INDIAN INSTITUTE OF TECHNOLOGY ROORKEE
NPTEL
NPTEL ONLINE CERTIFICATION COURSE
Mechanical Operations

Lecture-10
Size reduction

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Welcome to the fifth lecture of week 2 which is on.

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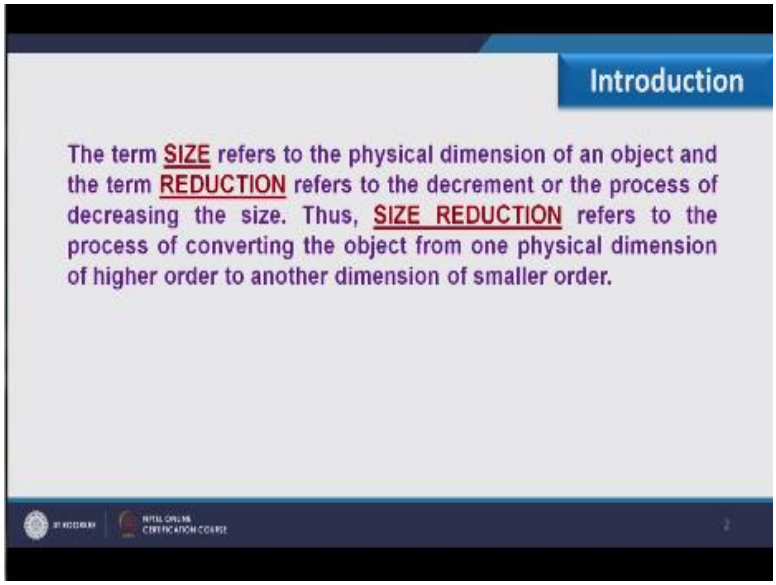

Size reduction, so in this lecture first we will see what is size and what we call reduction. The term size refers to the physical dimensions of an object and the term reduction refers to the decrement or the process of decreasing the size. Therefore, size reduction refers to the process of converting object from one physical dimension of higher order to another dimension of smaller order. So the size reduction, this speaks about itself like size reduction where we have to reduce the size of material.

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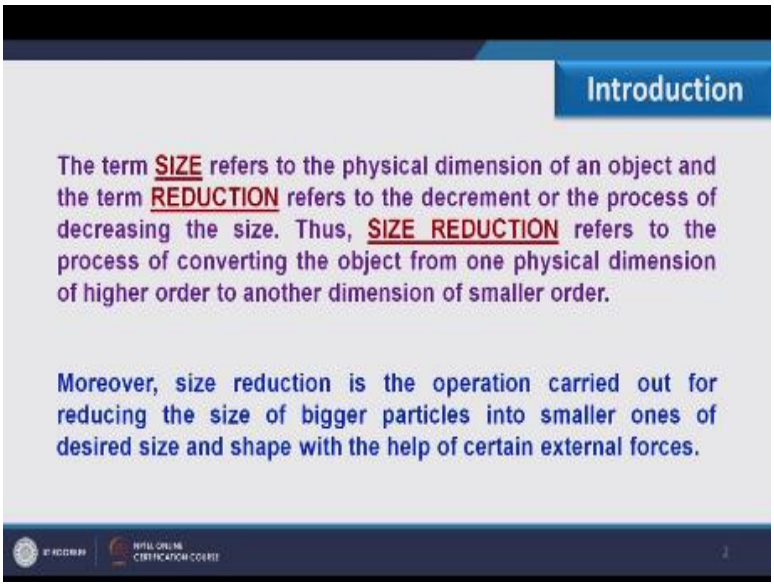

Moreover, size reduction is the operation carried out for reducing the size of bigger particles into smaller ones of desired size and shape with the help of certain external forces. And in this the size reduction basically as far as chemical engineering is considered we denoted this with the name comminution.

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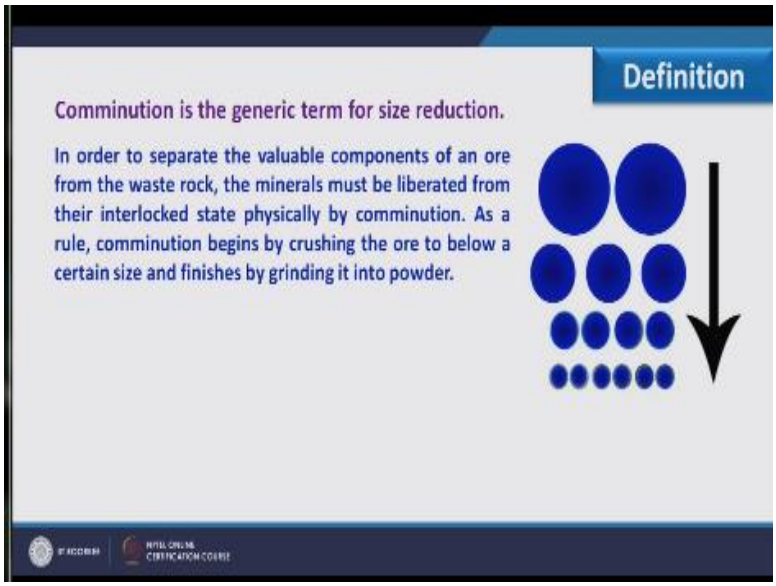

So comminution is a generic term for size reduction. As you can see this figure where the large size particle is converted into the smaller one, so this is basically the size reduction, in chemical engineering terminology we call it comminution. So in order to separate the valuable components of an ore from waste rock the mineral must be liberated from their interlocked state physically by comminution.

So what is the purpose of comminution, to recover the desirable material from the, or desirable mineral from the rock which are placed inside the rock. As a rule comminution begins by crushing the ore to below a certain size and finishes by grinding it into the powder.

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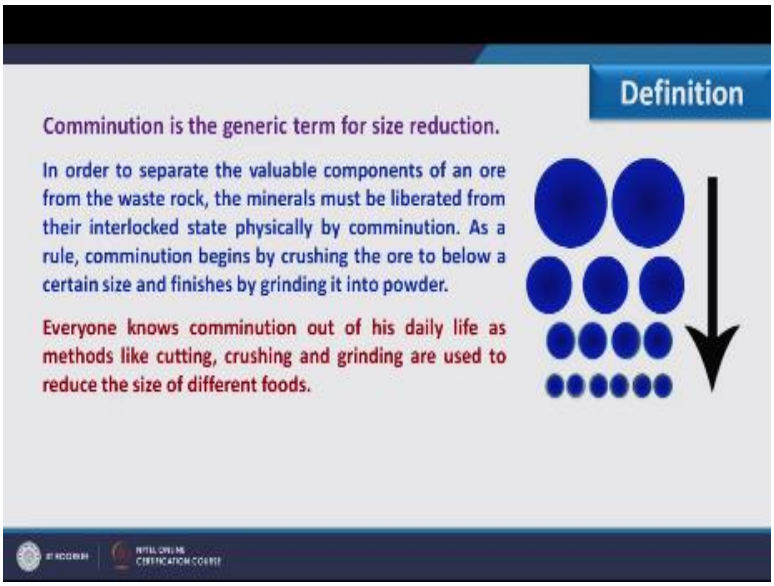

Everyone knows comminution out of his daily life as method like cutting, crushing and grinding are used to reduce the size of different foods. Basically this comminution or size reduction activity we usually have seen in our kitchen where we have mixer and grinder, and sometimes we also use stone grinder where we reduce the size of spices from bigger to the smaller and then it can be used for the food preparation purpose.

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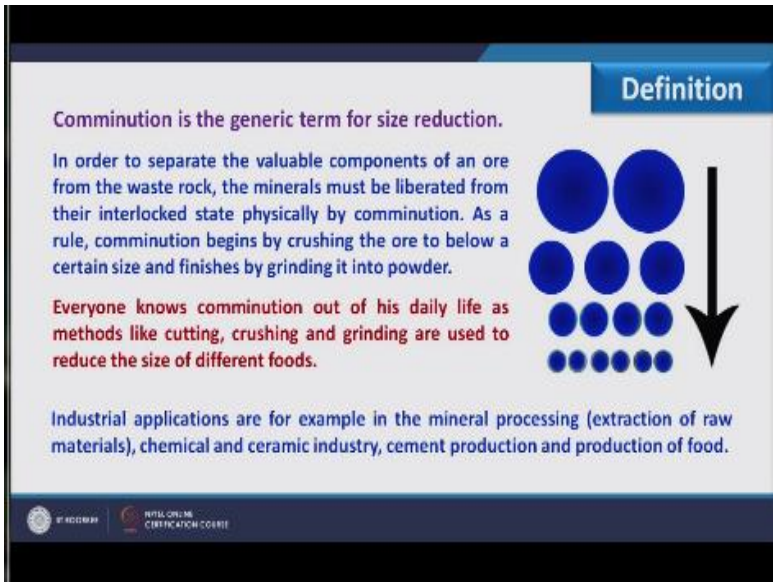

The industrial application for this comminution is in mineral processing where we have extract the raw material from the ore, it is also used in chemical as well as ceramic industries, cement production and production of food. So comminution is used in our daily life as well as in industrial scale also.

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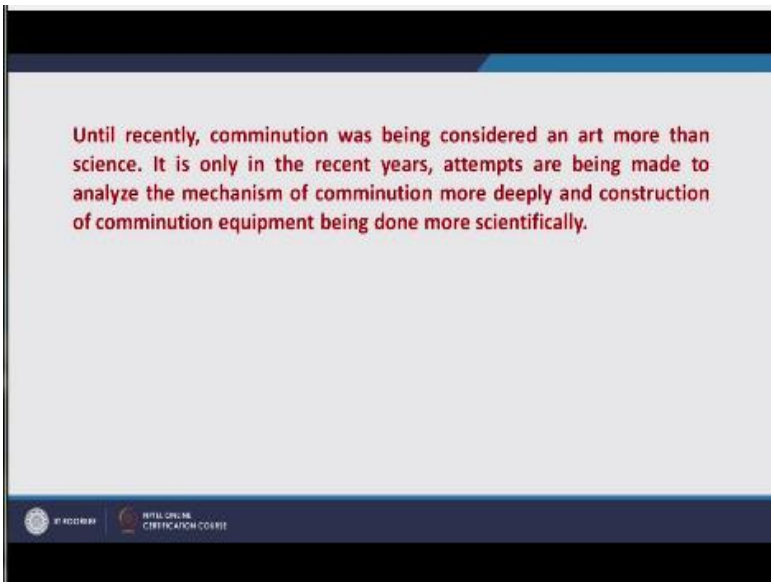

So until recently comminution was being considered an art more than a science. It is only in the recent year attempts are being made to analyze the mechanism of comminution more deeply and construction of comminution equipment being done more scientifically. So according to the requirement we prepare the equipment for comminution and if we consider the daily life as well as the industrial application the huge difference comes when we design the equipment for the kitchens as well as for industry.

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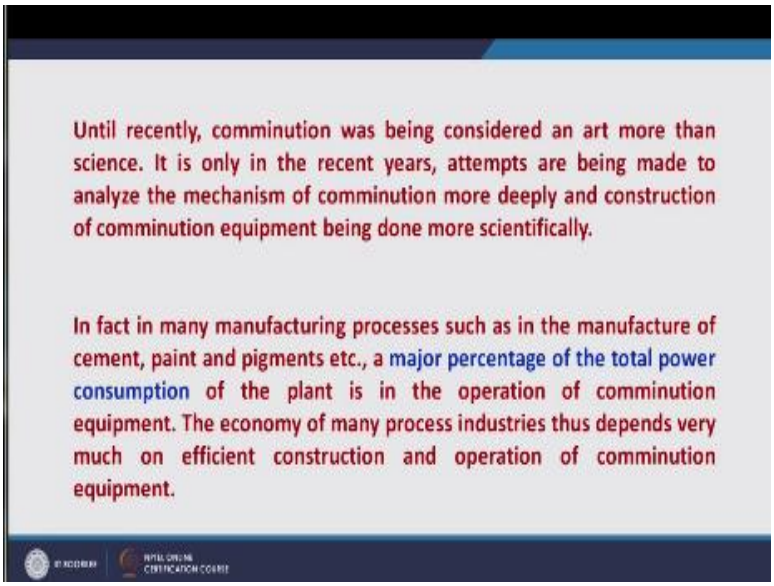

In fact in many manufacturing processes such as in the manufacture of cement, paint and pigments etcetera a major percentage of total power consumption of the plant is in the operation of comminution equipment. The economy of many process industries thus depends very much on efficient construction and operation of comminution equipment.

Now why it is so, why we say that the comminution is the process where major percentage of total power is consumed, that will be clear in subsequent slides. Now as far as objective of comminution is concerned the objective we can define as the first is the liberation, what is libration?

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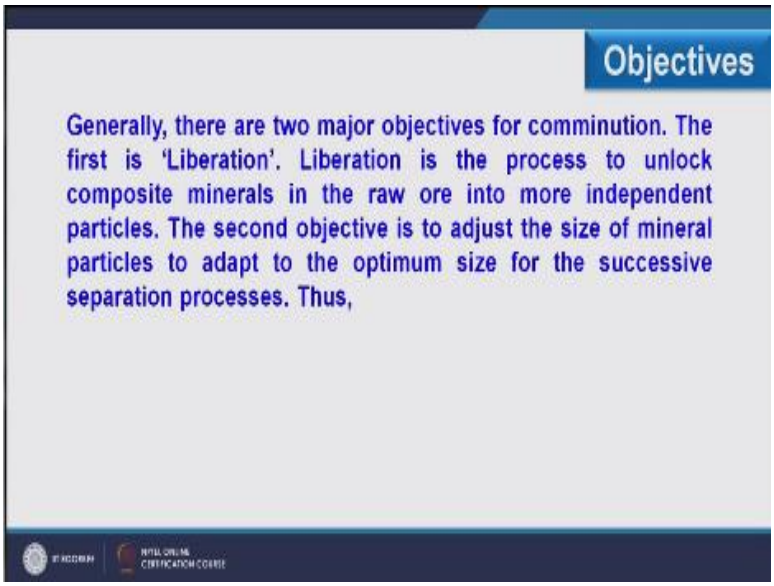

Liberation is the process to unlock composite minerals in a raw ore into more independent particles. The second objective is to adjust the size of mineral particles to adapt to the optimum size for the successive separation processes. Therefore, as far as object is concerned we have defined this, the first is liberation and second is to adjust the size.

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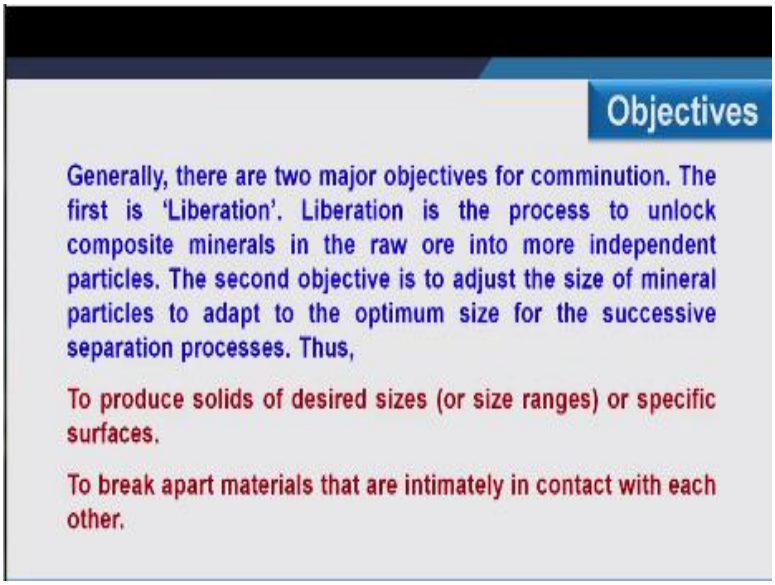

More precisely we can say to produce solids of desired size or size ranges or specific surface, that is the first thing of comminution, second is to break apart minerals that are intimately in contact with each other. So these are the two objectives of the comminution and accordingly we compute the power consumption for comminution for these two objectives as well as we design the equipment to meet these objectives.

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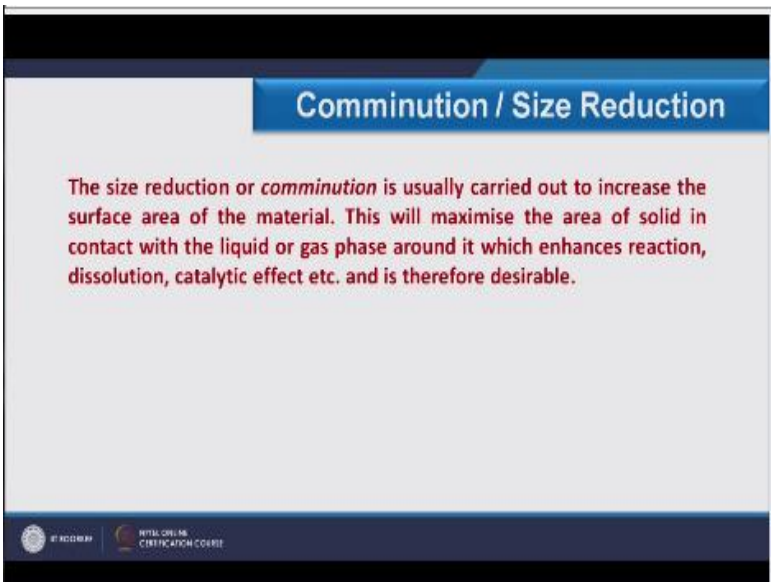

So the size reduction or comminution is usually carried out to increase the surface area of the material as in the lies, as in the last slide we have seen it as an objective of comminution. So this will maximize the area of solid in contact with the liquid or gas phase around it which enhances reaction, dissolution, catalytic effects etc. and is therefore desirable.

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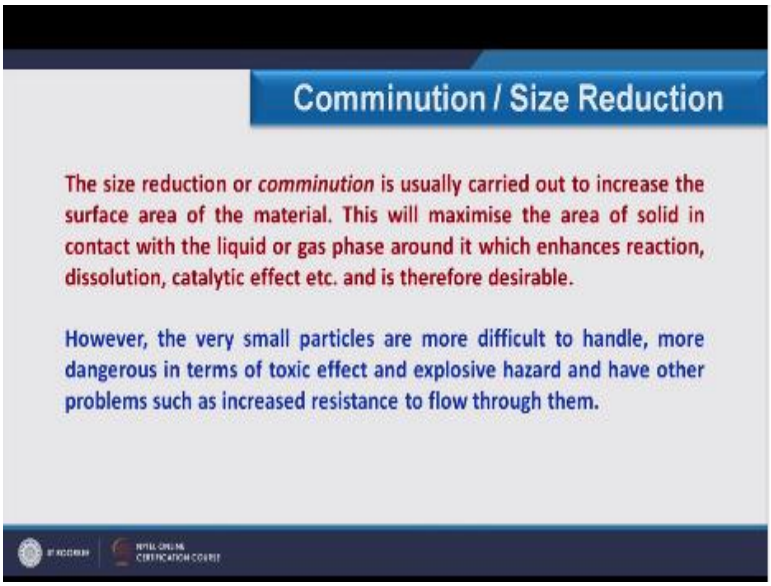

However the very small particles are more difficult to handle, more dangerous in terms of toxic effect as well as explosive hazard and have other problems such as increased resistance to flow through them. So when we have small particles we have to design the equipment, so that the flow of this small particle inside the equipment should not be blocked. Now as far as breakage pattern is concerned in size reduction or comminution we follow some of the patterns.

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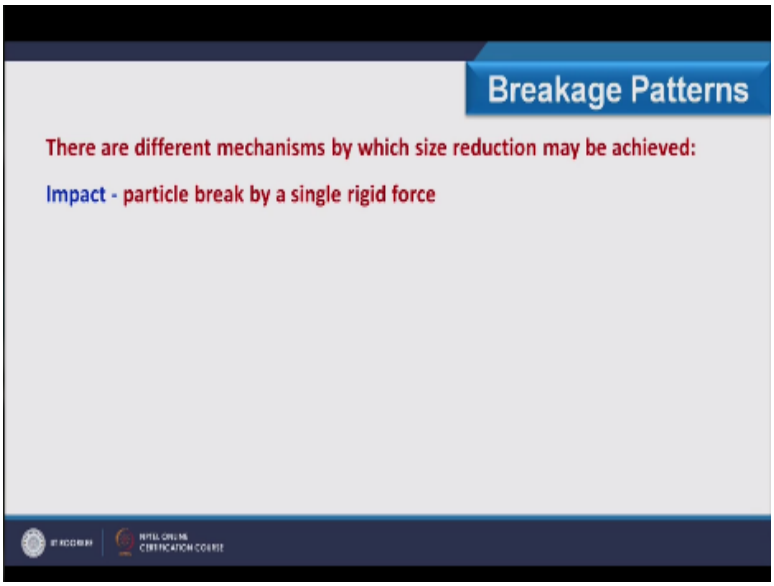

First one is the impact where the particle breaks by single rigid force. So impact you understand that when we put the impact using hammer the particle can be broken. So in impact particle break by a single rigid force.

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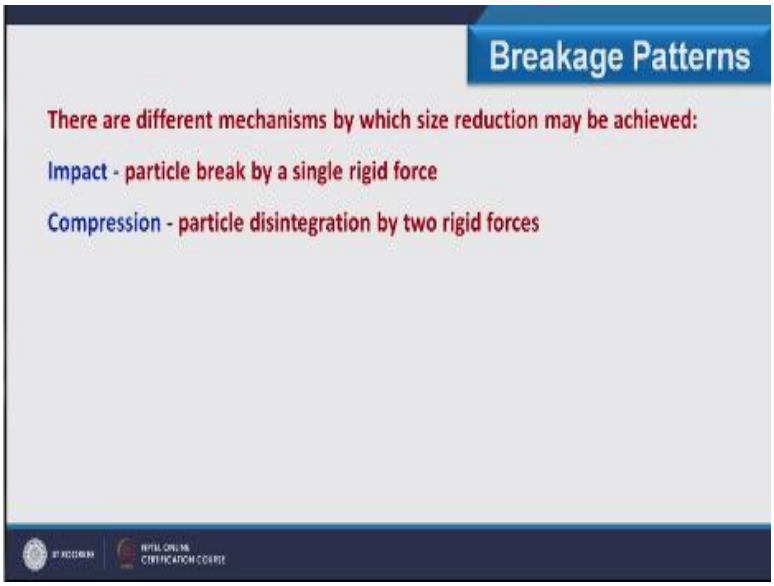

Second pattern is the compression where particle disintegration by two rigid forces when we have the two rigid forces and particle fall in between due to compression the particle reduces it size.

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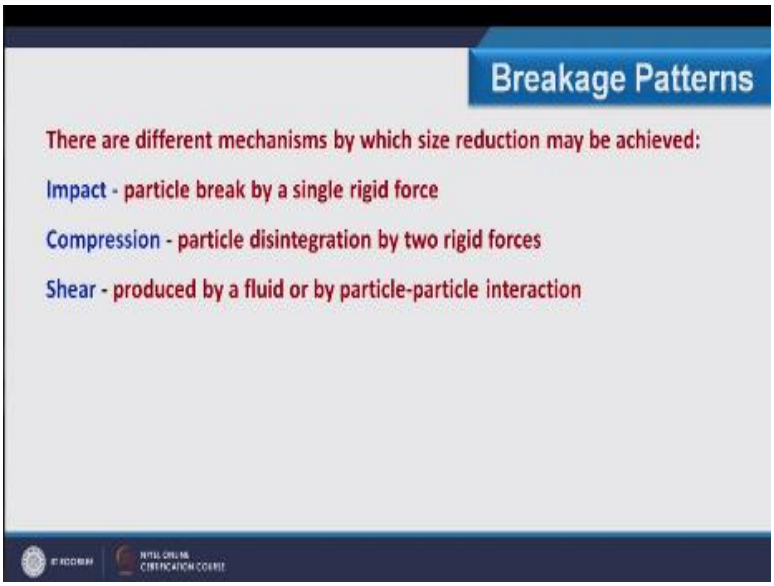

Third pattern is the shear, which is produced by fluid or by particle – particle interaction.

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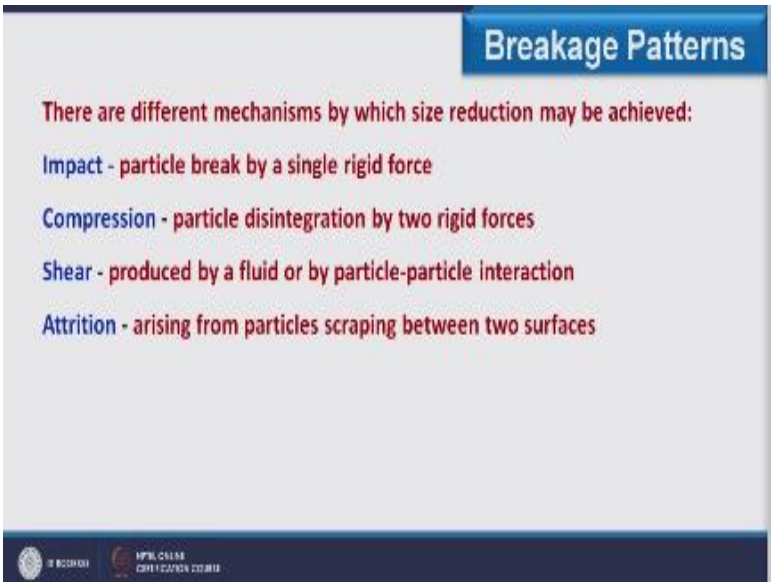

And fourth, mechanism fourth pattern we are having is the attrition and what is attrition it arising from particle scraping between two surfaces or we can say the rubbing of particle between two surfaces for example these are two surfaces and if in between particle is there, so usually one surface is stationary another surface is moving on this. So due to this rubbing action or scraping action particle reduces it size and this we call attrition.

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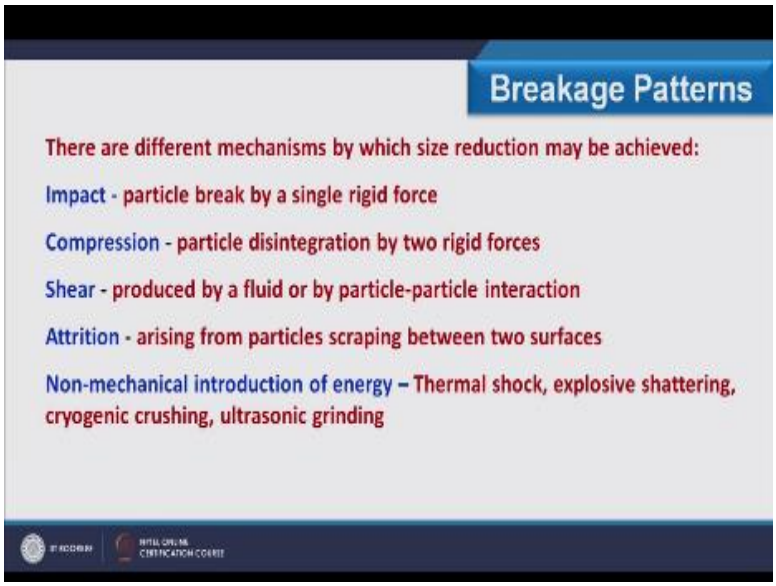

After these four patterns we have another pattern which we call non-mechanical introduction of energy and this includes thermal shock, explosive shattering, cryogenic crushing, and ultrasonic grinding. So all these five pattern we are having for size reduction in this top four are basically used for grinding equipment, and we are having also non-mechanical introduction of energy that also we use for size reduction.

Now here we will discuss the breakage mechanism previously we have discussed breakage pattern what are the, by which mean the particle break and here what are the mechanism we follow for breaking purpose the first phenomena we call as volume phenomena.

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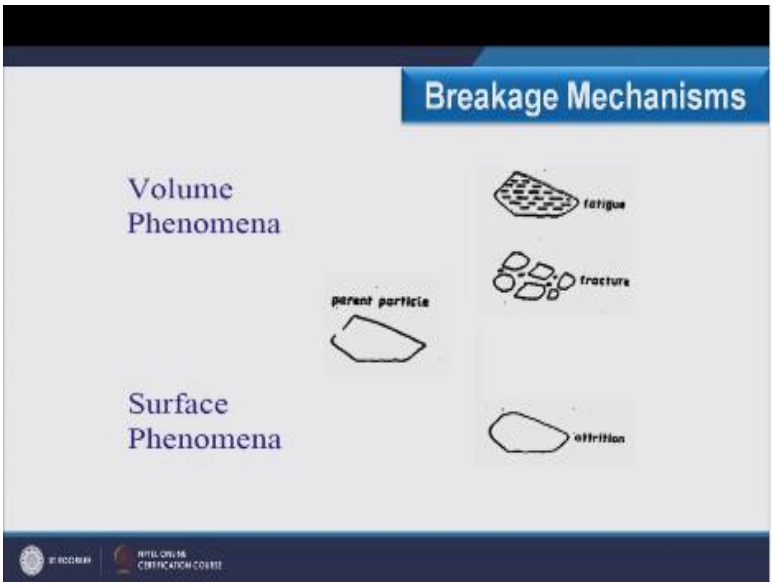

Now what is this volume phenomena? For example, if I am having this particle of irregular shape and we call it parent particle. Now if I consider volume phenomena what will happen, the particle due to that breakage pattern the particle reach to it is elastic limit and then it breaks into smaller particle. So therefore the larger particle is no more exist in place of this we have a smaller particle of a small volume and this we call volume phenomena.

Next phenomena we are having is the surface phenomena in which this pattern particle which has very angular corners very sharp corners. So what will happen ins surface phenomena due to attrition or due shear these cancers become smooth instead of being sharp. So finally when we consider the surface phenomena we have this kind a particle it is volume is very less change in surface phenomena particle does reduce it is size significantly only due to surface action due to attrition due to shear the surface becomes smooth.

So as far as volume phenomena is concerned it happens due to fracture of parent particle and surface phenomena occurs when we consider attrition or shear of parent particle. So these are the mechanism we use in comminution.

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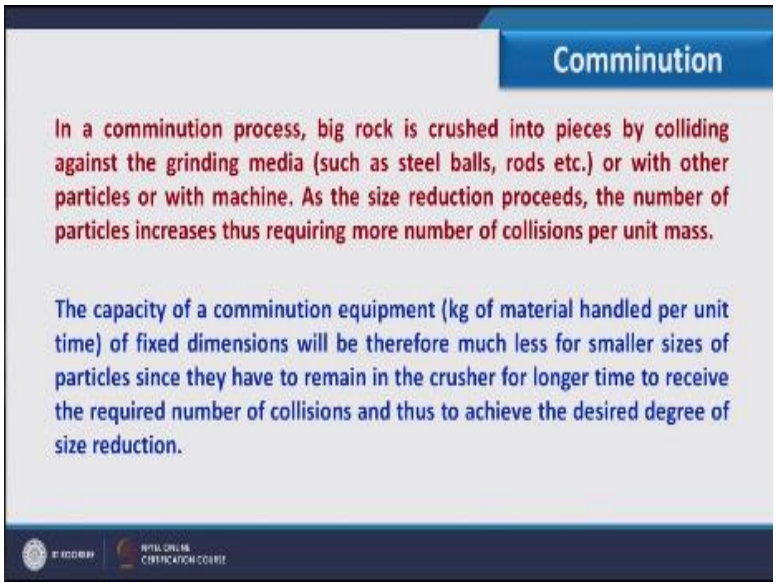

So in a comminution process big rock is crushed into piece by colliding against the grindin media such a steel balls, rod etc, or with other particle or with machine itself. As the size reduction proceeds the number of particles increases thus requiring more number of collision per unit mass. Therefore, if we have lesser size it will receive more collision to further reduce it size. So the capacity of comminution equipment which we have defined as kg of material handled per unit time or material handle by the equipment in a unit time that we have defined the capacity.

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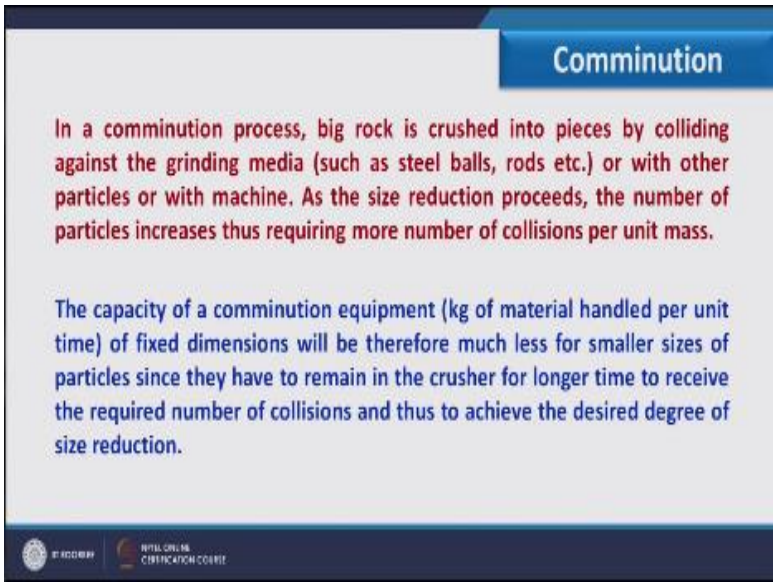

So capacity of comminution equipment of fixed dimension will be, therefore much less for a smaller sizes of particles since they have to remain in the crusher for longer time to receive the required number of collision and thus to achieve the desired degree of size reduction. So what is main fact over here that when we deal with the larger particle the it will receive lesser collision or lesser energy to further reduce.

However, when we have reduced size particle, when we have smaller size particle we need very large number of collision for father reduction of this. Now why it will happen because it is so small in size that many of the collision will be wasted and very less collision are occur on the particle surface itself and therefore the more number of collisions are required or smaller particle to be converted into further smaller size.

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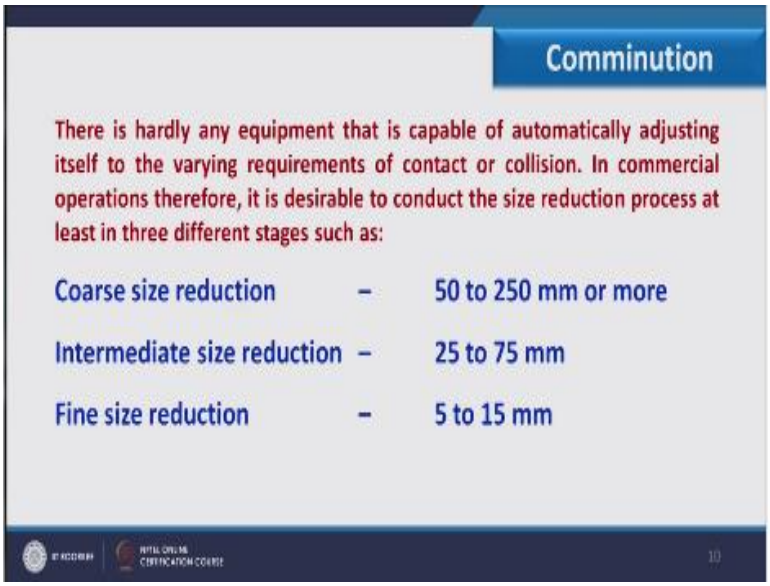

There is hardly any equipment that is capable of automatically adjusting itself to the varying requirement of contact or collision. In commercial operations therefore, it is desirable to conduct the size reduction process at least in three different stages such as: we define first stage is the coarse size reduction where size vary from 50 to 250 mm or more, intermediate size reduction where the size is 25 to 75 mm, and third is fine size reduction where feed size vary from 5 to 15mm.

So you see here we have 3 different category, so whatever equipment for size reduction we are having that also can be categorized based on these three sizes that is coarse, intermediate, as well as fine. And this we will discuss when we discuss the industrial equipment for size reduction. Now from here onward we will discuss the factors which are affecting the comminution different factor we will account over here the first one is the hardness of the feed. Now what is hardness that you can understand.

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The hardness denotes its resistance to scratching and is thus a good indication of abrasive character of the mineral and it is resistance to crushing. So usually what we consider that when material is very hard we need more and more energy, more and more power to crush it. So in general harder martial require more energy to comminute, therefore a longer residence time And more robust construction is required because hard material can harm the machine also so as for as equipment is concerned more robust construction is required to handle hard material.

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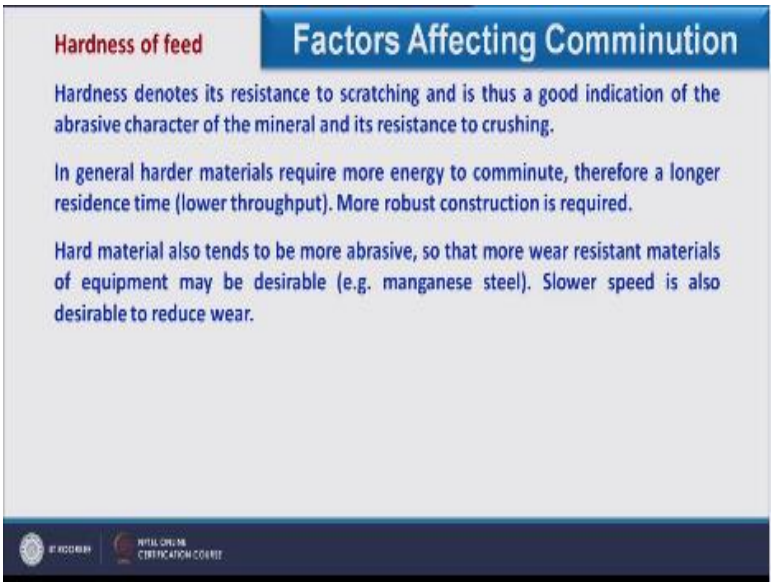

Hard material also tends to be more abrasive, so that more wear resistant materials of equipment may be desirable as we have discussed previously for example, manganese steel we can use slower speed is also desirable to reduce the wear. Therefore, when we handle the hard material accordingly we have to chose the material of construction of the equipment so that it should not get so much wear during the operation.

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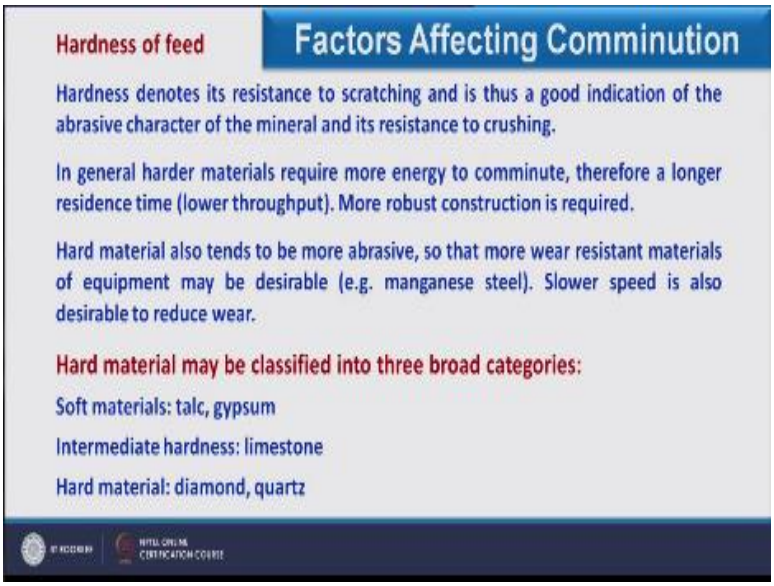

Along with this we also have to maintain lesser speed in equipment because then only we can reduce the wear inside the equipment. So hard material may be classified into three broad categories: the first is we call soft material, for example talc, gypsum; intermediate hard material is limestone; and hard material we are having as diamond and quartz.

So for this different category we have different equipment in which we carry out comminution of hard material. So hardness is one of the factor another factor is internal structure of the feed, now what happens in this.

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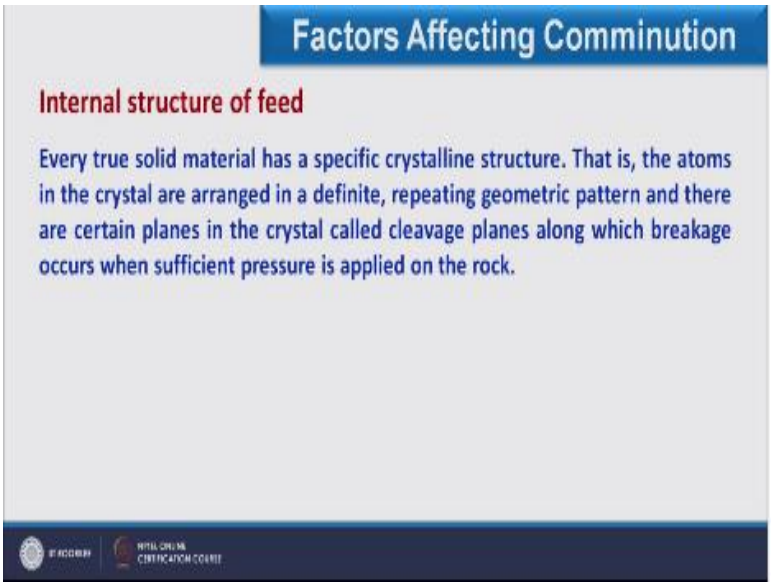

Every true solid material has a specific crystalline structure that is the atoms inside the crystal arrange in a definite repeating geometric pattern and there are certain planes in crystal that we call cleavage planes along which breakage occurs when sufficient pressure is applied on the rock. So what happens when we have the crystalline structure and when we put the desirable pattern, breakage pattern on this then it will reduce it size considering its crystalline structure from where it has the cleavage plane, if we put the pattern desirable breakage pattern over there then only it will reduce its size.

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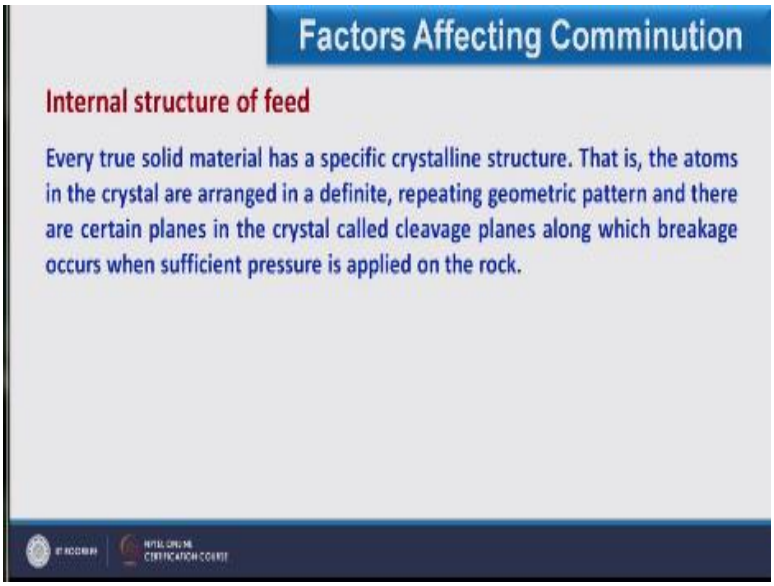

To consider an example if I consider the mica it is basically of simple plate and when we put breakage pattern over here like impact or compression whatever it will be very difficult from this side, it will be very difficult to break from this side. However, when we put any force any patterns from this side it will be very easily taken out. So what we have to do as far as crystalline structure is concerned then the cleavage plane should be targeted first as far as breakage pattern is concern to break the feed.

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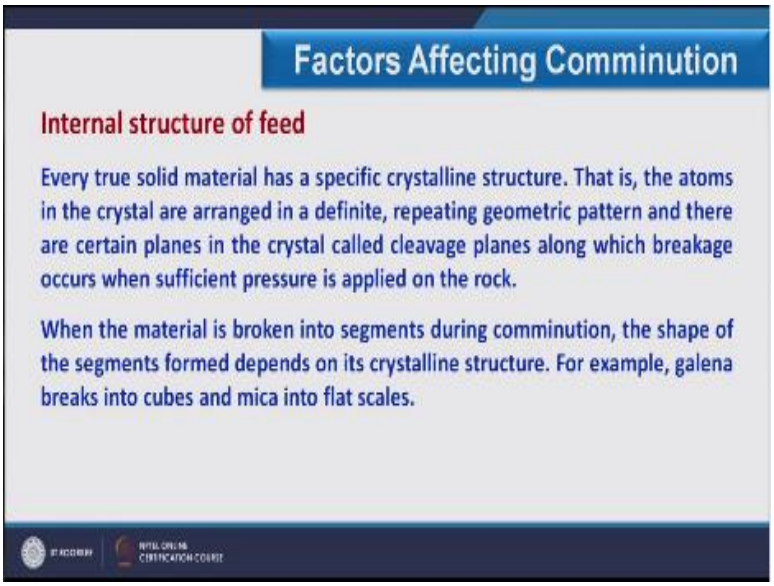

So when the material is broken into segments during comminution, the shape of segments formed depends on its crystalline structure. For example, galena breaks into cubes and mica into flat scale as just we have discussed. So as for internal structure of feed is concerned, if we put the pattern, if we put the impact or other pattern or for breaking it we have to target the clavish pattern of the feed.

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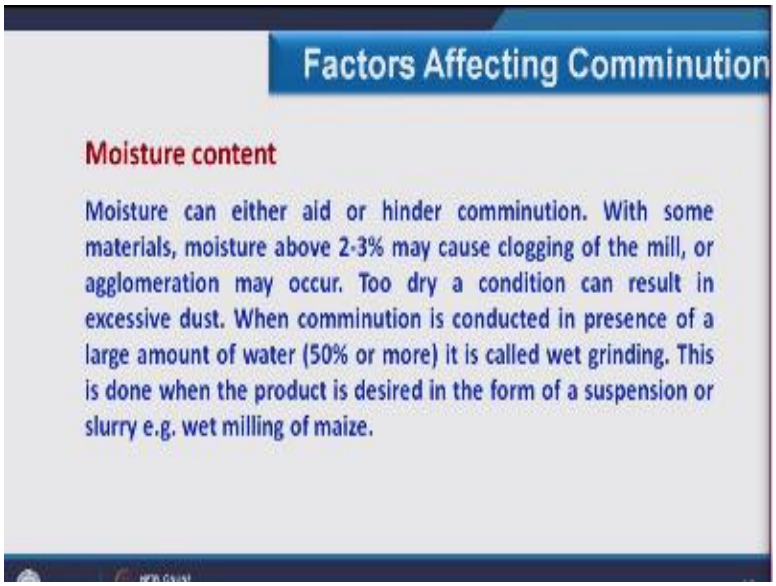

Another factor I am having is the moisture content. Now what happens in moisture, moisture can either aid or hinder the comminution. With some materials, moisture above 2-3% may cause clogging of the mill, or agglomeration may occur. Therefore, we do not consider very significant for moisture on the other hand the material should not be too dry, because when we reduce the size of dry material excessive dust will come out from this.

So when we deal with the dry material and when we reduce the size of dry material excessive dust will come out from this. So when comminution is conducted in the presence of large amount of water that is more than 50% or so, it is called wet grinding. This is done when the product is desired in the form of suspension or slurry for example, wet grinding or wet milling of maize.

So as well as moisture is concerned 2-3% or lesser than this we should maintain, we should not reduce the size of two dry material or two moist material. If water is present in significant amount, then we go for the wet grinding instead of dry. Another factor is very important that is temperature sensitivity of material.

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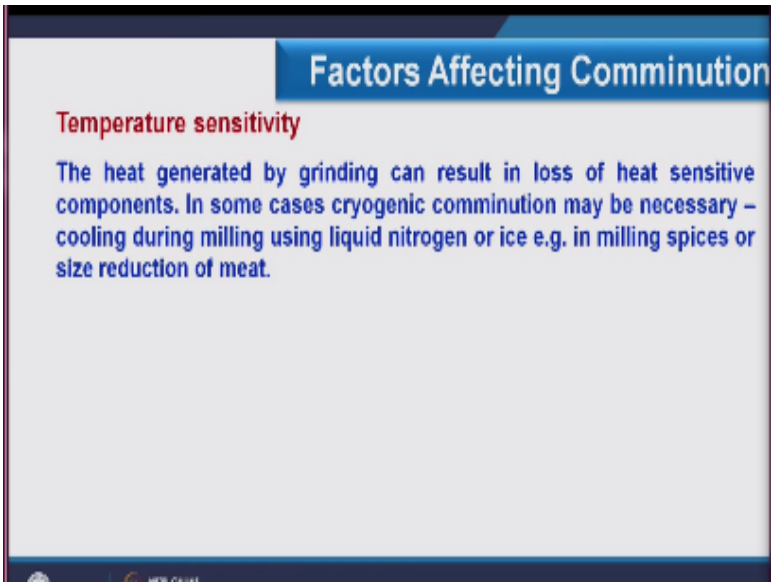

So heat generated by grinding can result in loss of heat sensitive component. When we reduce the size of any material some heat is generated during the comminution process which is harmful when we deal with heat sensitive component.

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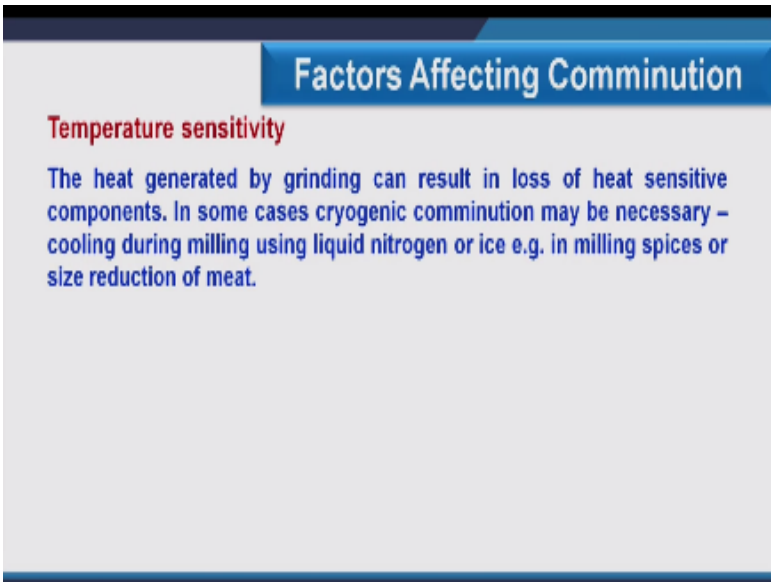

Therefore in some cases cryogenic comminution nay be necessary for example cooling during milling using liquid nitrogen or ice and this we consider in milling spices or size reduction of meat. So temperature sensitivity we also have to consider.

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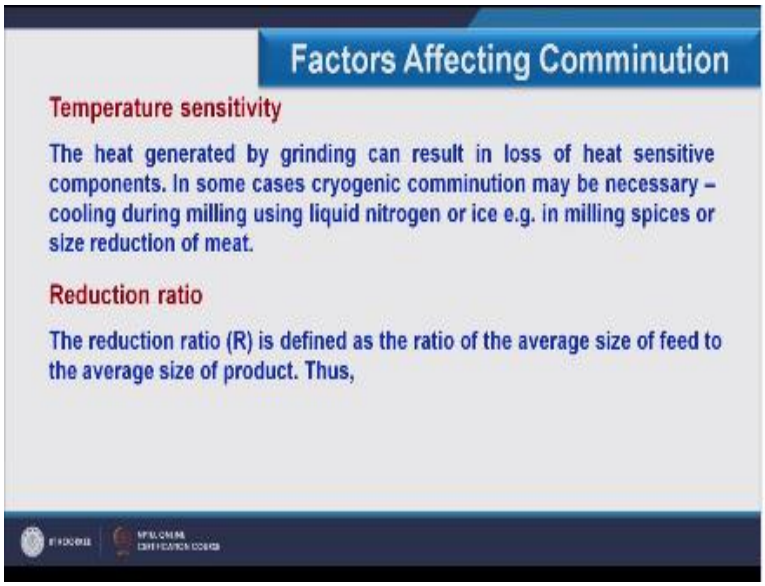

As far as comminution is concerned, next factor is the reduction ratio. Now what is the reduction ratio? It is defined as the ratio of every size of feed to every size of product. So what is the size of feed why I have called every size?

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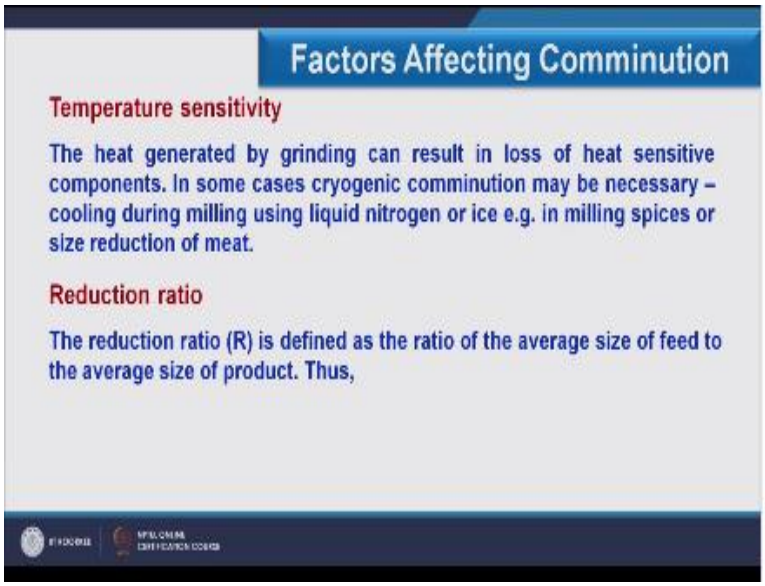

Because the feed will also have different fraction when we measure the size of this and product will also have different fractions when we deal when we measure the size of product. Therefore, we have defined every size of feed as well as every size of product.

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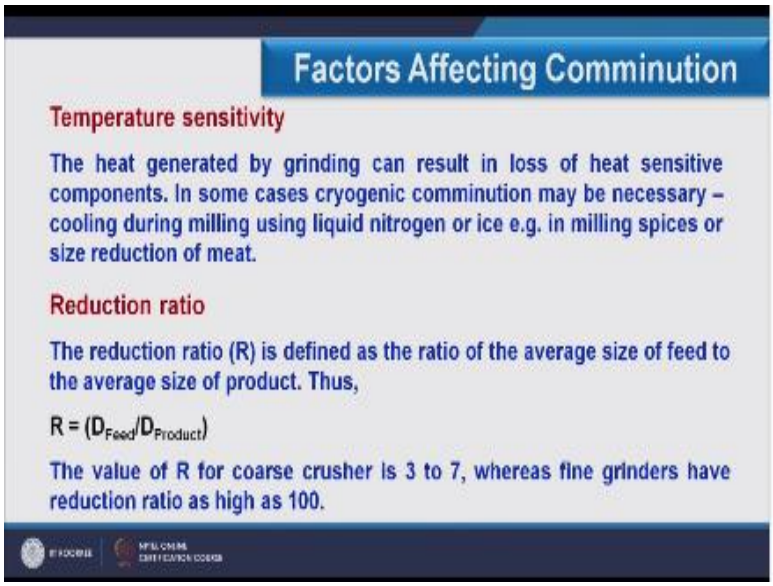

So size reduction or basically the reduction ratio we defined as D_{Feed} / $D_{Product}$, the value of R that is reduction ratio for coarse crusher is 3 to 7 whereas for fine grinders the reduction ratio is upto 100 value. Now another factor we have the modes of operation by which way we operate the comminution process.

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The first is the open circuit grinding. Now what happens in open circuit grinding, this is the simplest method of operating a mill product passes straight through. Now what is the meaning of this, for example if I am having the equipment for comminution and when we operate this in a open circuit feed comes from one side into the equipment, crushing takes place and product exists from here.

So if the equipment is placed horizontally the feed comes from one side and product exists from other side it means it is for certain time it will stay into the mill and then the product passes through the equipment. So that is the simplest method.

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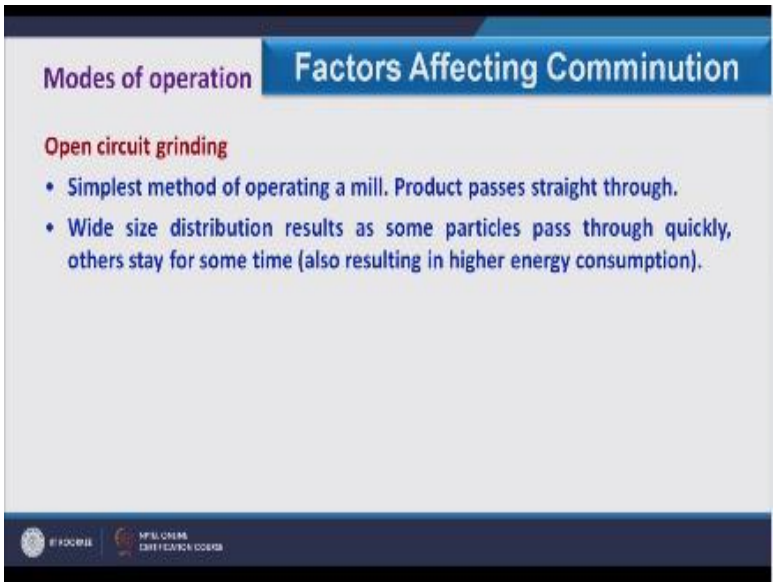

Wide size distribution results as some particles pass through quickly others stay for some time, so what happens when we, when feed enters into the mill from one side it may happen that some of the particle will pass through the through one or two strike only strike or one or through impact only. However, other will stay for longer time to get more impact.

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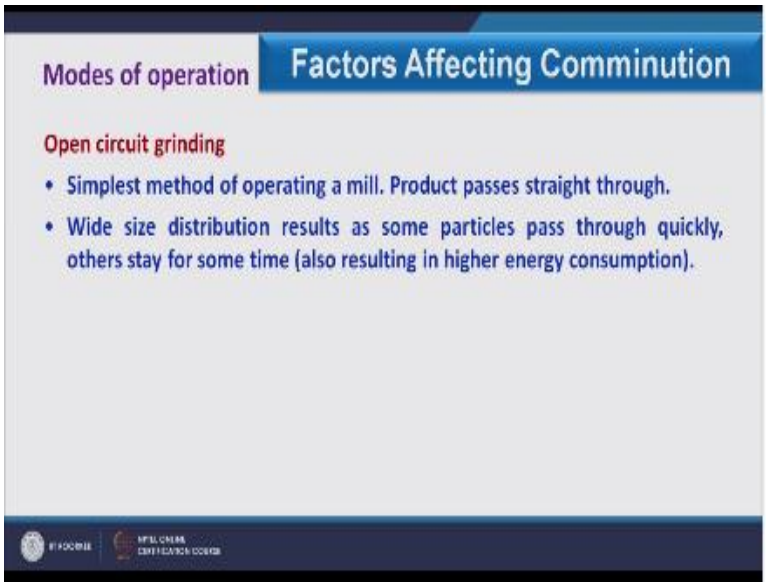

Therefore in open circuit grinding we usually have wide size distribution of product. And as well as, as it will some of the particle will stay for longer time it will be more energy consuming.

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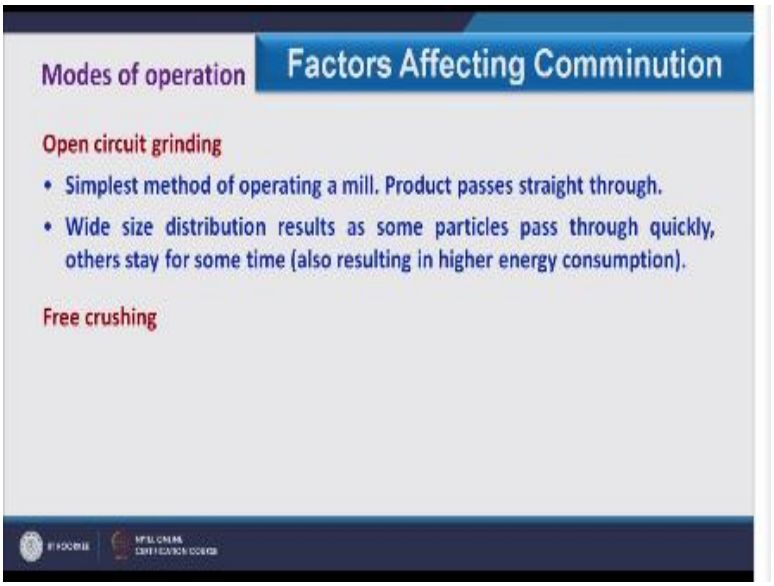

Second option, second mode of operation we have is the free crushing. Now in open circuit what happen feed enters from one side and exits from other side in free crushing the same method is followed feed enters from one side and exist from another side, but what is the difference that feed basically move through the action of gravity, that's why we call it free crushing.

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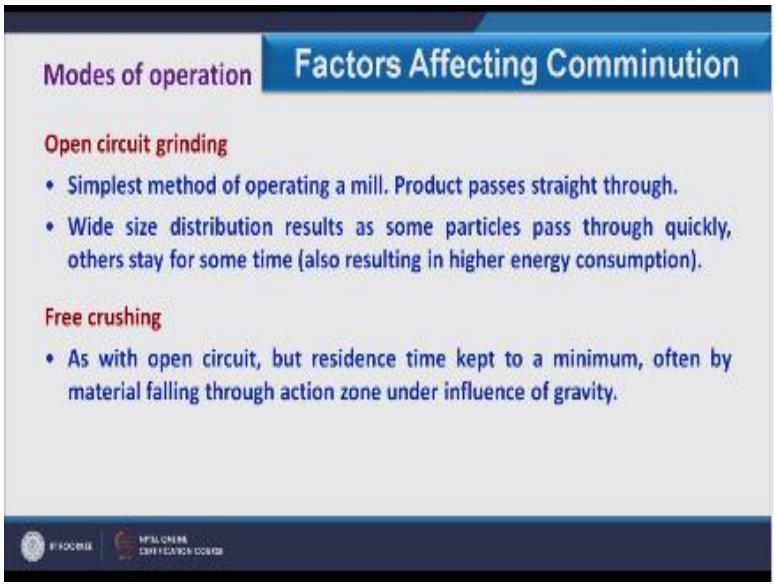

So as with open circuit the residence time kept to be minimum, in free crushing often by material passing through action zone under influence of gravity. So what will happen if material coming from top? The crushing takes place and product exist from the mill in a single impact or not, or without any impact.

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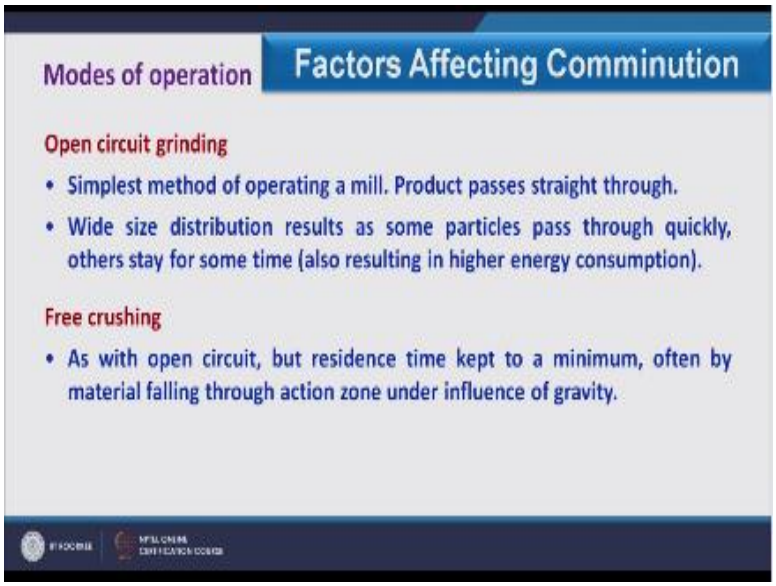

So in this free crushing reduced production of under size and lower energy consumption because some of the particle will pass without getting a single impact or collision. Third operation we have is the choked feeding.

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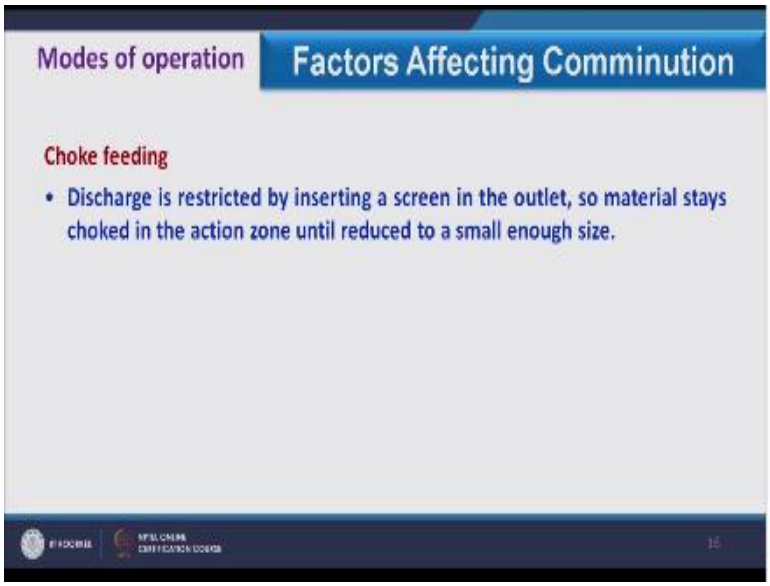

Now what happens in this choked feeding, it also operates under open circuit, but what happens discharge is restricted by inserting a screen in the outlet. So material stays choked in the action zone until reduced to a small enough size. In this choked feeding what happen in the equipment material come from, comes from one side and from another side we put a screen, so until, unless material will be reduced to that size then it can pass through the screen.

Then it will, then only it will exit the equipment. So it will stay for longer time in the equipment and continuously feed is there, so the complete operation is carried out at choked condition.

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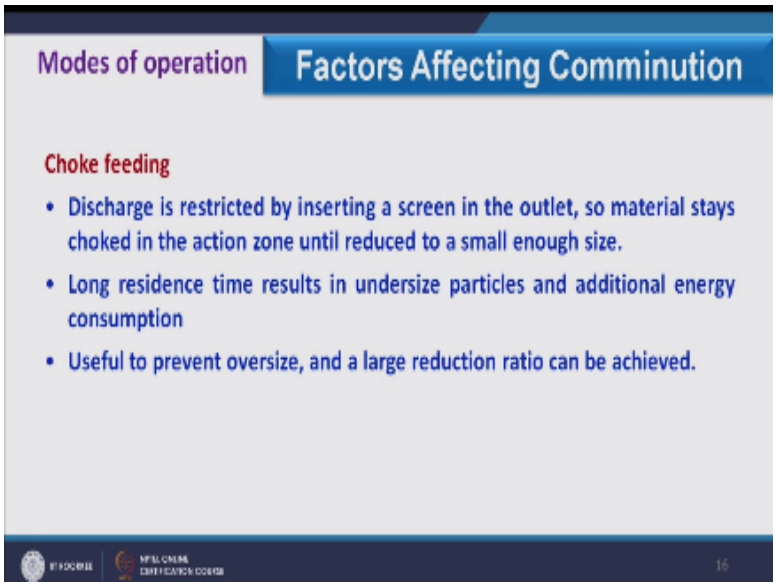

It has long residence time which results in undersize particles and additional energy consumption. Useful to prevent oversize and large reduction ratio can be achieved in this.

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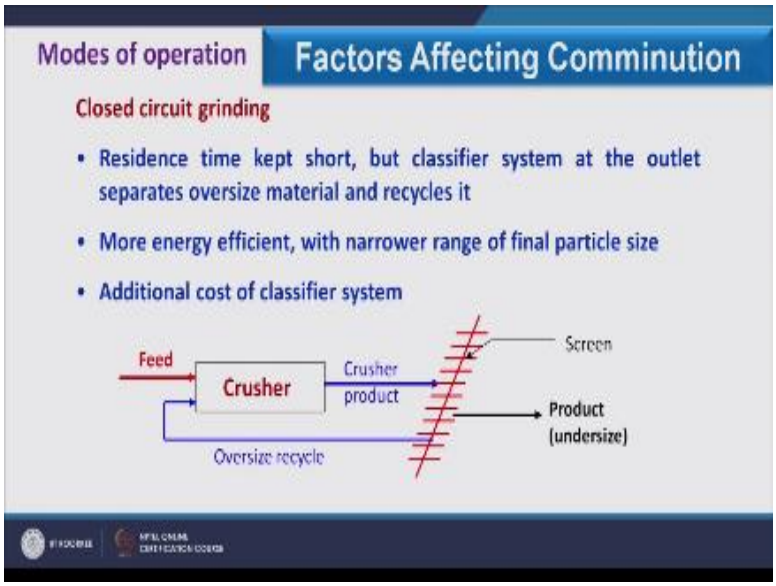

Here I am having the, another mood of operation which we call closed circuit grinding. Now in this what will happen this is the crusher feed enters from one side. Now in this what happens if this is the crusher and feed enters from one side the crushed product exit the crusher from another side so we call this as a open circuit.

Now when this crushed product is screened by a screening and we have undersize product, the oversize product which we do not want that is recycle back to the crusher. Therefore, in this operation oversize particle are usually operate in a close circuit until, unless the particle fall in the desired size we cannot collect the product. So in close circuit what happens residence time kept short, but classifier system at the outlet separates oversize mineral and recycles it.

More energy efficient with narrow size range of final particle size additional cost of classifier system is included in this.

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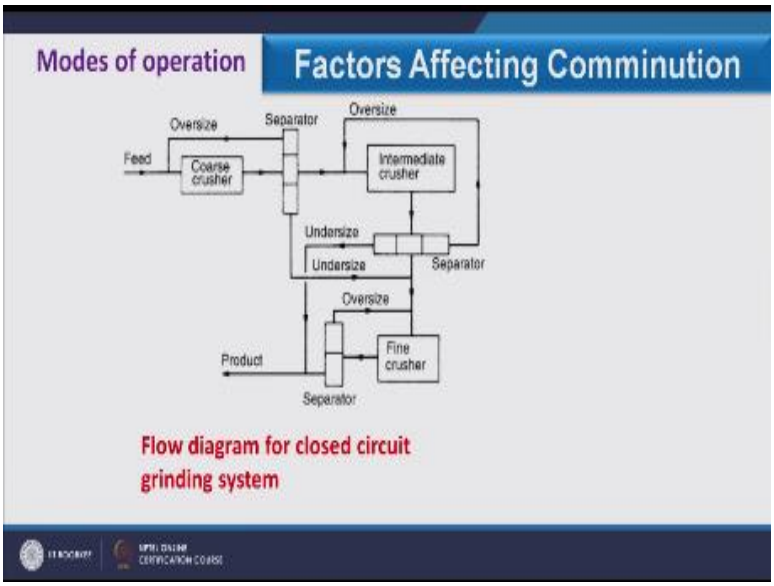

And here we have the complex close cycle where we have three stages where the crushing or grinding takes place for the feed, here we have coarse crusher, intermediate crusher as well as fine crusher. So in three stages we have the grinding where all three stages are associated with the close circuit grinding system. And finally we have the energy used in comminution.

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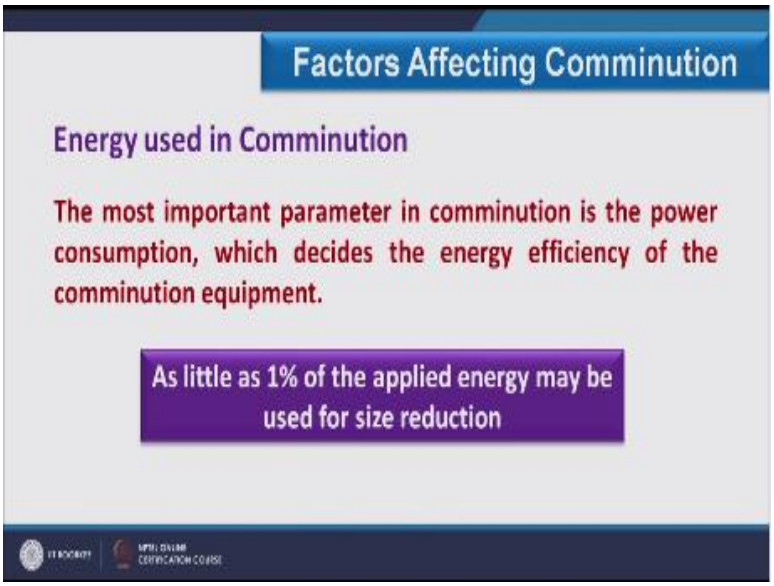

This is most important parameter in comminution which decides the energy efficiency of comminution equipment. As little as 1% of applied energy may be used for size reduction. So you see only 1% whatever energy we are consume, utilizing 1% is used in size reduction, so where rest of the energy goes. Energy lost in deforming the particle to its elastic limit.

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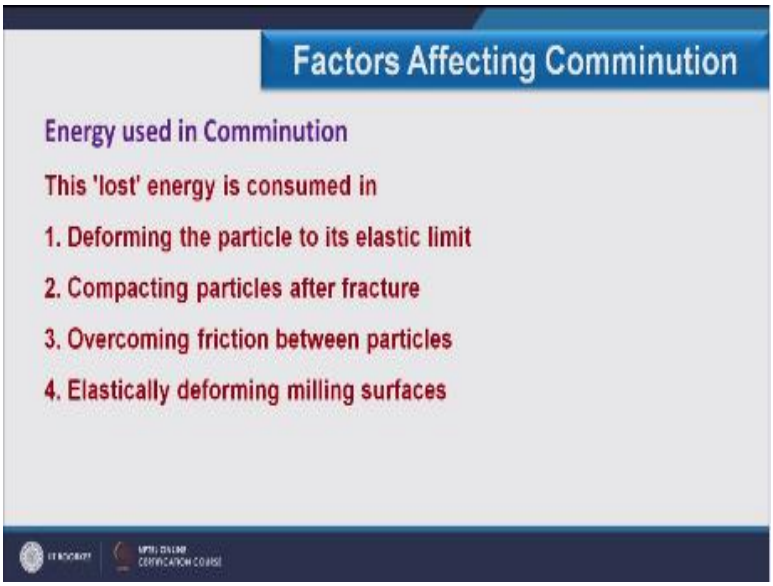

Compacting particles after fracture, overcoming friction between particles and finally elastically deforming milling surfaces. So in this four way the energy is lost, so this energy is dissipated as heat.

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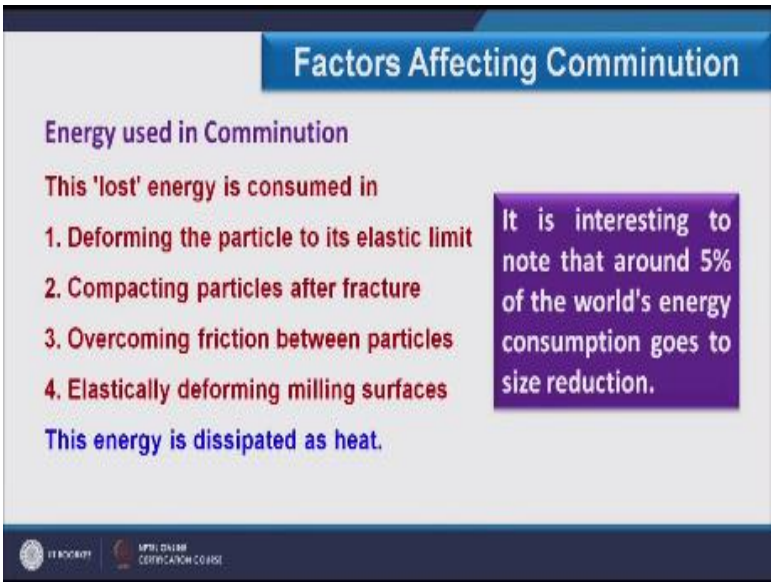

And here one interesting fact is there that around 5% of worlds energy consumption goes to size reduction, so this is a significant amount as far as world energy is concerned. And this is the motivation which says that we have to design the equipment for comminution more effectively, so that it can utilize maximum of its energy for size reduction.

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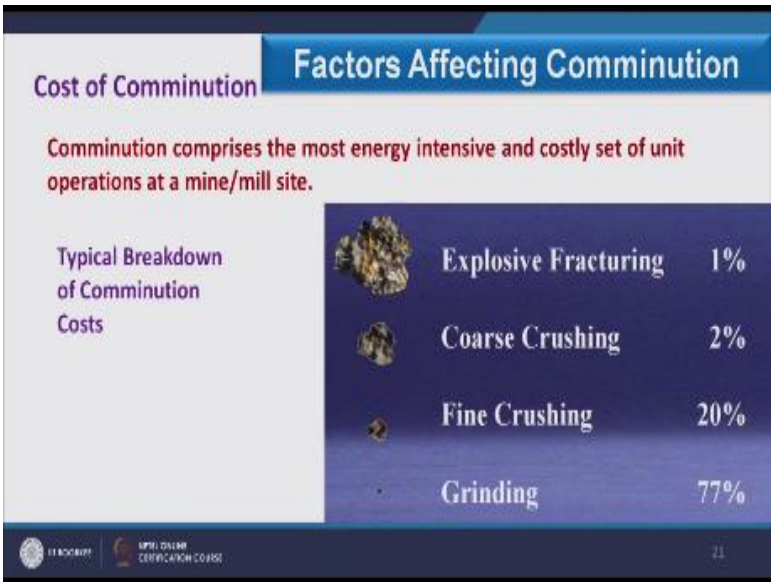

And here another factor we can discuss and that is the cost of comminution, the comminution comprises most energy intensive and costly set of unit operation at mine and mill site. Now here when we go for size reduction from larger to smaller the cost vary. For example, if we do the explosive fracturing 1% cost is there and if we go for coarse crushing the cost is 2%, this is basically the breakage of cost.

Fine crushing 20% and grinding that is small particle size reduction it includes 77% cost. So accordingly when we move from larger to smaller the equipment is very sophisticated and therefore the cost involved in comminution increases significantly. So as for a summary of this lecture is concerned.

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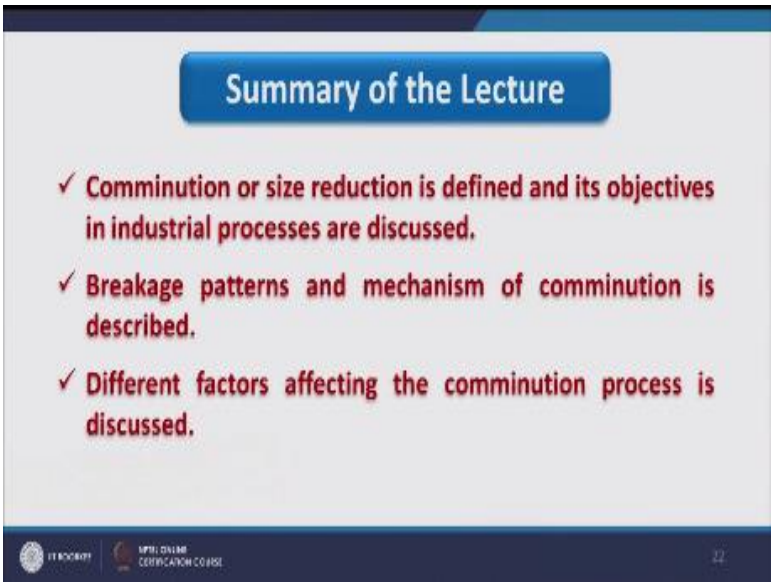

In this particular lecture comminution or size reduction is defined and its objectives in industrial processes are discussed. Breakage patterns and mechanism of comminution is described, different factors affecting the comminution process is discussed. So here we have discussed the comminution and their different factors, breakage pattern, mechanism etc.

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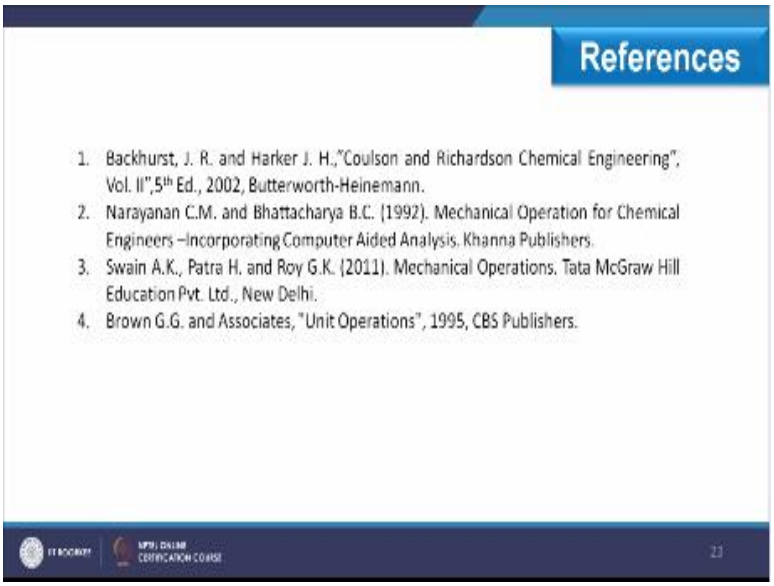

And these are the references for this lecture and that is all for now. Thank you.

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