Sustainable Materials and Green Buildings
Professor B. Bhattacharjee
Department of Civil Engineering
Indian Institute of Technology, Delhi
Lecture No. 19
Classification of Recycled Aggregate: Crushing and Grinding of Aggregates

So we continue to look to recycle aggregate.

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So we will continue with this I think whenever we stop may be, so I think what we have do is looking at the last time is a allowable limits for certain things. For example this is Japanese tenders, brick 2 to maximum 2 to 5 percent. I mean, you know brick in the demolished or particularly demolished waste, demolition waste. Glass 0.1, plaster etcetera, inorganic, plastic, wood and not more than 6 percent total all such material. Not more than 2 percent all such materials.

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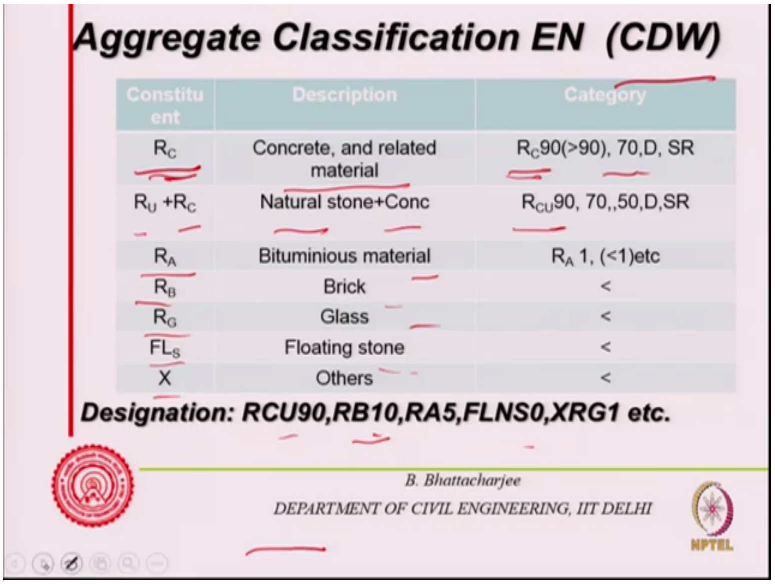

European code construction and demolition waste, they classify it in certain nomenclature is here. For example they call it RC. That is coming from construction material concrete and related, basically concrete and related material. RU and RC natural stone plus concrete. Then this is RA stands for bituminous material, so if the source is bituminous material I mean there is bituminous material in it, RB is brick, RG is glass, FLs floating stone, X others. So this is a kind of classification or nomenclature the European code uses.

So for this you know they have RC 90, now this means that this material is more than 90 percent concrete and such materials will be more than 90 percent. Rc 70 means that this will be more than 70 percent. RC 90 D, D would stand for demolition. So this kind of classification is there. Similarly, for bituminous material RA less than 1 percent of bituminous material and so on. So have a classification based on this.

So for example RCU 90, RCU 90 means, RCU 90 would means this basically natural stone and concrete they are more than 90 percent. RB 10 so the brick should be less than 10 percent, because you want to use them as a aggregate so you do not want to much of bricks so where it is brick, glass, etcetera this is less than and where it is concrete and natural stone it is more, more than. So you know this floating stone 0, S, 0 etcetera, etcetera. So this is how they classify them. The European code they classify it in this manner.

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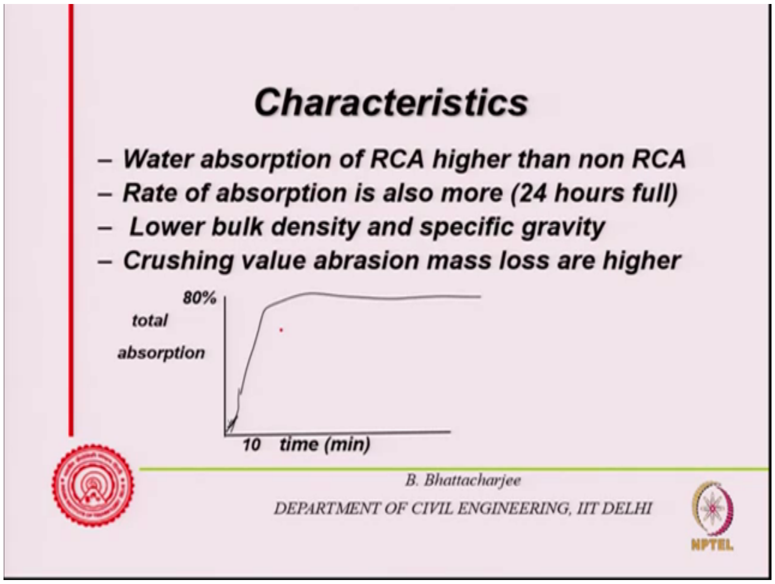

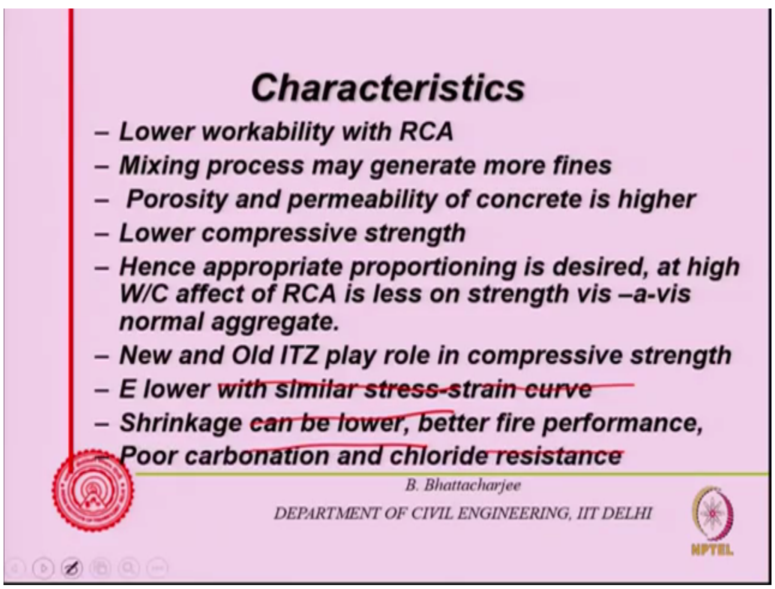

Characteristics whatever you do you cannot get as good as natural aggregate. For example water absorption of recycled aggregate RCA is always higher than you know non-recycled aggregate that is your natural aggregate. You just cannot help it because there will be different interfaces, porosities of those materials they are different. So water absorption is usually higher. Rate of absorption is also more, suction rate so that means your also total porosity is more and there are significant amount of finer pores also which controls the rate of absorption.

Then lower bulk density and specific gravity, bulk density obviously specific gravity is less, bulk density will be less because there shapes are also classed and they would not packed very well as good as natural stones. Crushing value abrasion mass loss are higher. Crushing value is aggregate crushing value used for quality of aggregate. So what we do is, we take a specific size let us say 12.5 mm to 10 mm and then put them under load in a particular rate.

For example 40 ton in 4 minutesand when you do that, the good lot them would get crushed, so now xement through 2.6 is 2.36 millimeter sieve and percentage is called aggregate crushing value, like similarly aggregate in packed value also there . So 40 ton in 4 minutes just to recollect, you know in 4 minutes for your purpose this is how the load is applied and this value if it is higher it means that it si a poor poor on aggregate. So these values are higher similarly aggregate mass loss if it is more these are poorer.

So recycled aggregate do not have the same kind of quality as our normal natural aggregate. So you have to use them judiciously. Now total absorption if you look at it 10 minutes you know time versus so 80 percent comes in 10 minutes itself and after that of course it remains I mean does not most of the it absorbed very quickly. Obviously it is the shape is crushed and there lot of absorption particularly is crushed so lower workability you will not packed very well, you will need more cement paste in the system to come to the same level of flow so lower workability.

Mixing process may generate more fines because already you know it is crushed do there must be lot of what we call, fracture planes already existing the moment you do further mixing little bit of abrasion that would result in may result in more fines. So courses size one may become finer so that is also another issue. Porosity, permeability of concrete is higher. Lower compressive strength I mean obviously. Hence, appropriate proportion that what is required. You know you can always design the system supposing know, know it is bad it is not a problem.

Supposing know you know it does not perform as good as the normal aggregate, natural aggregate you need not actually be worried about it because you can design the system. Now you cannot design very high strength matrices or high strength cement based composite with this, because aggregate themselves will fail. Normal strength concrete it is the aggregate, mortar interface or you know paste interface which are the weakest link.

Aggregate themselves are stronger, so that you might use a slightly lower strength or lower strength potential aggregate, in normal strength concrete, but if you want to of high strength concrete where interface ITZ is very strong, ITZ is made strong there the failure might start from the aggregate itself, So you cannot may use this aggregate. So selectively you can use this aggregate design the system in such a manner something of the kind of 30 MPa concrete, 40 MPa concrete can be easily made out of this (7:57).

So your bulk of concrete is actually that, very high strength concrete will have smaller sections and we use it selectively, because of that cost another issues. So therefore one can make use of them. Main problem comes with this old ITZ and the new ITZ that is what I showed you earlier. So weakest, they are the weakest link actually. E is E is lower with stress, strain curve similar to the normal concrete.

E is lower with stress and curve similar to source. Shrinkage can be lower but fire performance you know shrinkage can be lower but fire performance basically would depend because it may not, I mean it may provide some better insulation depending upon the situation but they may strength or performance in terms of stability structure you know strength stability, mechanical stability that might be lowered. So these are the issues actually with this poor durability problem, carbonation resistance is lower and chloride resistance is also lower so that is what has been seen.

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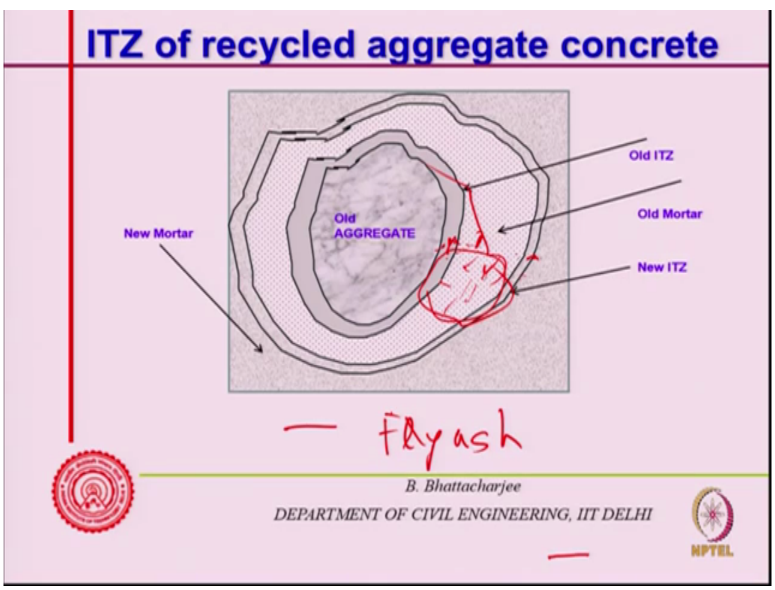

What I am trying to say is this is I think, I think this diagram most probably I have you know this diagram just what I said there is a original aggregate, old aggregate and that says old ITZ you have one would have try to remove them as much as possible but that seems cost heating etcetera, etcetera. But even if you remove fully you may not be able to remove so the this is the old ITZ. Now new mortar which is come in or new ITZ will come in so this is your new mortar entering to it old mortar, old mortar sticking to it and new ITZ will come here and you will have new mortar on its surrounding. New mortar will be there in the surrounding.

So therefore now anyway this was the weakest link earlier, so now the aggregate itself becomes poorer because of the, the shrink. And this is another weak link. So as long as this, this weak link and this weak link they have similar strength I mean similar performance wise it is fine. Which means that you cannot use it for a very high strength system, high strength system. So normal concrete you can where use them and this also results in all other properties as we have seen absorption and everything, because this will be now absorbing, the mortar will be now absorbing, aggregate are generally you know they are pieces of rock do essentially they came from the parent rock, so therefore they absorption is very less for them, but this will have higher absorption.

And so is this so that is why your absorption is higher but you can use them judiciously and bulk of your natural aggregate can be replaced if you design them, design the system properly,. Now there several things people have tried to do. For example soaked them in fly ash, deep them in fly ash. So I will come to that but deep them this is your rubber tires and all this is use but before that let us many people have tried to do what? Put this aggregate, this aggregate, this aggregate in fly ash you know put them in fly ash, put them in fly ash emerge them in fly ash, submerge them completely fly ash, so fly ash will penetrate into this one and the calcium hydroxide of the new cement you know which your new one that, that will try to react, so pozzolanic reaction might improve its somewhat.

This are the attempts that have been made besides heat treatment and so on which I discussed earlier, so this are also being tried to improve this, this business, this is what was poor because this mortar adhering and this is old ITZ they are the poorer one, see if it can improve. So fine material which can go into this suppose you put in there fly ash slurry so since this very coarser there, this pores will be filled in with fly ash and the calcium hydroxide liberated from the cement that you have added in the new concrete they might react and improve. So some improvements you do see but this kind of things allow researchers, still you can.

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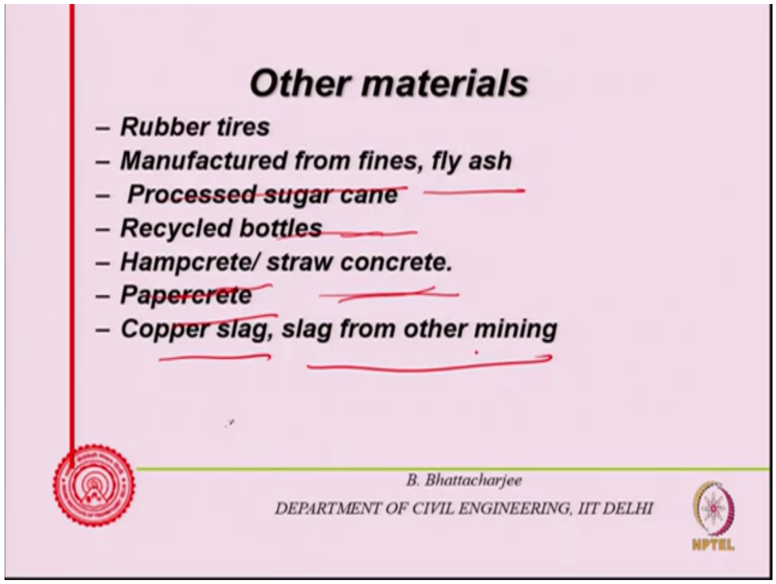

Other materials which are tried, are people have tried like rubber tires you know but I do not think they can come to them for specific purposes. For example, insulation damp you increase the damping properties, you might put rubber in a concrete you know damping properties. So the structurally, structural properties may not be very very good then, then these are fly ash for example fly ash you can center them make aggregate out of them but then you are using energy manufactured form some fines like fly ash as I said then processed sugar cane, bagasse processed and all that and recycled bottles but in alkaline system glasses are problem.

People have tried also something you know hampcrete, straw crete this in Europe you will see lot of work on this. Singapore they did quite a bit of work on this kind materials straw concrete so using straw directly. Papercrete using paper but they would have specialized use not in structural concrete, insulating concrete for example you want to make it do something like that and these are also used instead of you know you can manufacture aggregate out of this by different kind of, for example fly ash you might do a geopolymer reaction to produce fines and then use it as replacement of fine aggregate. So combinations are all possible to reduce down the natural aggregate usage, so that is what related to our recycled aggregate, that is what related to recycled aggregate.

So essentially what we see that we can make use of them significant portion of it but you need an engineered construction and selectively you will have to use you just cannot use it as you wish, So that is, that is all about recycled aggregate. So we look into then certain other properties grinding, we look into grinding because lot of energy is spent in grinding you know lot of energy is spent on grinding, crushing and of course the thermal properties are important because of operational energy. So if we look at grinding, cement grinding, course aggregate also you actually crush them so therefore these are important and the energy uses in this are important.

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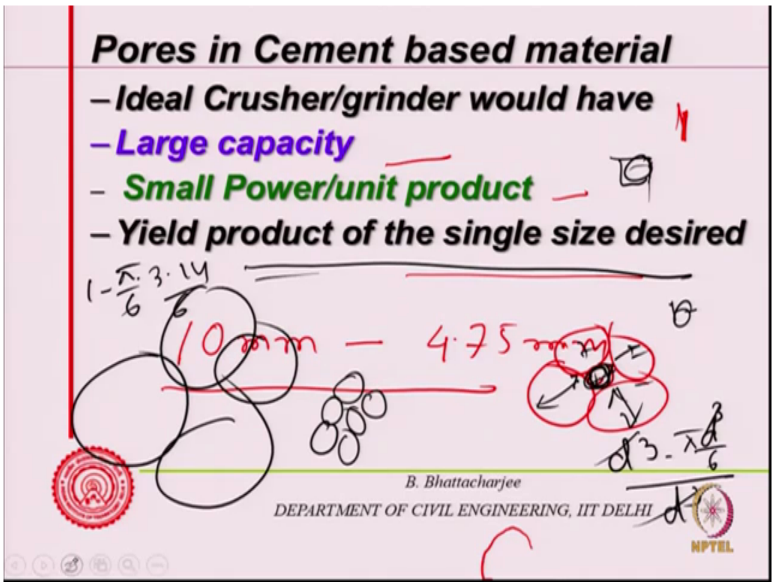

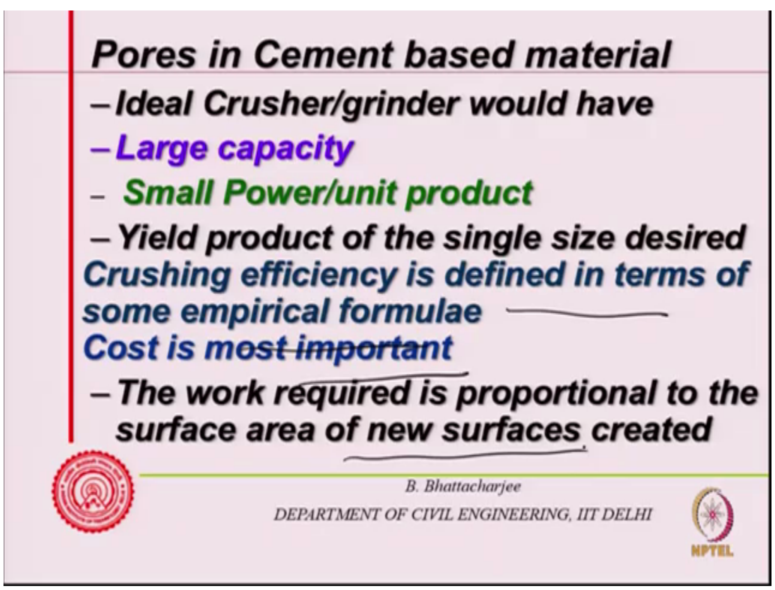

So let us look at some of the those theories related to this. Now, generally you should have high capacity crusher or grinder. Large capacity, small power requirement, power unit of the product that is formed and it should be producing same sized of aggregate all the time you know through your grinding or crushing because size control is important. If you look at sizes for example let us say, I have an aggregate one size aggregate 10 mm down to 10 mm to 4.75 mm, now this will have the grading within itself and which we do not know how it is.

If it is, if it is appropriate for the best packing that is a different thing because as you know the sizes should be such that if I have one large aggregate and you know this is the largest aggregate. Of course which is roughly you have seen that it might be you can calculate out simple cubic packing let us say, let us assume simple cubic packing so this should be your size of the next one. I have this is the size of the larger one, smaller one would be the size which will fit inside such larger particle and next one should be fitting into this.

So the size ratios are important, size ratios are important and their proportion is important because if we have too much proportion of this, this will anyway push the you know first of all I increase the proportion this will push the larger aggregates. What we call particle interference they will push the larger aggregates and if I have too much of it, there will be balls left in the single sized particle themselves. If I have single sized particle the porosity depending upon the nature of the packing, porosity is constant irrespective of the size. So there are internal grading within the material also which is important so we would like to have single sized product so that you have some control on to it you know.

As I said you make it this size ball or this sizes ball the porosity is same, porosity is volume of pores divided by total volume. So for simple cubic packing as we understand for simple cubic packing it would be 1 minus or rather v minus or let me put it like this straight away say d cube minus pi d cube by 6 divided by d cube because d cube is a total volume so porosity is this much so this d cube will cancel out from everywhere, so you are left with simply 1 minus pi by 6 which will come out to be something like 48 percent or some such thing because this is 3.14 so 3.14 divided by 6 is point how much?

52 it would be 0.52 something 0.523. So 1 minus 523 is 0.48, so irrespective of the size because their ratio will be same so we would like to have single sized particle, controlled as much as possible control as much as possible. Crushing efficiency is defined in terms of some empirical formulae. Crushing efficiency is defined in terms of some empirical formulae obviously cost is very important and work required is proportional to the surface area of new surfaces created. We

might have looked into it when we were discussing about strength but just we will recollect if there is something with my slides otherwise I will write it down.

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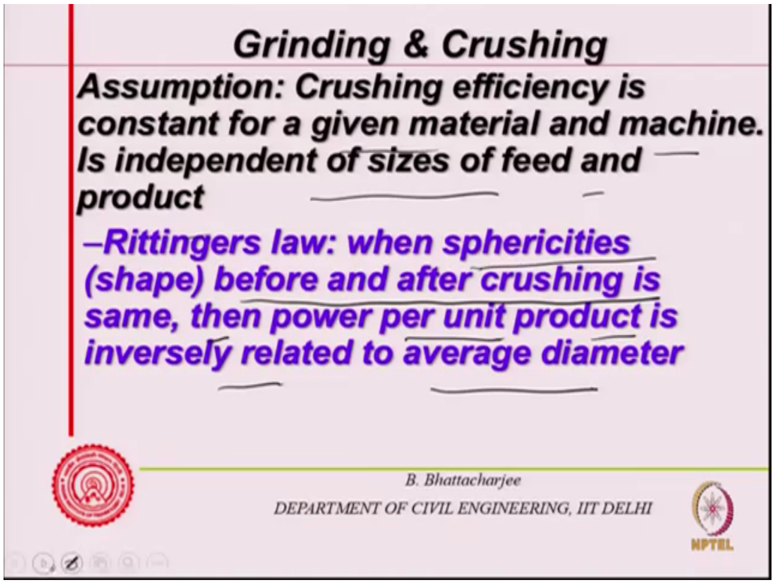

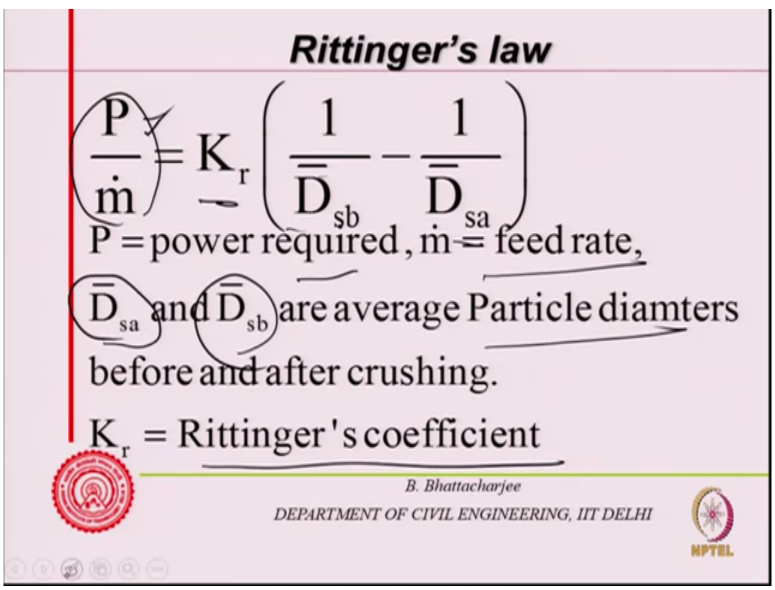

Let us see, let me see I will come back to this in a moment, let me see if this is there, no it is not there, so let me write it straight away. Is it basically if you have a size like this making into smaller sizes, let us say diameter becomes half and this is D by 2. So surface area increases first one had an Pi D square you know it is 4 pi r square so this divided by which is D by 2 square. So pi D square is a surface area and what will be the surface area of this one? 2 into pi D by 2 square. So surface area part of it volume if I calculate out, then I will get how much Pi D cube by

6 so this is equals to in this case 6 by D, this if I calculate out I will get 6 by, 6 into you know 6 into 2 divided by D by 2 actually.

6 into 2 divided by d by 2 because diameter of each one is now D by 2 so 6 divided by D, and twice of this so which becomes actually four times so from 6 by D it goes to 4 times 6 by D just reduce it by half. Now you are creating new surfaces, you are creating new surfaces so energy associated with it is a surface energy because you are creating new interfaces and this comes from the grinding energy that you are providing for grinding, energy that you are providing for grinding.

So therefore basically you know you have seen in case of strength also when you are looking at strength that fracture means creating new surface and surface area multipled by the surface energy is what is supplied by strain energy, in case of strength when you are stressing a material you are supplying strain energy which is half stress into strain per unit volume. So if you know the amount of surface area you are creating by fracture per unit volume, you can equate them and find out whatever relationship is there but I am not interested at the moment and at the moment what we have understood is the moment I reduce down the size I need, I create new surfaces and this is infact not linearly related.

You know it is just reduce the size by half surface area increases by 4 times. If you reduce by 3 you will find that possibly it will increase you know it is not linear possibly if it is 3 then this will be D by 3, and there will be 3 such spheres so it will become 9. So D, you know it is if we reduce the surface by, reduce a diameter by 2 half surface area increases 4 times, if we reduce by 3 surface area increases 9 times and so on so forth. So surface area increases as I, surface area increases as I crush them or grind them so the I have to supply that energy.

However, modelling that is not easy rather you know there are lot of, lot of other things happening losses here and there because energy there losses of energy, right and also there will be losses first of all they have dissipation in the surrounding friction loss etcetera, etcetera. so entropy and all that change so therefore crushing efficiency is constant for a given material and machine of course is independent of size of feed and product crushing efficiency. But energy required is function of the size.

So there is something called (Retting) Rittingers law, when spherical, sphericities shape before and after crushing is same, then power per unit product is inversely related to the average diameter. So his law is, average power is required is related to inversely proportional to average diameters same empirical relationship. So that is what it is if the shape is same, sphericities are same then shape is same because shape can be defined in terms of sphericity factors. So if this is same, then this is what is law is, so that is what it is.

P stands for power required so in a crusher or a grinder if feed mass, you feed it so is the feed rate mass power time that you are feeding. So power unit mass is proportional to some constant called Rittingers coefficient and Dsa and Dsb are average particle diameter you know before and after crushing, so this is before and this is after D is stands for shape is same, shape is same. So 1 by D minus this is average, because exactly same diameter would not be there so average. So therefore power per unit mass feed rate, feed rate that it says is according to this law and it is an empirical observed from there, observe from there that this is you know this is linearly related.

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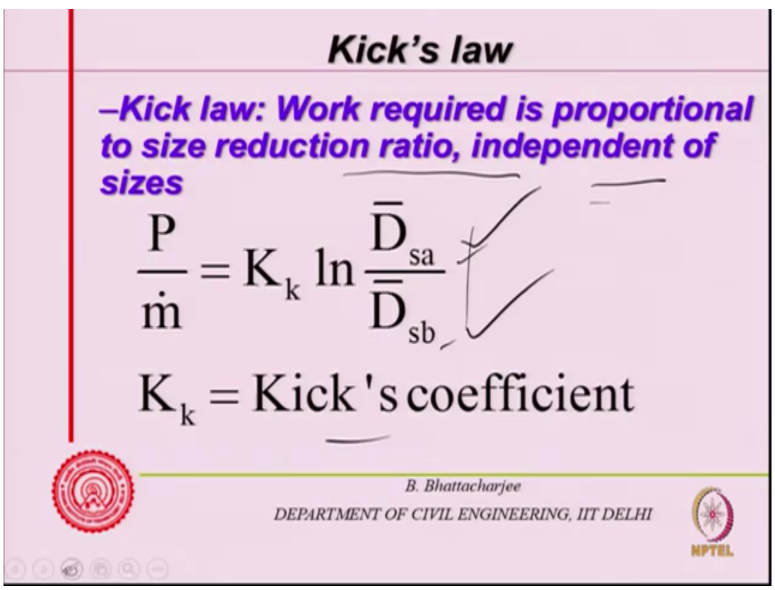

Then there is another is another one Kick's law which is slight modification Kick's law, Kick's law work required is proportional to size reduction ratio, independent of sizes, So how much is the reduced size and again say it is not size ratio both are trying to find it out in terms of ratio in some manner that was linearly related if you see, this was linearly related to 1 by D. In a previous one was related to 1 by D,1 by D and this is before and after 1 by D so is related to 1 by D so 1 by D you know linearly related to 1 by D actually and this is logarithmically related, this is logarithmically related ratio size ratio.

So before and after, So log ln of this so the power per unit is this is another one work required is proportional to size reduction ratio this Kick's coefficient. You see when we do not have full understanding and we cannot derive it from fundamental principle we rely on empirical loss and there can be different one depending upon how one is done the experiment and found it out, but it is it depends on size ratio actually that is what it is before and after so the Kick's law.

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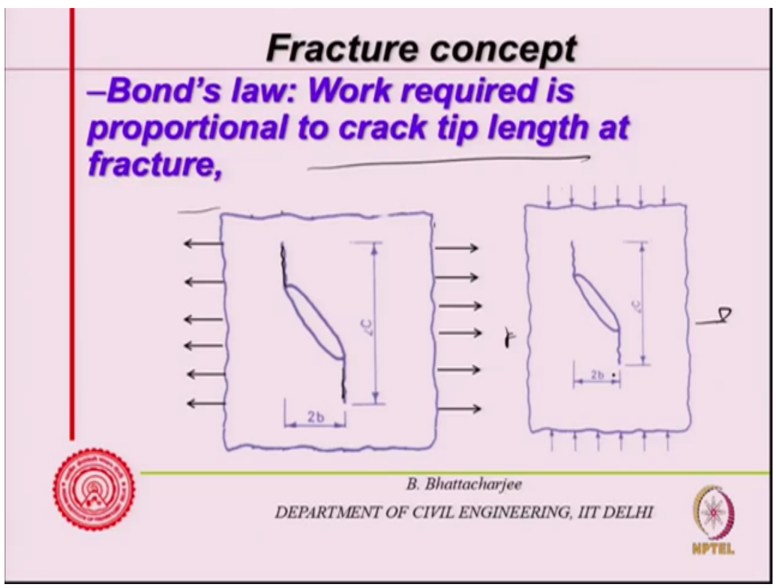

Now that is what I have saying the fracture concept. Work required is proportional to crack tip length at feet fracture. See the crack tip let us see if I have some diagram,yes. This diagram I think I might have shown in concrete technology class and this is what I was looking for in a minute. If you, if you have a already existing flaw in the system like a hole elliptic hole, the and you are pulling it, tensile pull you are giving fracture will progress like this the crack will this will extend in this manner.

And rate of yeah so this, this would be, this if it is compression obviously there is a tension acting along this direction presence of it and therefore you will get fracture parallel to the, fracture parallel to the direction of the load itself in case of compression, in case of tension it goes like this. But mostly crushing means you are applying compression, you are applying compression, compressive forces so that is why this is important to understand.

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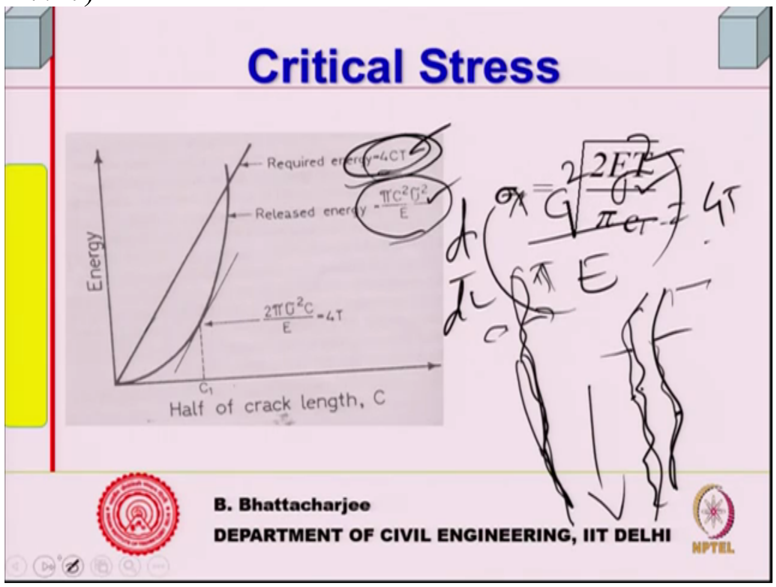

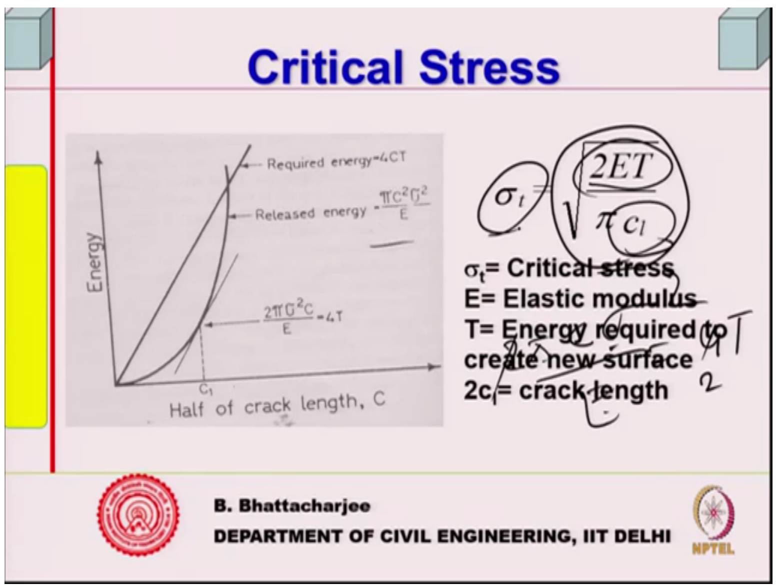

And if you recollect critical stress you can find out critical stress, which was you know energy strain energy release from ferroelasticity one can know is equal to pi if this was 2c, if this was 2c,if this was 2c, if this was 2c the existing crack length you know is 2c, existing crack length this was the whole the crack fracture progress went to 2c. This is of course 2b this, this distance so 2c if this 2c then what we have seen is the critical stress or strain energy release is given by pi C square by sigma square by E, that from ferroelasticity you know using a close from solution one can get that the stress around, the stress concentration around such a crack.

And the surface energy will simply increase as 4CT, because you have one crack here hole and there is another crack here so 2c is this length 2 surfaces would be there one on this side, one on that side so therefore, this is C and if I take unit length 2c on one side, 2c on the other side, a crack,A crack if I have a crack that means I want surface this side, another surface this side you know crack means one surface is here, another surface is here. so 2c if the length of the crack is 2c then this is 2c and thickness if it is unity then it is 2c into 1.

So 2c into 2 because this side is 2c, this side is 2c makes it 4CT. So that is what is strain energy is required to creates if T is a surface energy per unit area, area is 4C into 1, area is 4C into 1 multiplied by T is the energy required, is the energy required, multiplied by T is energy required to create those surfaces and this comes from the strain energy. So once strain energy release rate is parallel to this or in other words if I differentiate this with respect to C , d dc and differentiate this with respect to C which is 4T, then I get an expression you know there is a one at that C cracks will propagate spontaneously.

I have to find out the C at which the crack will propagate spontaneously, crack will propagate spontaneously. So did you depend upon the sigma value, the stress level I mean to say in the stress at what C is stress you know stress level at a given C when crack will propagate spontaneously. So as the, as I apply stress crack will you know crack will start propagating when I have gone to the stress level which is related by this sort of a relationship you know differential, differentiation of this is equals to 4T.

Now this is the expression actually, this is the expression sigma you can derive from this one because if you differentiate this you get twice pi C sigma square by E is equal to 4T and this is 2, so 2TE divided by pi C and Sigma square so sigma becomes so this is the critical stress at which for a given C this is a critical stress as a fracture will progress spontaneously. So it is a critical stress is proportional to this is so let us go back to this, this is important you know so work required is proportional to crack tip length in the fracture.

So the stress at this point is important. This is the simplest Griffith's law you know the fracture mechanics of courses improved much higher than this. So is what we looked at critical stress at which fracture will propagate and remember if you have attended a course on concrete technology we said the strength is a function of pore size as well it together with the porosity. So this follows from here because larger the size, larger the size, lesser will be the critical stress required. (32:03).

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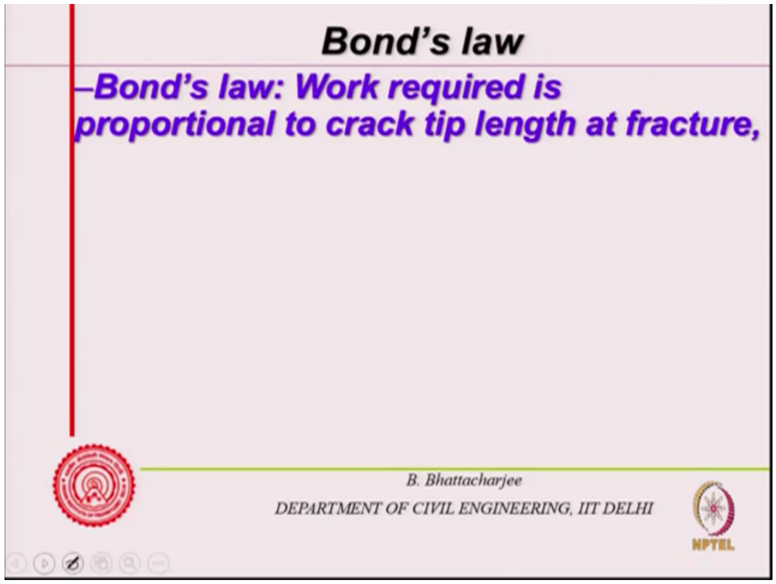

So here also grinding is something to do with Bond's law, work required is proportional to crack tip length at fracture, crack tip length at fracture. Simply we can so it is a crack tip length he is it is talking about and the fracture point. So he is come more realistic than the previous 2 laws. So will just discuss this at this moment.