naturally represent by a triangle. Here that in a triangle, this may be V a point, this may be a and this may be V b point. This may be V p point; that means, if if something is here that means V a is 100 percent or 1. And if it is here V b is 100 percent bond; that means, it is full of bond material 1 and here that it is full of pole 1. We do not of course, always operate in the vertices in a state, we may have some type of situation like this. Suppose some value some point is in the centralized; that means, here that V a is 33 percent, V b is 33 percent V p is also 33 percent.

So, anyway this triangle just helps to better understand the things, and depending on that you can design your system. And so, these 3 constituents means V a V b and V p, V p is not any constituent, but it is basically absence of anything; that means, these are voids only; that means, nothing is there. But by wiring there so, it can also be considered one constituent constituents. So, this is a these 3 constituents can be altered to control the structure and grade.

Grade means, hardness of a grinding wheel. Hardness does not mean in that sense that which you studied in the single point turning etcetera are in milling; where you know you are concerned with the hardness of the tool. Here abrasive is anyway very hard. So, here a feel will be called hard, if it is able to hold the abrasive particle very tightly; that means, even if you apply large amount of force it is not breaking then it is hard.

And if it can be easily dislarged from the bond material then that one is soft. That is the meaning of the hard wheel and soft wheel. So, abrasive particle may be same, but one grinding wheel may be hard; because bond material is holding it very properly. And another may be soft because bond material is not holding it very properly. So, this is what it goes down.

We discuss about now the grade of this one. So, strength of bonding is normally termed as the grade of the field. If the strength is more then naturally that it is said that there is a high grid field. Property is characterised by the mean force required to dislarge a grain from the surface of a field. If we want to quantify the grade, we can quantify it by the amount of the force require to dislarge, that if you require more force to dislarge, a grain from the surface, then naturally that it is called it is grade is high. Now grade of a field is designated by a letter of alphabet; like, A can be soft and Z is very hard. So, we can designate by this one so, 26 division. So, roughly we can do that.

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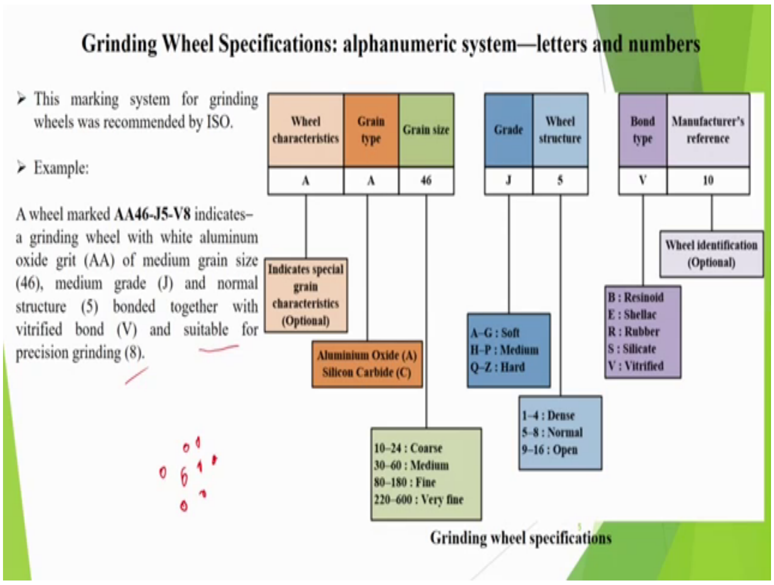

Now let us discuss about this is very important grinding wheel specification. We use alpha numeric system; that means, we use letters and numbers to characterise a grinding wheel. This making marking system for grinding wheels was recommended by ISO. So, ISO has recommended this type of things. So, let us see what really happens? That first suppose coming to the first letter A, field characteristic, it indicates special grain characteristic it is optional. Another is grain type A if I use A, then it is aluminium oxide if. I use C that means silicon carbide. Like that there may be different type of letters for different type of abrasive materials and then about coming about grain size.

So, grain size also be designate by numbers grain size. Suppose grain size is 10 to 24, then that is coarse grain. Why 10 to 24? 10 to 24 grain size; that means, this is a small number 10 to 24. So, grain is bigger as I told a few minutes are real. That it is reverse type of system. If the grain size is small; that means, grain is a bigger diameter. And if grain size is big; that means, grain diameter is small. So, 10 to 24 is coarse 30 to 60 is medium. 80 to 180 is fine 220 to 600 is very fine. So, this type of system is there.

So, suppose I have used 46 so, naturally this particular wheel is of medium grain size, medium grain size. Then we talk about the grade. Grade is A suppose this is j, I have used here J letter. But it can be A to G that means, it is soft. G then if A is there then soft B is soft, but less soft than less soft than a like that A B up to G. Then h to P is medium and then Q to Z is hard.

So, here I have written J, A, B, C, D, E, F, G, H, I, J so; that means, it is of the medium a size, medium grade. That means, strength is medium ok; that means, abrasive particle is not very tightly attached with the bond, but it is also not very loosely attached. Know, it is you will require some medium amount of force to dislarge the grain.

Then wheel structure. Wheel structure means that here you have wheel structure; that means, here I have written 5, but it can be between 1 to 4. 1 to 4 means, if it is a dense structure, then it may have 1 to 4 so; that means, this is dense structure then 1 to 4, wheel structure and then if it is 5 to 8, then it is normal. And 9 to 6 means open; that means, spacing between the abrasive grains is very high, then you will give be giving something like 16 or something or yes or 15 that means, it is gap is like that. So, bond type is V means vitrified and B may be resinoid, E is shellac bond, R means rubber bond, S means silicate bond and v means vitrified. And then there may be some manufacture or reference number say suppose I have given 10.

So, this is some wheel identification it is optional, it may be manufacturer to manufacturer. Like one example is they that suppose I say my wheel is a 46 J 5 V 8 suppose I have said V 8. So, A, A means it is a special type of aluminium oxide. And it is white aluminium oxide of medium grain size 46, 46 means grain size is medium. And medium grade J is medium. And normal structure that means, it is medium structure type of thing ok. It is means abrasive particles are not very close to each other, but they are not very far away also from each other they are at some reasonable distances like this type of thing.

So, here this one and they are bonded together with vitrified bond, and it is this wheel is suitable for precision grinding. So, we just manufacturer has indicated some 8 designation. So, this type of nomenclature system is implied, and this is how that we go about that.

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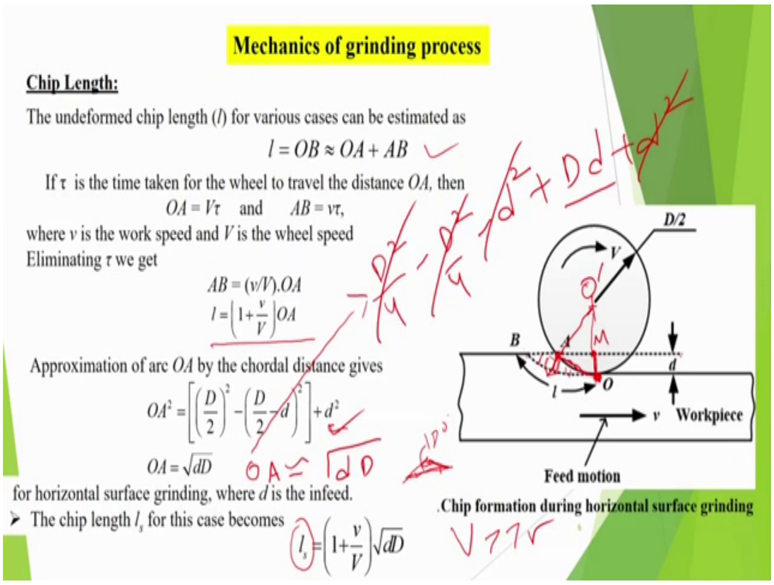

Now let us discuss about the mechanics of grinding process. You have to little bit visualise and put some effort. It uses lot of geometry and some trigonometry; that suppose consider a surface grinding type of operation. In which suppose work piece is moving like this and there is a wheel. Relative motion is only important suppose the table is reciprocating or moving in this direction, wheel may be stationary or alternatively the wheel can move and this can be this one.

So, means table can be stationary, but most of the places we use a surface grinder in which there is a hydraulically operated table that keeps reciprocating that type of phenomena happens. So, this we are calling as feed motion, it is expressed in V; that means, it is mitre per minute. And if wheel diameter is D so, this diameter is d, and wheel radius is D by 2, and it is rotating with velocity V.

And now what happens? That here this one is the d depth of depth is d, d is the depth of grinding wheel that depth of cut type of thing you can call that; where we are giving the feed depth basically, and it is a type of that it is called in feed here, d is basically in feed; that means, I am feeding that. That means, from the surface we are removing d amount of material d, d is getting removed.

Now, what happens? That suppose it is you have given the depth of this one, and this point is O and it is digging like this. Naturally that this point is O, O is the point of contact here; that means, from the surface, it is ok. It is on this one, V is the peripheral speed. And then you have got some a this point is A. Naturally that this A means that here when it is digging, and suppose up to this it has been machined. So, it is contacting like OA so, but what will happen? That by the time this wheel goes this point goes from O to A; that means, this is moving it is rubbing it is going removing the material O to A, if it was not moving at all, that v was 0.

In that case I would have removed upgraded this much amount of material that is OA, but what happen that simultaneously this point has moved also so; that means, this B point of the surface has come here. Or in other words I can say that if I assume that work piece is stationary then my centre has moved little bit. And whatever that A point was here in the mean time it has gone at this point B. So, and in the same time O point has gone to A. So, basically we have not upgraded material OA, but we have upgraded material OB basically, OB this much material we have upgraded so; that means, this much junk has gone. So, if it moves there was already some material. So, this material also has been removed like that.

So, that means, this has been pushed in that way. So, that is why that this is the basically we consider that OB is the length of the chip; that means, this is a chip so, the chip length is basically this. And thickness is naturally perpendicular; that means, it is here something like this here like this. So, thickness is thickness is this, if you drop from a perpendicular that will be one type of thickness. So, you see thickness is varying also here. It is 0 here, it is more like that. But what happens that the length of the chip is basically this OB. So, undeformed chip length l for the various cases can be estimated as l is equal to OB, which is approximately we can say it is OA plus AB. Because if this angle is very small it is a very small triangle OAB is a triangle.

And this triangle is a very small in the sense that of very small area that here OA and OB. So, naturally OA plus OAB will be always more than OB, but as you see if this angle is much more like in this case. It is almost 180 degree, then it is OA plus OB AB is exactly OB, but it may not be 180 degree, these 2 angles are very small, and this angle is very big. So, approximately l is equal to OB that is OA plus AB.

Now, we have to estimate so, if we want to get the length, we have to estimate what is OA and what is OB. So, assume that time tau is the time taken for the feed to travel the distance OA; that means, point o reaches point a in time tau. So, OA is equal to naturally

V tau, v is the surface speed of the wheel. And in mean time this point AB this movement will be there a point has gone actually to be because the table is moving so that AB is equal to small v times tau. So, v is the work speed and capital V is the wheel speed capital V is much more than small v.

Now eliminating tau from both the equation, we get a relation AB is equal to small v by capital V multiplied by OA. So, we can put it there, and if we put in the this expression, then we are getting l is equal to 1 plus small v by capital V OA. So, approximations are of all OA now suppose. So, we have to only find out OA. Now how do we find out OA? Well, finding OA is very easy, because we can use the Pythagoras theorem. So, OA means this much, and OA is equal to so, suppose I say I drop this one this triangle. So, OA is equal to d square; that means, perpendicularly square into this base thing.

So, base thing means that this one suppose OM so; that means, AM that one so; that means, this half the cord length AM ok. So, this so OM that means dD square that is ok. Now AM square we have to write. So, AM is how to find out? By Pythagoras theorem, if I take a centre and drawing like this. So, here it if it is suppose it is O dash centre, O dash A; that means, D by 2 square minus O dash M square, O dash M is what? From here to here d by 2. So, D by 2 minus d, d is the wheel depth. So, D by 2 minus d whole square. So, this becomes D by 2 square minus D by 2 minus d square plus d square. Like that we can do and after that we can simplify this expression.

So, we can say that yes, D by 2 square; so, this becomes D square by 4, and minus D square by 4 minus D square plus Dd. So, we get OA is equal to Dd. So, OA square we get dD because this cancels you know d square is added here, that d square was here. So, this d square got cancelled here d 4 got cancelled here, and you are left with Dd.

So, that is why we get OA is equal to under root Dd. Of course, I must call OA not equal to under root Dd, but OA is approximately under root to dD. Why approximate where is the approximation? We consider that OA like a straight line whereas, there is a some curvature. Of course, the wheel is of big size so, OA will be more always it will look like a straight line only, because even if I make in this figure OA comes like this. So, it is very OA r can OA line is basically same, almost same. So, for horizontal surface grinding this expression is ok and d is the in feed.

Now the chip length L S, for this case becomes if we put that and we say chip length now I am using the L S sub. So, subscript I am using s. So, why I am using? That means, it is surface grinding. So, surface grinding means L S and that is 1 plus v by V, v by V already I wrote under root Db d under root dD. So, that means the length of the chip will be will be increased if the feed depth increases or the diameter of the feed increases. And well, it is also if the feed is more; that means, v is more, naturally the length of the chip will be more.

And if you know that feed is, if that feed is speed is more, then it is having slightly less effect. So, that means, suppose V is much more then v, V is much much more than v then chip length simply becomes l s is equal to under root d so, that is how that it goes.

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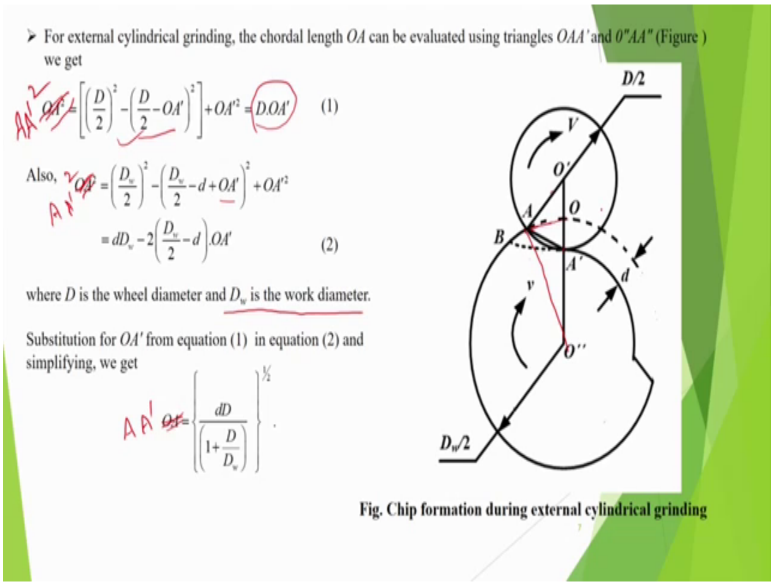

So, for external cylindrical grinding, the chordal length OA can be evaluated using triangles OAA prime, OAA prime and O double prime AA prime, AA prime so; that means, similarly we can extend that theory to cylindrical grindings suppose we have got this as job diameter. So, D w is the diameter of the work piece and this distance is D w by 2, this radius basically of the job. So, work that is job, and this is rotating by a very D w is the work diameter, remember that. And it is rotating which is surface speed of small v; like in a surface grinding, small v same symbol we use. And v speed is usually as capital V, and this is centre here and this is like that.

So, in that case when I am rotating, then I am concerned about finding out that basically that this one is OA means that this distance. So, this will be yeah. So, this will be OA on this one. So, we will we want to get a about OA. So, OA is chordal OA can be evaluated like this. OA is equal to in this case D by 2 square minus D by 2 minus OA prime. So, D by 2 square OA so; that means, D by 2 here and this is D by 2 minus OA prime square so that means whole square. So, this will be basically what will be that?

OA square; that means, OO prime A square, D by 2 square and you did minus minus d by 2 this 1 minus this much. So, you got this horizontal distance. But then if you do that OA, then you also did OA prime square. If you do OA, this is OA yeah this is OA square, OA square is this much only. And if you do OA prime square; that means, this and this square then you get AA prime square. So, basically you get AA prime square. So, this should be AA prime square AA prime square. This I am correcting on line here, though AA prime square. And if you simplify this, you cut that it; it will be basically D time OA prime square.

Also OA square is like this, suppose now from this one, now from this one if we get D w by 2 square in the same way. And then we say D w by 2 square suppose suppose from here to here this one. And minus D w by 2 minus small d small d and plus OA prime. So, plus OA prime we have added and plus again. So, this much if we do, then we get this 1 OA prime minus yeah and then minus d square. So, we get minus d plus OA prime and plus OA prime square OA prime square I have added.

So, again you will be getting from here another expression and that will be AA prime square. And this will be D w by 2 minus 2 w OA prime; where D is the wheel diameter and this one from this one.

So, substituting from this to this we have got ok. So, this is yes. So, this if we substitute both the thing. So, we get and we simplify so, we get that basically AA prime is equal to AA prime is equal to this one. Under root D by 2 under root dD 1 plus D by dD by D w is this one. Now what happens that here this is basically this will be like this one and this will be like in the previous case, this will be chip length for external cylindrical grinding is obtained by putting this expression that 1 plus in the similar way v by v and this is OA and this one is like that.

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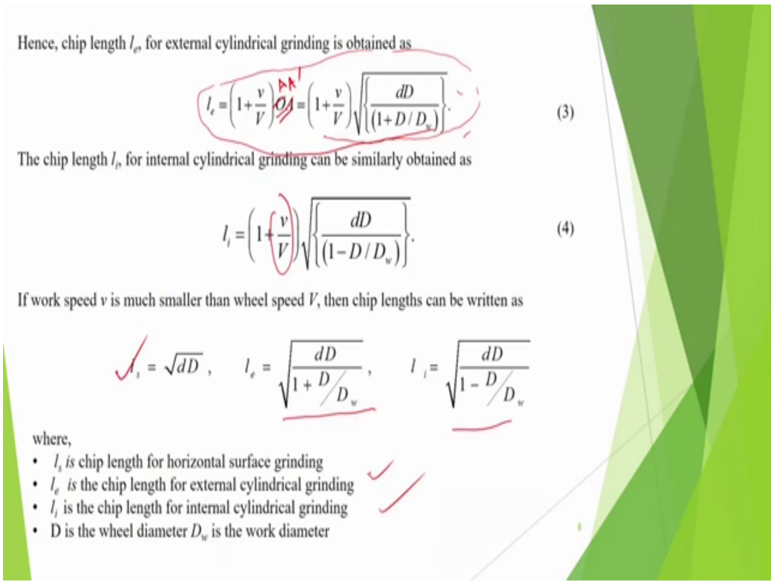

So, we get only this type of expression. Here that you have to see, little bit carefully that in this I think it was OA square and OA square, they are writing OO was the basically the contact point here, that like this OA O and then O was this one OA. So, this was like this OA square. So, this was yes here, this is was the it is making that contact AA square ok. So, that means, actually it was corresponding to something like that like here O goes from A.

So, similarly here that contact point A dash is going to a here. And that is what that this is the thing, I think there was some misprinting the that your textbook also, but this you have to understand very correctly that this is A dash. And then finally, it is going to that here A and length of the chip will be basically A dash A and AB and A dash B. So, it is like that in that fashion. So, that is what so, it should be actually AA dash, and then it will be consistent and then you will be having suppose I put AA dash. And AA dash expression is this one, and 1 plus v by V is this one.

So, hence the chip length for external cylindrical grinding is obtained as 1 plus v by v and under root this one. So, we got this expression, this expression has to be reduce to this one surface grinding if D w becomes infinite, because there is infinite. So, D w is equal to infinite if we put we get back the same expression.

Similarly, if we do this type of exercise, then for internal grinding we can obtain a similar expression. And we can say l i is equal to 1 plus v by V under root dD 1 minus D by D w. So, if work speed v is much smaller, then wheel speed v, then the chip length can be written as l s becomes under root dD ok because this portion will be almost this one. l e becomes this thing dD 1 plus D by w, and l i becomes dD 1 minus D by w. So, l s is the chip length for horizontal surface grinding. And l e is the chip length for external cylindrical grinding. And then l i is the chip length for internal cylindrical grinding. D is the wheel diameter and D w is the work diameter.

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Chip thickness:

- It significantly influences the grinding energy, wheel wear, surface finish, etc.
- Assume that all chips are of the same average size and that the chips have a constant width b.
- The volume of an individual
- chip is

$$(\text{Vol})_{chip} = \frac{1}{2} l_s t b = \frac{l_s t^2 r}{4} \qquad (4)$$

where $r = \frac{b}{t/2}$

and t is the undeformed chip thickness.

- The chip volume can also be calculated as

$$(\text{Vol})_{chip} = \frac{\text{rate of metal removal}}{\text{number of cuts made per unit time}} = \frac{vdB}{VCB} = \frac{vd}{VC}, \qquad (5)$$

where C is the number of active grains per unit area and B is the width of grinding wheel in contact with the workpiece.

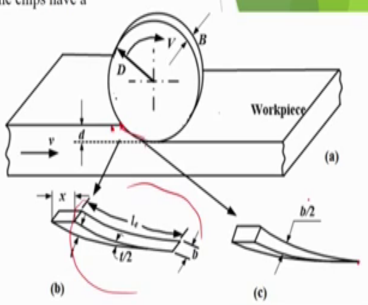

Fig. Chips produced in horizontal surface grinding (a) schematic view of the process (b) idealized chip and (c) actual chip

Now, let us find out some expression for the chip thickness. Chip thickness significantly influences the grinding energy wheel wear and surface finish etcetera. We assume that all chips are of the same average size; that means, width wise it is same D suppose wheel is there [FL] width wise it is same, and chips have constant width b. Now volume of an individual chips suppose we are cutting you see that chip thickness is gradually increasing. You can see that here it is cutting like an arc from here to here. So, somewhere and it is moving also. So, that means, here it is not cutting much material, but when it has moved.

So, this point has gone here. So, here the thickness is much more. So, we are assuming that it is gradually increasing, and let us say the maximum thickness is t ok. So, in that case, this will be t is the undeformed chip thickness, and in that case what will happen? That t by 2 is the average type of thing, and volume of this chip is equal to l s if the l is the chip length. So, we will say l s, half l s in to t by b ok. So, it will be that basically average this one and width is b. And we can say that it can if we define r is equal to b by 2 t by 2.

We have defined like this, then it can be called as l s t square r by 4; where t is the undeformed chip thickness maximum thickness. And chip volume can also be calculated as volume of the chip is equal to rate of metal removal divided by number of cuts made per unit time.

So, metal suppose the wheel width is B, and v is the surface speed of this one, and d is the depth. So, v into d into B that will be the volume of metal removed. And if we make mean time, if suppose there are c number of active grains per unit area, if there are c number of active grains, then number of cuts made in unit time will be V into C into B, because c is in per unit area. So, you know that in per unit time suppose this covers a distance v. So, V b area it covers so, V C B divided by V C. So, that means, that volume of chip then we can obtain ok, because each abrasive grain is removing one chip and then we are getting like this.

So, v d divided by this one, and then we are getting giving this one, C is the number of active grains, and B is the width of the grinding wheel in contact with the work piece. So, chips produced in horizontal surface grinding has been shown here is schematic view of the process is this idealised chip is actually this. So, chip length I am assuming like this, but here chip width I am assuming b there may be many active grains parallel wise.

So, that I am assuming this one and actual chip is actually of this shape so; that means, the is it is width is we are assuming that actual chip suppose here it is width is b and we are assuming that chip width is B and this actually should have been thickness actually. So, this is in fact, t by 2 ok; that means, this is t by 2 will be the thickness, but actually this is ok; that means, idea like actual chip ok. So, I am showing that we are idealising like this b, but we are having actually the chip like this that even the width is also may be changing ok, that may be situation.

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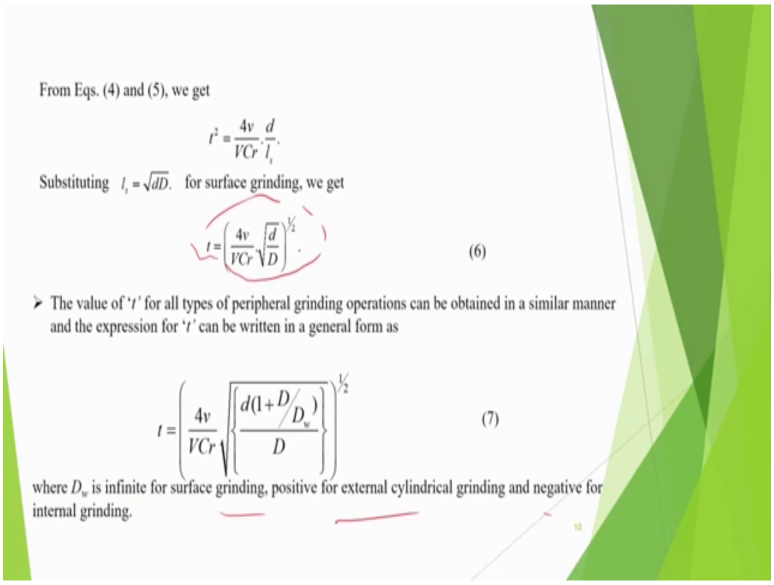

Now what happens from equations 4 and 5 if we volume of chip we have got and this is also we got required these 2. So, we get t square is equal to 4 v divided by V C r and divided by d l s. And if we substitute l s is equal to under root d by d. So, we get basically t is equal to this thing. So, we get that tip chip thickness is actually will increase if small v increases, but if capital V increases it will reduce and if the more number of grains are there in per unit area like c is more, then also it will reduce r is equal to we have assumed a parameter that is the aspect ratio type of thing it is b divided by t by 2.

So, if r is more naturally the chip thickness will be less, and it is also dependent on D and D capital D is the wheel diameter, if the wheel diameter increases the chip thickness will reduce. And is square root type of relation is here. The value of t for all types of peripheral grinding operations can be obtained in a similar manner. And the expression for t can be written in a general form. So, t is equal to we can write 4 v and this is how that means it is for cylindrical grinding. So, you are instead of under root d by d it will come here. And so, D w is infinite for surface grinding, positive for external cylindrical grinding and negative for internal grinding.

So, we have now these cutting point C, that how do we obtain C, that which we said that about this one C is the number of active grains per unit area.

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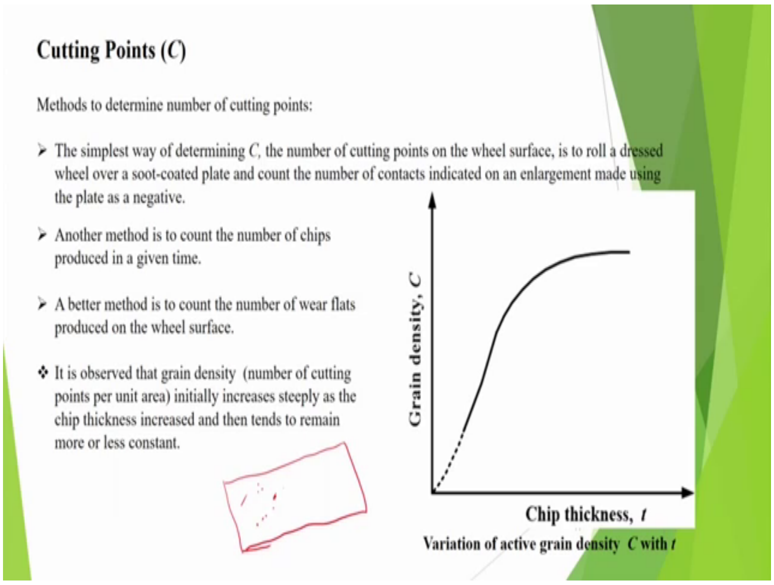

So, methods to determine number of active grains per unit area is like this. Simplest way of determining C the number of cutting points on the wheel surface is to roll a dressed wheel; that means, we have done the dressing operation; that means, we have sharp sharpen that wheel by a diamond dresser. And then we take a shoot coated plate know, just we put a shoot that what we call in Hindi kajol. And in that we just put here, and then we (Refer Time: 47:29) work and we count the number of contacts indicated on an enlargement need using the plate as negative.

So, we can see that and we can after that we see that high parts will take the shoot away. So, that means, you will get the idea the from that place that shoot will move away. So, you can number of so, you can actually know that type of thing indicated. So, this is what you can get that.

Another method is to count the number of chips produced in a given time that if you can do. A better method is to count the number of wear flats produced on the wheel surface, we can see how many wear flats are there. That means, it will be visible on the way grinding wheel surface, that those portions will be flattened many places. It is observed that the grain density means number of cutting points per unit area, initially increases steeply as the chip thickness is increased. At chip thickness is increased abrasives are dislarged and more active edges come, and then it tends to remain more or less constant. So, that type of thing is there.

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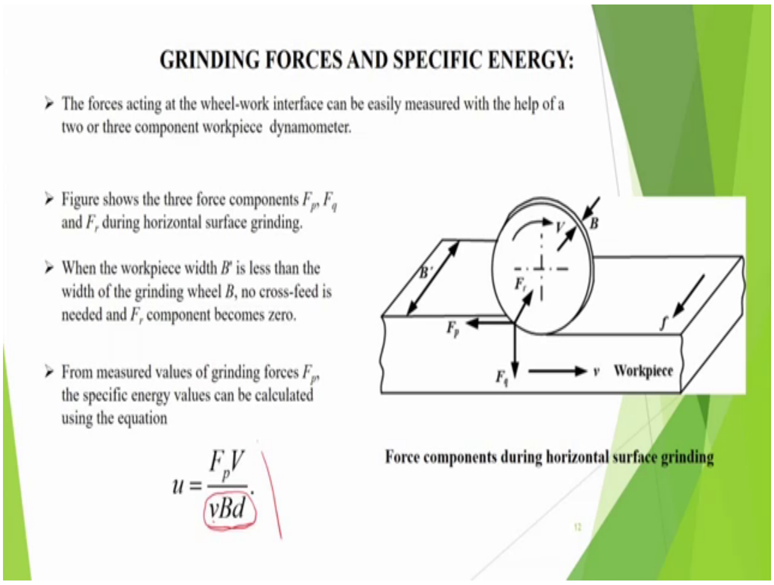

Now, we discuss about grinding forces and specific energy. So, forces acting at the wheel work interface can be easily measured with the help of a 2 or 3 component work piece diameter. Now figure is showing 3 components F p, F q and F r using horizontal surface grinding. When the work piece width B prime is less than the width of the grinding wheel B; which is not the case here, B prime B prime is much more than B. But in other case there will be not cross feed no cross feed will be need and F r component will become 0, in this F r component will also be there.

And from measured value of grinding force F p, we can find out energy F p into V, V is the surface velocity of the wheel that gives the energy, F p into v and divided by v B d. V B d is the volume removed per unit time. So, if you divide u by this one that power divided by this you get specific energy. Specific energy means energy needed to remove the unit volume of material. So, this is the expression you are getting.

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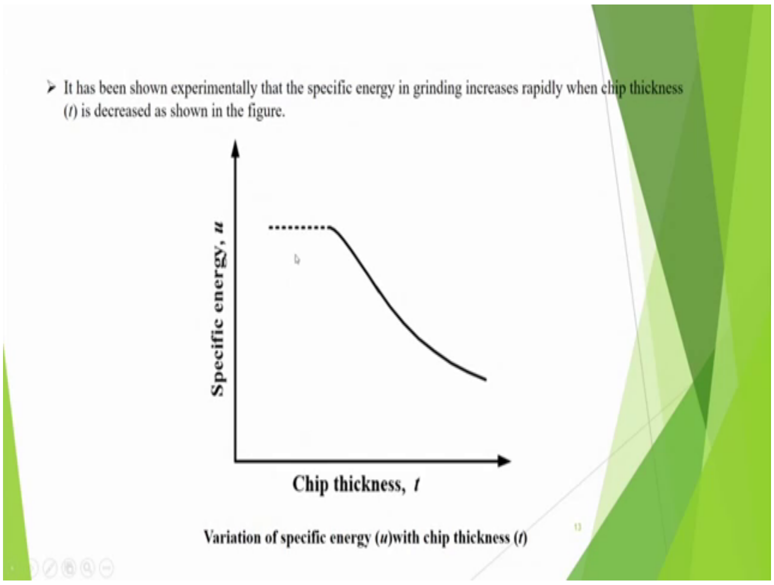

Now it has been shown experimentally that specific energy in grinding increases rapidly when chip thickness t is decreased. Like here, it is increasing very rapidly for high chip thickness it is less, but then it increases that we called so called size effect.

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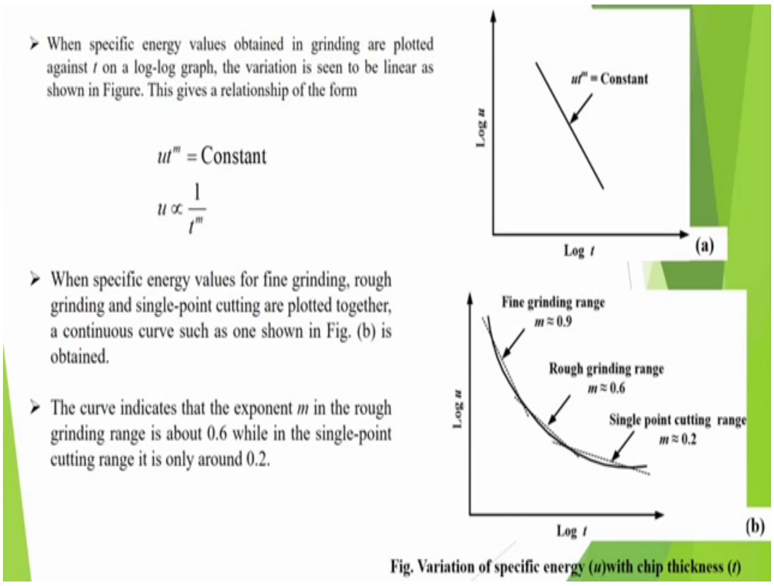

When a specific energy values obtained in grinding are plotted against t on log log graph, the variation is seen to be linear. This gives a relation in the form u t m is equal to constant or u is proportional to 1 by t m. So, when a specific energy values for fine grinding rough grinding and single point cutting are plotted together, a continuous curve as shown in this one is obtained. And this curve indicates the exponent m in the rough grinding is about 0.6, while in the single point cutting it is only around 0.2. So, this shows that size effect in grinding is much more.

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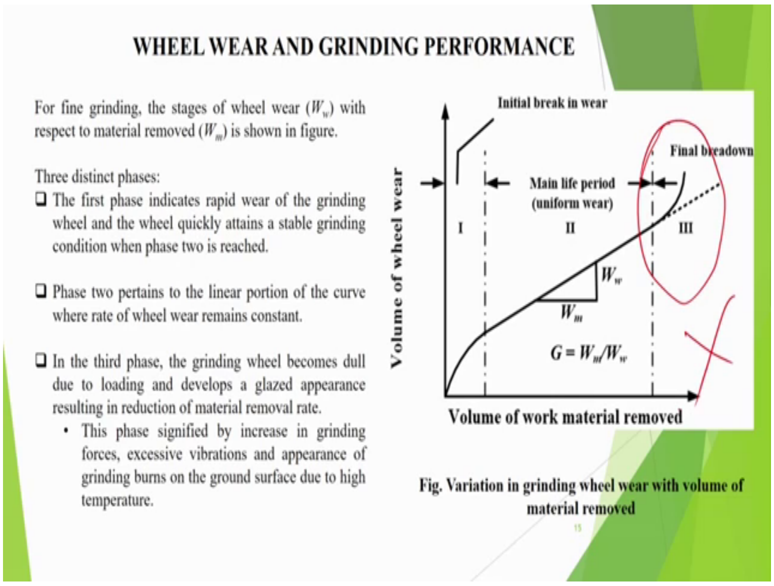

Now, wheel wear and grinding performance for fine grinding the stages of wheel wear W with respect to material removed W m is shown in figure. So, volume of wheel wear and volume of work material removed is plotted here. G is the grinding ratio that is volume of material removed divided by volume of the wheel remove thing removed, wheel material removed.

So, this is what a in the beginning G increases rapidly then; that means, volume of wheel wear means increases rapidly because that is breaking period because lot of wheel wears. And after that there is a constant uniform wear region, and then after that final breakdown occurs and this is what you are going here. So, this is a just like a typical in cutting tool also the same type of curve you get.

So, first phase indicates rapid wear of the grinding wheel, and the wheel quickly attains a stable grinding condition when phase 2 is reached phase 2 pertains to the linear portion of the curve; where rate of wheel wear remains constant. In the third phase the grinding wheel becomes dull due to loading and develops a glazed appearance resulting in the production of reduction of material removal rate.

And that means, wheel wear will be more. So, this phase signified by increase in grinding forces excessive vibrations, and appearance of grinding burns on the ground surface due to high temperature. So, this phase has to be avoided. Do not grind in this region if this phase is better ok.

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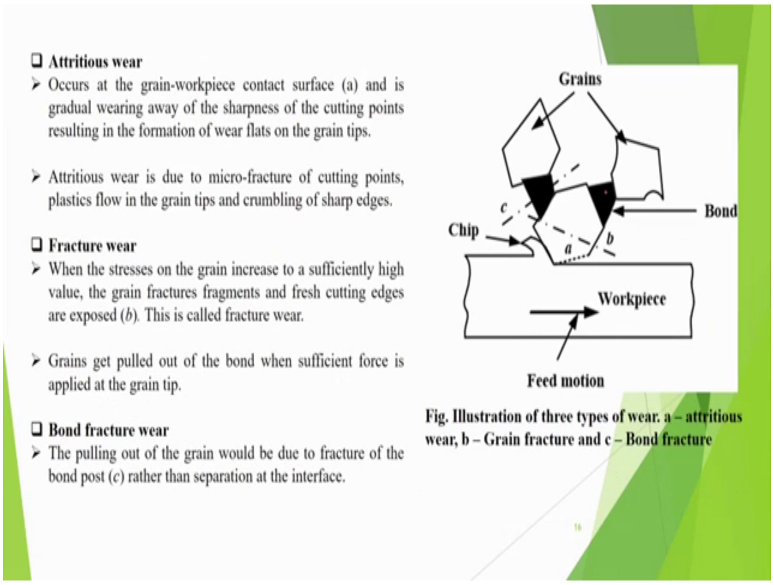

Now, what are the wears of the grinding wheel? That means, attritious wear we told that it is basically due to contact and rubbing. It occurs at the grain work piece contact surface, and is gradual wearing away of the sharpness of the cutting points, resulting in the formation of wear flats on the grain tips. Now attritious wear is due to micro fracture of cutting points. Plastics flow in grain tips, not plastics flow it is plastic flow and crumbling of sharp edges, sharp edges get crumbled.

Now we go to fracture wear, when the stresses on the grain increase to a sufficiently high value, the grain fracture fragments and fresh cutting edges are exposed like this. This is called fracture wear. See this is fracturing here; know grains get pulled out of the bond, when sufficient force is applied at the grain tip. And then there is a bond fracture wear; that means, this is the bond here, dark portion and these are the grains which are attached. So, pulling out of the grain would be due to fracture of the bond post rather than separation of the phase. So, that means, they get removed together this is this one.

So, we show 3 types of wear, attritious wear grain fracture attritious wear is shown here in the a portion; that means, it is just gradually wearing and producing some wear flat.

Grain fracture means grey grain gets broken in between, and bond fracture means bond gets broken.

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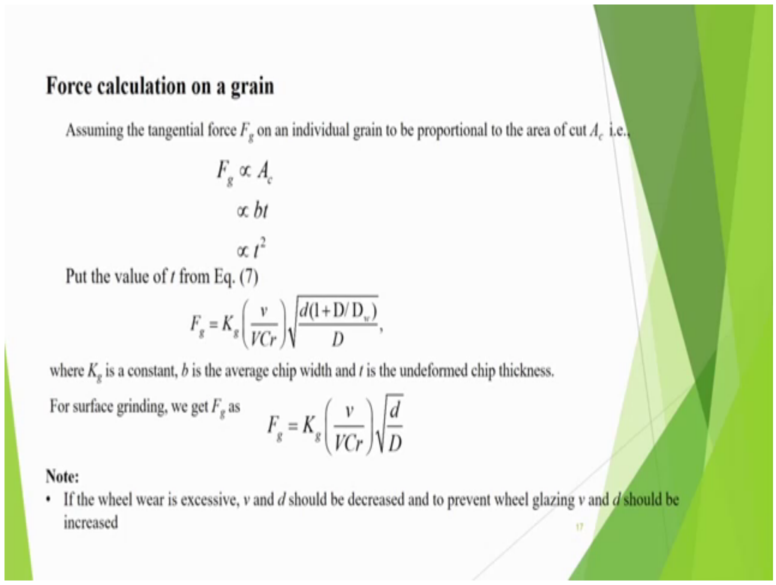

Now, about coming about force calculation on a typical grain, assuming that the tangential force F g on an individual grain to be proportional to the area of cut A c that is suppose F g is proportional to A c. And area of cut can be taken proportional to width of this one and thickness t b t. And since b is roughly proportional to t; that means, width is more than naturally we can have assume that may be thickness is also more, I thickness is more than the width is more.

So, that means, this is it is proportional to t square, and if the put the value from equation 7 what was equation 7? That means, here it is it is that type of here equation 7; that means, expression for t is there. So, use the expression for t, then you get basically this type of thing. F g is equal to K g v divided by this thing. And K g is a constant b is the average chip width, and t is the undeformed, chip thickness r is a type of expect ratio. So, for surface grinding we get F g as F g is equal to K g v divided by this much, and we get this type of.

So, we see that force will be much more if the depth is more, but if the wheel diameter is more it will be reduced, and it is proportional to small v, but inversely proportional to capital V. It more number of grains are there then the force will be reduced like that. So, if the wheel wear is excessive suppose wheel is wearing the excessive. So, what you should do in the soft roll? You should ask the operator to reduce the table feed; that means, v it should table should reciprocate slowly.

And D should be decreased, but if suppose wheel is getting glazed; that means, it is it becomes glaze type of thing means it loses it is sharpness. It will look shiny type of surface and you will see that yes, this is that there is a glazing it just rubs. So, that means, v and d should be increased. So, that more force should produced and the grain should be disrupt.

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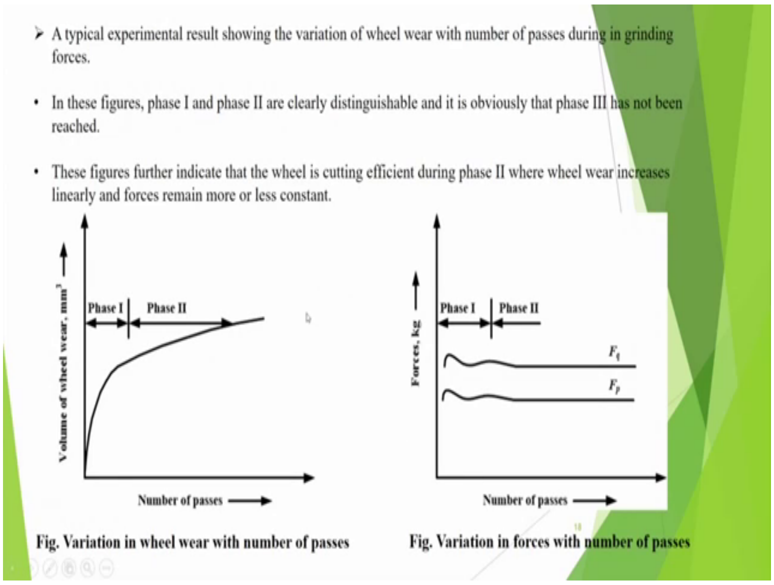

So, a typical experiments results showing the variation of wheel wear with number of passes during grinding process is shown here, volume of this one in these figures phase one and phase 2 are clearly shown; obviously, the phase 3 has not been reached. I told that we should not do the grinding operation in phase 3. These figures further indicate that the wheel is cutting efficiently during phase 2; where wheel wear increases linearly and forces remains more or less constant. So, force is shown in the beginning the force increases. Then more or less it remains constant, this is cutting force F b and thrust force is F q and this is shown with this one.

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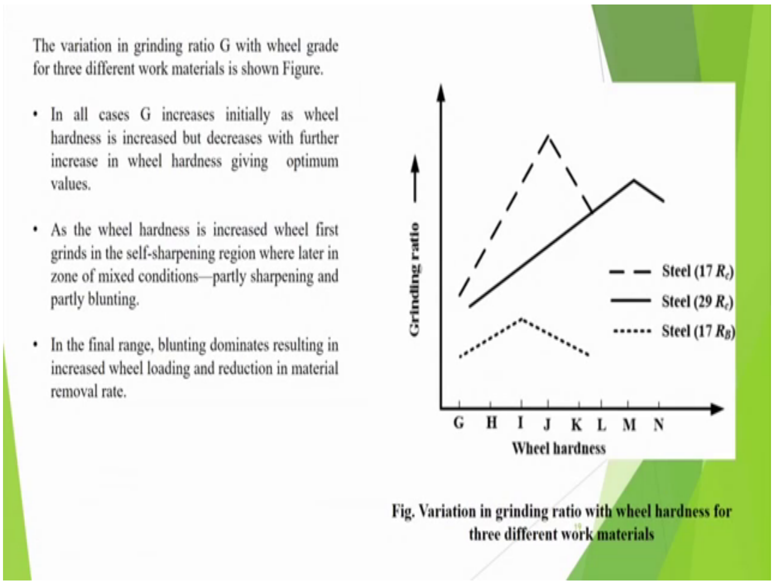

Now, variation in grinding ratio G with wheel grade for 3 different work material is shown here. In all cases G increases initially as wheel hardness is increased; that means, grinding ratio will be high that is good, but decreases with further increase in wheel hardness. Because then it will cause glazing type of thing so, there is optimum value. As the wheel hardness is increased, wheel first grinds in the self-sharpening region where later in zone of mixed conditions partly sharpening and partly blunting. We need sharpening operation not blunting operation.

In the final range blunting dominates resulting in increased wheel loading and reduction in material removal rate. So, this is what it has been shown, and you see that it is 17 R b; that means, this is 29 R c, this was 29 R c and this is what this one. So, it is depending on that material roll characteristic will also differ and this is wheel hardness increases from G to n.

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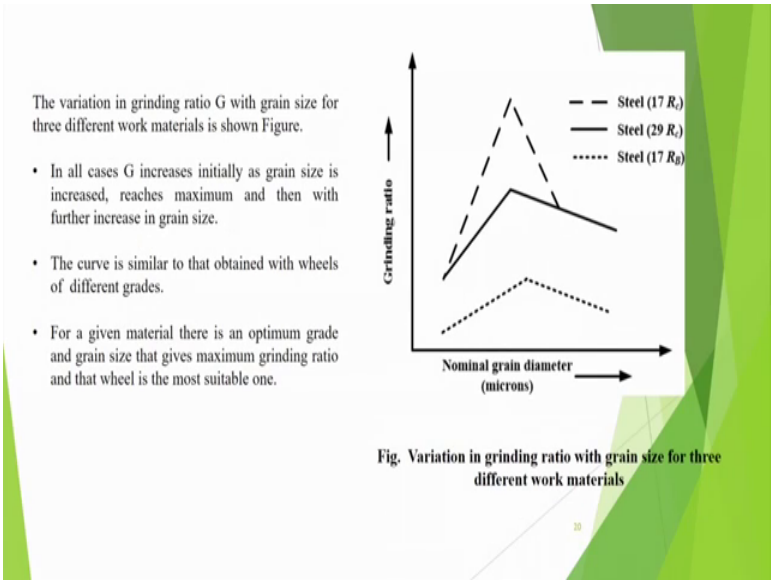

So, it is like this here. The variation in grinding ratio G with grain size also is shown increases initially with grain size, but reaches maximum and then with further increase in grain size, it reduces, it is similar to previous curve for a given material there is an optimum grade. And there is optimum grain size also. So, this has been shown here.

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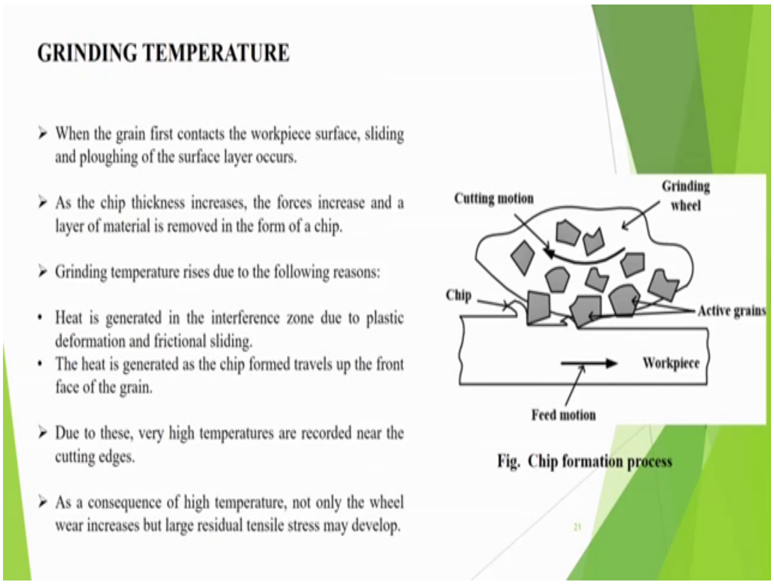

Now, grinding temperature, when the grain first contacts the work piece surface sliding and ploughing of the surface layer occurs. And then as the chip thickness increases the force increase and a layer of material is removed in the form of a chip, grinding temperature rises due to following region; heat it generated in the interference zone due to plastic deformation and frictional sliding, then heat is generated as the chip harmed travels up the front face of the grain. And due to these very high temperatures are recorded near the cutting edges. You can see the small chips will fly like a fire sparks. As a consequence of high temperature not only the wheel wear increases, but large residual tensile stresses may develop. So, this is large tensile stresses are not good.

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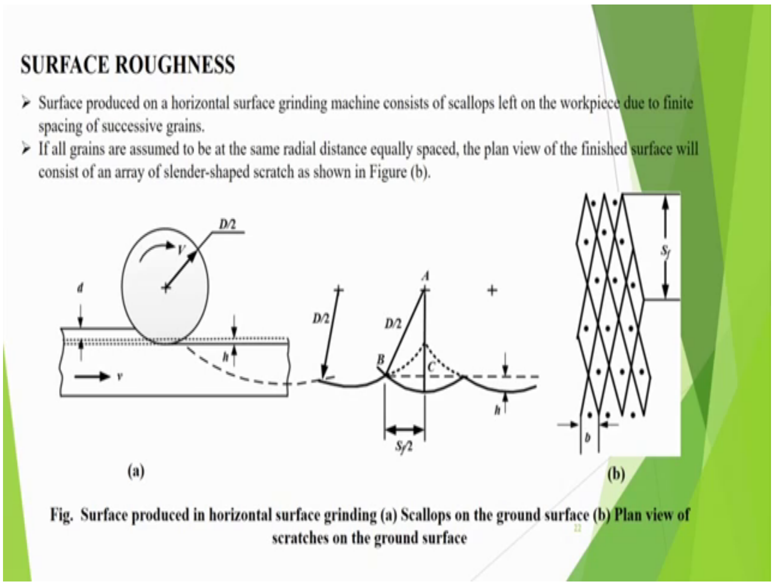

Now we discuss about surface roughness. Surface produced on horizontal surface grinding machine consists of scallops left on the work piece due to finite spacing of successive grains. If all grains are assumed to be at the same radial distance equally spaced, the plan view of finished surface will consist of an array of slender shaped scratch as shown in B. So, you will get this one, this type of situation you will get. And we are getting this type of shape, and this is S f by 2 that feed here. These are scallops on the ground surface and plan view of scratches are shown here.

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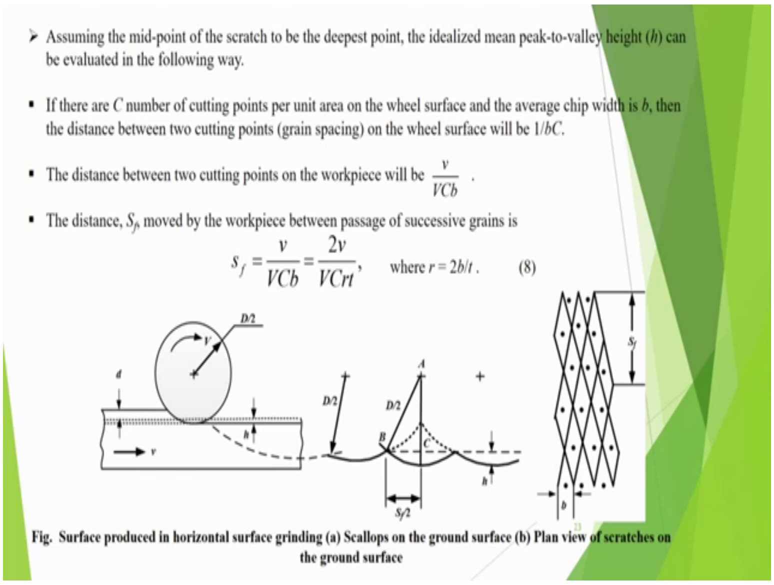

So, here assuming the midpoint of this scratch to be the deepest point the idealised mean peak to valley height h can be evaluated. If there are c number of cutting points per unit area on the wheel surface and average chip width is b, then the distance between 2 cutting points on the wheel surface will be 1 by b C. And distance between 2 cutting points on the work piece will be small v divided by V C b. Then distance S f moved by the work piece between passages of successive grains is S f is equal to v divided by V C b and this is 2 v divided by V C r t; that means, we have got S f this one.

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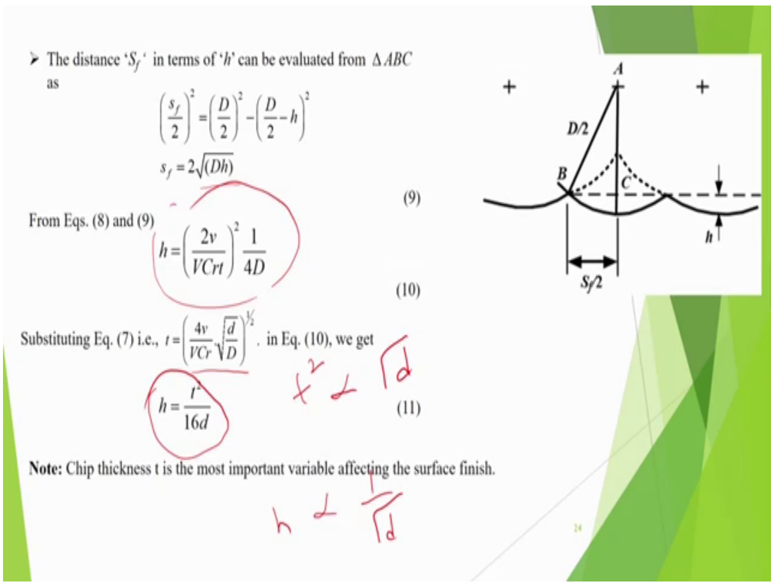

And then distance s f in terms of h can be evaluated from triangle ABC like here. And this is S f by 2 D by 2 square D by; So, s f is equal to under root 2 D h. So, equate both the portions h is this so, you get h is equal to this much. And substituting the expression for t we get h is equal to t square by 16 d. So, that means, basically this that peak to valley height h. That is proportional to t square, but it is 16 by d that means inversely.

So, that means, if you take more depth of cutting factor, then your surface finish will be good surprisingly this comes like this. Why this will be good? In that sense, because more cutting force and this will activate and this will large of course, t itself is also dependent on under root d this one. So, t is in fact, basically t square is proportional to under root d.

So, if I put that thing also here, then it will show something like this h is proportional to 1 divided by under root d. So, that means, anyway that if you take more depth of cut, it will be better it will produce more this one force it will produce more force and it will help in the dislarging. And it will activate the self-sharpening action. That is what that know the simple mechanics analysis (Refer Time: 63:55), and another thing is that this thing you also remember that hard wheel is implied for grinding of the soft material.

And soft wheel is implied for the grinding of the hard material, why if the material is hard ah? It will cause frightening of the abrasive particles soon. So, we want those let them dislarge fast so, better make a soft wheel so that it will dislarge and new edges will come. Whereas, if the material is soft then lot of chips will be generated, and we can afford to get hard wheel so that unnecessary the wheel does not dislarge and they can do.

Similarly, about the structure also if it is a soft and ductile material, we can have a bit open structure. Otherwise we can have dense structure, like that these type of concepts are there. So, we have discussed about the grinding process. And we will continue our discussion in the next class.