Fuels, Refractory and Furnaces

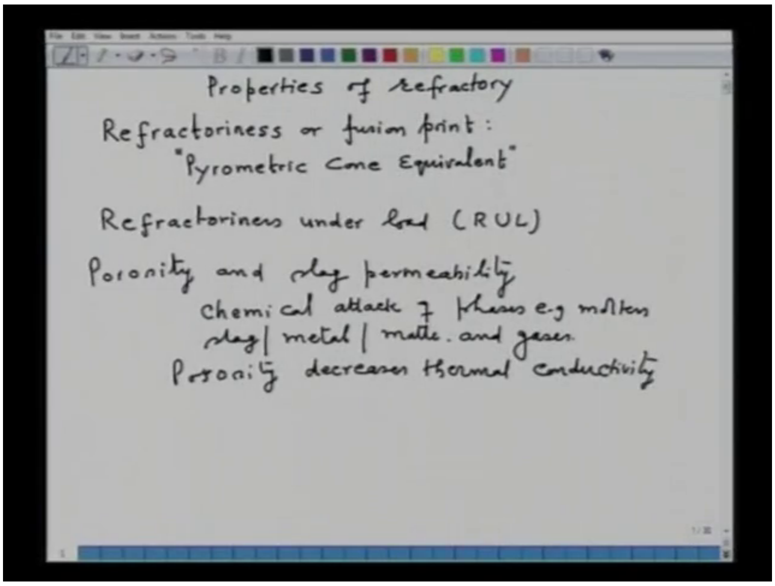
Prof. S.C. Koria
Department of Materials Science and Engineering
Indian Institute of Technology, Kanpur

Lecture No. # 15

Refractory in Furnaces

So, today we will talk on properties of refractories. As you recall from the earlier lecture in metal extraction industries, several diversified requirements of the phases are there. There are liquid phases among liquid there are molten metals, molten slag, molten matte, hot gases, solids, moving at different speeds, different viscosities, different temperature. What I wanted to say is that now, you have to look into the property of the refractory which are available to us. So that for a particular application we can integrate some of the properties or the properties which are required for a particular application, it can be determined from that.

(Refer Slide Time: 01:18)



So, the first property that is important is refractoriness or fusion point. Now, this is the temperature at which a refractory will deform under its own load, remember refractoriness is the temperature at which a refractive material will deform under it is own load, that is important. It just begins to fuse that is the point at which the refractoriness is determined. And this refractoriness or fusion point is commonly expressed in terms of pyrometric equivalent cone. Pyrometric cone equivalent that is out of the refractive material which you want to determine the refractoriness. A cone of certain dimension is prepared it is heated and the point at which it begins to fuse that cone is taken out, it is compared with the standard cones and from there the fusion point of the refractory is determined.

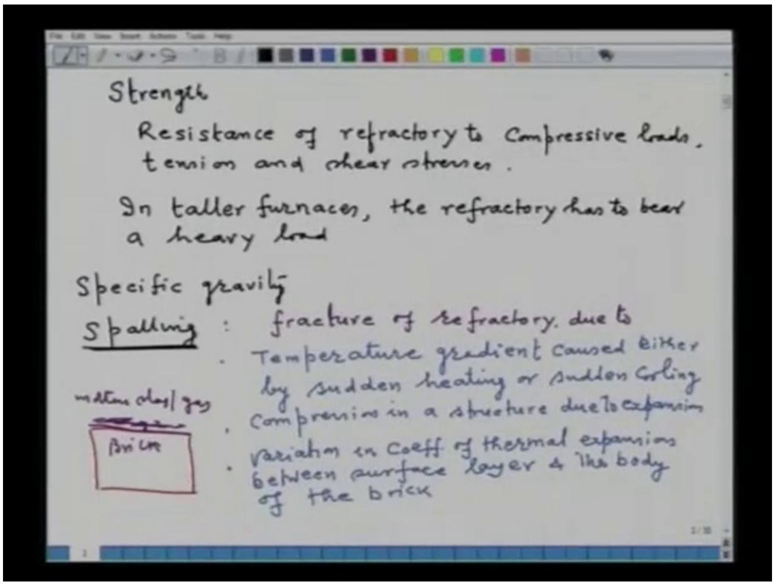
Another important property that is important is the refractoriness under load, in a short form it is called R U L that is here. It is the temperature at which the refractory begins to fuse under a certain specified load. That is a certain amount of load is applied on the refractory and then the refractory material is heated and the point at which it just begins to fuse that is the refractoriness under load.

Now, remember the refractoriness under load or the so called rule is the most important property of a refractory particularly, when the refractive material are subjected under the load. For example, you are constructing a brick wall so, for the construction of the brick wall the refractive material which is at the bottom, it is subjected to the load of the entire column of the refractory. So, it is at that moment though refractoriness is also important, but for this particular application where the refractory is under load. The R U L or refractoriness under load is important because both are temperature, but the refractoriness under load and the temperature corresponding to which is smaller than the refractoriness without load, so that is an important property.

Another important property is the porosity and slag permeability. Porosity. Now, as you know that there are molten phases, there are gaseous phases so, the phases which are in contact with the refractive material. It should not penetrate into the refractory otherwise some chemical reaction will occur and the refractory may collapse. So, for that purpose the porosity of refractory is important because the porosity will determine the chemical attack of phases. For example, molten slag, metal matte and gases. So, it is for this purpose, the porosity in the refractory is important. The refractive material which is in contact with the phases which have returned, it should not be porous. If it is porous, then these liquid will penetrate. And accordingly the properties of the refractory is affected and it is possible some chemically reaction may occur between the component of the refractory and the penetrant. And as a result the refractant may deteriorating and it may fail under an application.

And also porosity is inversely proportional to strength, higher is the porosity, lower will be the strength. But in the same time higher is the porosity, the refractive material will have very a low thermal conductivity. So, it depends on the application of the refractive material. Which you want to put the refractive material in contact with the phases of course, the refractive material should not be porous. But if the refractive material is to be put just to avoid the heat losses, then probably a porous refractory is desirable because porous refractory has a very low thermal conductivity. So that means porosity decreases thermal conductivity (No audio from 0741 to 0747) that means higher is the porosity, the material will have low thermal conductivity. And an account of which the insulating property of the refractory can be impacted by producing the porous refractory.

(Refer Slide Time: 08:06)



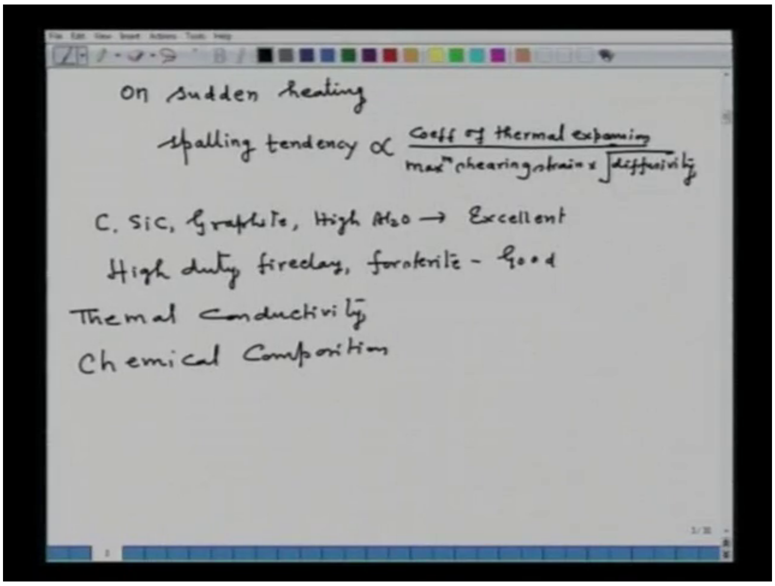
Next important property is the strength. Actually, the refractive material which are chosen for example, to build the side wall or to build the arc or to build the roof, it should have sufficient strength. That means the resistance of refractory to compressive loads, tension and sheer stresses. Otherwise, the refractory will collapse. Now, see for example, in taller furnaces if you have a very tall furnace so, in taller furnaces the refractory has to bear the heavy load. And accordingly one should have a sufficient strength of the refractory is important therefore, strength of the refractory under the combined effect of temperature and load they are important issue. Another important property is the specific gravity. Now, specific gravity should be low to produce more number of bricks per unit weight. If the brick has higher specific gravity it is cost will be more and if the specific gravity is high, the brick will be heavy. Well, heavy or lighter brick it has to be selected as as per the application required.

Next important property is the so called spalling. Now, spalling of the brick is a very important property of a refractive material. Because this correspond to fracture of refractory. Spalling in fact it correspond to fracture of refractory. Now, this fracture of refractory it may occur due to the following reason, due to the following or one of the following reason;. the one reason is that temperature gradient. Now, the temperature gradient may introduce thermal stresses on a on account of which the brick may collapse. Now, this temperature gradient this may be caused either by sudden heating or sudden cooling both cases. That means you are heating the refractory and you are heating at very high rate and the refractive material is not resistance to the temperature gradient then it may fracture.

So, what I wanted to say is that the temperature gradient it induces the so called thermal stresses and any kind of stress that is being induced in the refractory. And if the refractive material is not resistant to those stresses then it may spall, that is what the spalling tendency. One of the reason is, the temperature gradient and this introduces the so called thermal stresses and another reason is the compression in a structure (No audio from 12:51 to 12:57) due to expansion. Say this means that if you have metal wall and if the refractive material is under compression which may because an expansion of the brick then it will also introduce the stresses and that may cause the spalling of the refractive material.

Another reason could be variation in coefficient of thermal expansion between the surface layer and the body of the brick. Now, this can be explained for example, if this is the brick and this brick is exposed to the so called some of the slag, molten slag or molten metal or some gases, then what will happen? This say molten slag or gas and this is the brick and this is the surface of the brick, what will happen this may react with it? A slide deep into the depth an account of the reaction, the material which is on the top or surface of the brick exchange on the interior one and that may cause a difference in coefficient of thermal expansion. And an account of thermal difference in thermal expansion and again the brick may spall. So, what I mean these are the three reasons or any reasons which induces the so called thermal stresses or stresses of some kind. Maybe due to the thermal expansion, may be due to the temperature gradient or compressive stresses, any stress which is introduced in the brick that may be that may give the spalling of the brick.

(Refer Slide Time: 15:40)



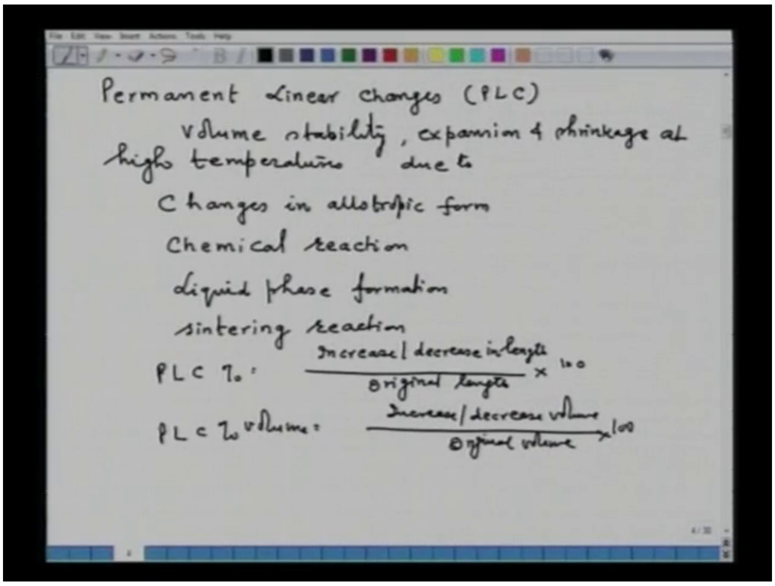
Now, say on sudden heating spalling tendency is proportional to coefficient of thermal expansion (No audio from 16:07 to 16:13) coefficient of thermal expansion divide by maximum sheering strength into diffusivity. Finally, spalling is a very important property and in this connections say Carbon, Silicon carbite, Graphite, high Al 2 3 they have excellent spalling tendency. They are excellent against resistance to spall. Whereas, the brick like high duty fireclay, fosterite, fosterite is a angio based refractory that have spalling tendency so called good. So that is what the spalling mean.

Now, another important property is the thermal conductivity. Now, thermal conductivity of the brick it determines the heat losses. It is an important property from energy conservation point of view, but if you want to have low thermal conductivity brick, then the brick has to be porous. So, porosity and conductivity it is they are opposite. Higher porosity low thermal conductivity, low porosity high thermal conductivity. So, if you want to have a low thermal conductivity brick that means the porosity has to be very high. Accordingly strength and all these values will affect it.

So, here the selection of the refractory is very important so, these refractories which are of insulating in nature. They cannot be used wherever phases are in contact with that they can be only used for heat losses purposes, one of the main objectives of bricks having low thermal conductivity. Of course, chemical composition is important in the sense as you recall now the bricks or the refractive material they comprise of SIO 2, Al 2 O 3, MgO 2 and so on. And the same oxides are there also in the slag. So, if you have an acid slag you cannot use basic refractory like MgO or CO based refractory.

Or if you have a basic slag then you cannot use acid refractory like SIO 2 or fireclay because then the reaction will occur and that is what the chemical composition of the refractory. Means that means the chemical composition of the refractory it must match with the so called the chemical composition of the refractory must match with the composition of the phases such that no chemical reaction occurs that is a important thing.

(Refer Slide Time: 19:49)

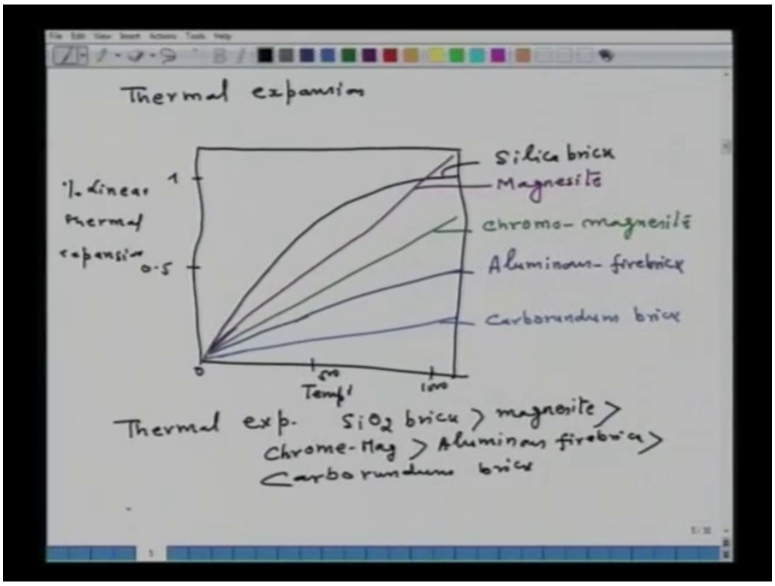


Next important property is the permanent linear changes which is also called P L C. Now, these permanent linear changes this may occur on heating. If they are reversible or irreversible changes accordingly this is a important property. Now, the permanent linear changes they determine the so called volume stability, expansion and shrinkage at high temperatures. Now, these permanent changes that can occur if say changes in allotropic form. In many situation the allotropic transformation they are complete by the volume change then there is a problem of volume stability of the material. Also these may occur due to chemical reaction, this may occur also due to liquid phase formation. Or it may occur due to sintering reaction. (No audio from 21:44 to 21:50) Now, sometimes this permanent linear changes has advantages also.

So, while designing the brick structure you will leave a space between the two brick. If you know very well what is the permanent linear change on heating because if you leave the space according to which linear expansion then on heating the brick will expand and it will rather seal the joint. So that is also an important so, these property is very important from several issues. One of the important I have just now said so that is the important thing for permanent linear changes. Now, this permanent linear change in percent it can be determined by determining increase or decrease in length and if you divide by original length into hundred that will be in percent linear change.

Now, a knowledge of this is very important or also P L C on percent volume basis. That will be equal to increase or decrease in volume divide by original volume into 100 that is also expressed in terms of percentage, so that is about the permanent linear change.

(Refer Slide Time: 23:35)

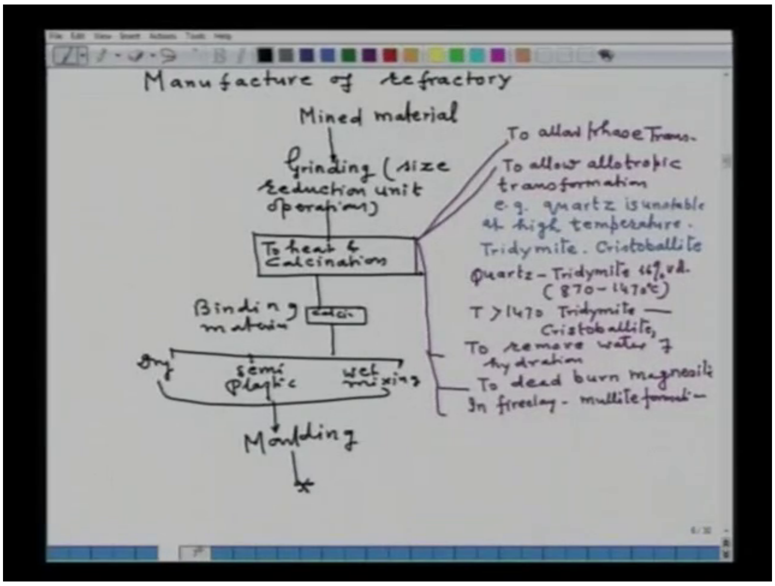


Another important property is the so called thermal expansion. Now, certain bricks they expand when they are heated. So, in this in this connection for example, if we see qualitative representation say if I plot here here if I take temperature 0 it should be symmetric not intended to read the values from here just to show the trend of the variation of thermal expansion. So, here this is percentage linear thermal expansion and plotted against temperature so you know silica brick, this is the silica brick it has very high thermal expansion. Very low thermal expansion brick they are the carborundum brick. This is a carborundum brick they have very low thermal expansion and carborundum is brick followed by the magnesite brick. This is for the magnesite brick. Then the chrome magnesite is somewhere here, chrome magnesite and these are the aluminous firebrick.

So to conclude the figure, what we can say from here that the thermal expansion of silica brick is greater than magnesite is greater than chrome magnesite I just put chrome-mag is greater than aluminous firebrick and is better than carborundum brick. So that is how this thermal expansion of the brick that is an important thing for this. And these are the properties of the refractories now remember for one particular application could be roasting or sintering or say steel making or iron making, you require a several combination of properties in order to find a particular application. So, it may not be possible that you may, that you get one refractory which satisfy all the requirements, no it is not possible. Therefore, depending upon the requirement a suitable selection of the refractory has to be made.

For example, if you are selecting refractory where phases are in contact, then it is the porosity is very important because the refractoriness is very important the penetrability is also very important. If you are looking for a refractory for to just minimize the heat losses then porosity should be very high also for insulating refractory you are using. So, what I mean? For a particular application it is the combination of properties that is important what is suitable for that particular application which you are looking for.

(Refer Slide Time: 27:53)



Now, after knowing this let us see now how the refractories are manufactured, say manufacture of refractories. (No audio from 27:55 to 28:01) Now, remember as I have said earlier, refractive material they are not naturally occurring material. What I mean to say with that, that it is not that you dig a material from the mine and begin to use as a refractive material for that application, no sir. Refractive material are not naturally occurring material however, they are manufactured from the naturally occurring material. So that is an important thing when they are manufactured from the naturally occurring material, then we have to take care certain material properties during manufacture stage. So, I will just draw in the form of a flow sheet so that you can understand the manufacture of refractory.

Now, for this we have the mined material, this mined material that is what is coming from the mine. It is subjected to grinding or so called size reduction operation, size reduction unit operations. It may consist of crushing, grinding and whatever required maybe. So, you have got the ground material, it is screened and rewinding. That stage the required material is taken and then it is subjected to heat and calcinations. That is subjected to high temperature or it is so called pretreatment at high temperature now, why it is done? It is done to allow phase transformation.

As I have said earlier, they are the materials and in the materials of phase transformation and in the phase transformation is accompanied by the volume change. And if you put the material without taking care of the phase transformation during the phase production stage, then at the application the phase transformation will occur and the material may not be suitable for that application. So, one of the objective of heating and calcination or the so called pretreatment is to allow phase transformation to occur during the production stage itself, so that the refractive material which is being produced is stable at the temperature of application.

Another objective of this heating and calcination is to allow allotropic transformation Now, remember these allotropic transformation are also accompanied by the volume change. And there are certain materials which have a very high volume change and in those allotropic transformation are not taken care during the production stage, then those transformation will occur at that temperature. So, of the particular importance for example, if we consider quartz for example, quartz which is used for silica brick, this is unstable at high temperature.

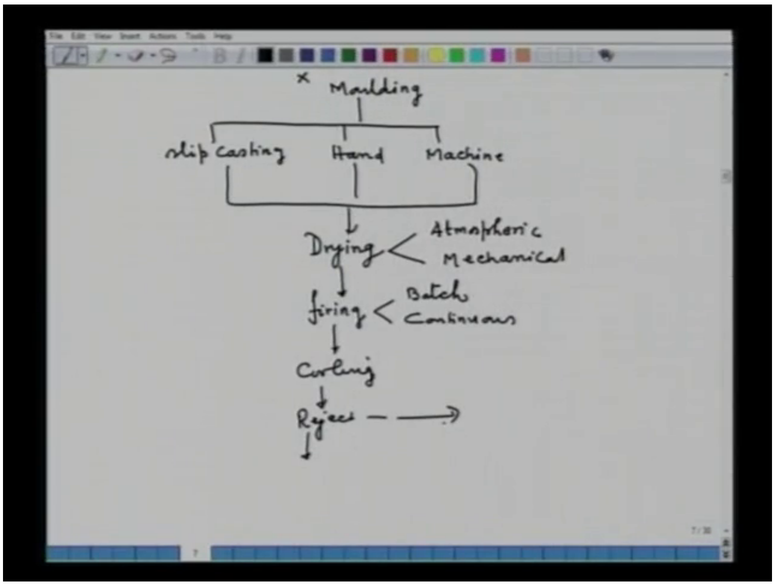
And it forms the two phases; one is the tridymite and another is cristobalite. So, these two phases are formed when quartz is subjected to high temperature. Now, quartz to tridymite say quartz to tridymite this particular transformation is accompanied by 16 percent volume change. That means there is increase in volume and this transformation occurs between the temperature range 870 to 1470 degree Celsius, what does it mean? The quartz says on heating it transforms to tridymite and there is a increase in the volume by 16 percent. So that particular allotropic transformation must be taken care.

Now, at temperature greater than 1470, the tridymite it transforms to cristobalite and there is a contraction of volume. Here, the contraction of volume occurs so what is important in this stage of heat and calcination that is to see the phase transformation, allotropic transformation it must have been taken place prior to putting the material into the service. That is one of the very important case of heating and calcinations. Another important process or another important objective is say to remove water of hydration. Now, for alumina refractive oxide is used and fireclay is also used and fireclay has water of hydration. That water of hydration means that the water is in chemical contact or in chemical bonding with the main material. So, this water has to be removed and removal requires very high temperature in order to remove water of hydration.

In case of magnesite the naturally occurring material is MgCO 3 or dolomite CaCO 3 so, those materials are to be dead burned in order to remove carbon dioxide. So, another objective is to dead burn magnesite. So, as to remove carbon dioxide which could be dolomite or which could be MgCO 3 or it could be calcium carbonate where CO 2 has to be removed. Another thing in fireclay the mullite formation is important. So, in the pretreatment stage air is to be done so that the mullite also forms because mullite is a phase which is resistant to slag as well it is imparts high temperature to the refractive property.

After heating and calcination now, we have got a material which is processed further now here this material is taken and here these binding materials are added into this calcin material and a this is subjected to give a shape. Which is for example, it could be dry or semi plastic or wet mixing, any of the mixing method can be done. And all these the products from all these is subjected to so called molding. Molding means to give a particular shape and this I am taking to next page so, you have molding.

(Refer Slide Time: 37:50)

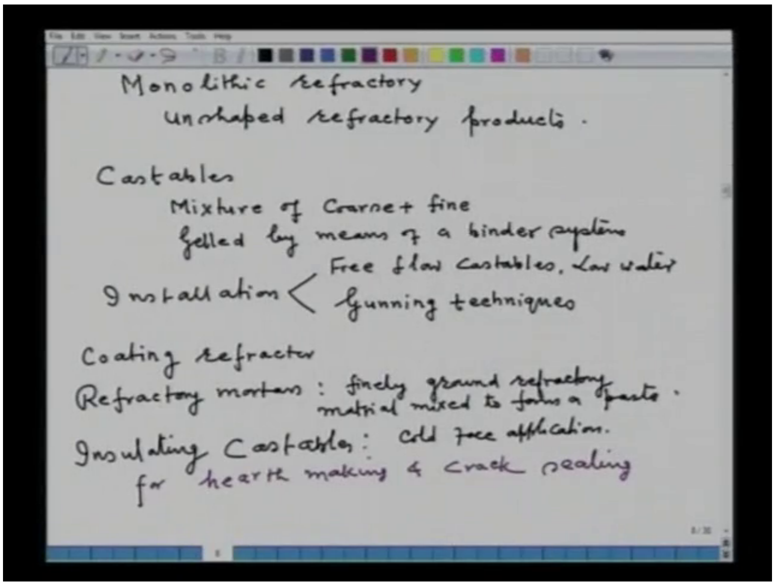


Now, here there are different methods of molding that means you have to preparing a shape, different shape of the refractory. So, this molding you can have shape casting, hand molding or machine molding. Well, machine molding is better for dimensional accuracy or whatever advantage maybe. So, the material from all these the shaped one which you have got, it is further subjected to drying because it is a green shape that you have got it has to be dried. And for drying one can just do atmospheric drying or one can go for mechanical dryers.

Depending upon the applications or depending upon the size and so on these are the important, then it is further subjected to firing. Now, here the time temperature schedule of firing is very important, you have to go for firing between 1250 to 1600 degree Celsius depending upon the material under production and the firing one can have wedge or one can have continuous firing. Then subjected to cooling, then whatever rejections they are being recycled. And the rejections they are recycled for the process and extract will go to the customer. So, that is how these refractories are being manufactured for the so called particular application.

Now, these refractories are for the shape of refractories that means that you are giving a shape. Now, here for example, you are having the silica refractory then quartz is used. If dolomite refractory dolomite is used, magnesite refractory MgCO 3 is the raw material and so on like that there are different raw material. If there is alumina refractory, boxite or siliminite or canite they are the raw material both canite and siliminite are heated till they transformed to the so called mullite phase. The mullite is three Al 2 O 3 to S I O 2 it is a very good phase or very good material and it has a fusion point of the order of 1800 degree Celsius. What the mean these are the say these material this is the method of the production of the shaped refractory.

(Refer Slide Time: 40:46)



Now, in recent years the concept of monolithic refractory has also been advanced and used. Monolithic refractory. Now, these monolithic refractory it is name generally given to unshaped refractory products. Now, these are materials they are in powder form, they are installed in some form of suspension which ultimately hardens to form a solid mass. So, they are not like bricks, they are the unshaped material and they are installed in place in the form of suspension which subsequently hardens and gives you the shape whichever, whatever is desired.

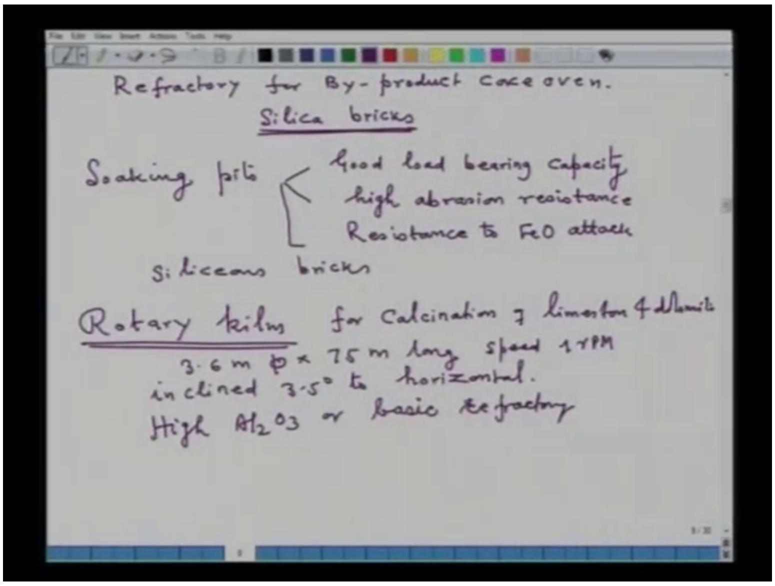
Now, there are types they are available as castables that is these castables they are in fact mixture of coarse and fine refractive grains, coarse plus fine refractive grain. And a combination has to be there because the fines will be there to decrease the porosity as compared to the coarser grains. So, a optimum mix of the different sizes is prepared then this mix is gelled, this scale by means of a binder system and a green mass is prepared the common binder which is used is alumina content and then they are installed. Now, these castables are say the installations, the installation of monolithic refractive are the castables are because they are in a powdery form, some binder is added so that it can provide these things.

Now, you have to install it. So, certain methods of installation are there installation either we have free flow castables normally, they have low water content or some gunning techniques are used. That means this mix is taken in a gun and it is rather with the ginning technique it is placed at the place of location and then it is hardened. You may also castables then you have coating refractory, so called coating refractory. These coating refractory are used to coat the working lining then you have refractory mortars. They are finally, ground refractory materials mixed to form a paste.

Now these refractory mortars they are used for laying and bonding shaped bricks that means you have the two bricks. You have to bond them, these mortars are placed in between them, the two bricks or for brick laying purposes, this refractory mortars are used. Then another we have insulating castables. (No audio from 45:25 to 45:33) These insulating castable are used for cold phase application and these insulating castable they are manufactured from light weight aggregates like vermiculite, bubble alumina and clay. They have low density and low thermal conductivity.

Now, these monolithic lining they are used for hearth making and crack sealing. Now, say these are the two types of refractory which are being used, one is the shaped one and the manufactory that I have said and another they are the unshaped one. Now, unshaped refractory they have become very common because they can be installed in situ at a place and a shape of the whatever shape that is required that can be obtained at the location. All brick laying and all these things are not required when you go for the monolithic refractory lining.

(Refer Slide Time: 47:06)



Now, I thought I will give you some certain examples say for example, refractory for by-product coke oven. Now, these modern coke ovens are very tall around 7 meters by height, higher coking temperature, higher coke chamber volumes so, silica bricks are normally used. Soaking pits: soaking pits are furnaces which are used to heat the material below the melting point. And these soaking pits or the refractory materials it should have good load bearing capabilities, high abrasion resistance, and resistance to FeO attacks because during heating some iron, may oxidize and accordingly FeO may form. So, these soaking pits bricks should have these three properties besides temperature is of course, important.

Now, the top of the pit wall and soaking pit must be highly resistance to spalling that is also highly important. So, here in the soaking pit silicious bricks are used besides superdity brick, semi silica bricks and castables and ceramic fiber lining are also suitable for cover lining. So, you see from here that one type refractory does not suit the requirement of a particular process. Now, similarly, if you see Rotary kiln (No audio from 49:29 to 49:37) now the Rotary kiln are used for the calcination of lime stone in cement industry. Rotary kilns are also used for calcination of hydrous alumina that is produced from the bathe process. Now, the whole objective of calcination is to remove the water which is in chemical contact with the material. So, in order to do that very high temperature of firing is required. Now, particularly if you look the Rotary kiln which is used for cement production, the rotary kiln for calcination say for calcination of limestone and dolomite typically in cement industries.

So, these rotary kilns they are 3.6 meters diameter, 75 meters long and they rotate at a speed of 1 revolution per minute. And inclined 3.5 degree to horizontal (No audio from 51:04 to 51:10) so it is a huge structure. And also the material enter from one end and is discharged another end. There are different zones in the rotary kiln and all the zones are not subjected to the same severity of temperature. The material enters at 25 degree Celsius from the entering side and discharges at around 1200 or 1250 degree Celsius. So, in between from the entry to exit, there are also different zones I will not going to take details. But for the account what I want to say is that you may brick line with a very high quality material and unnecessary increase of cost of the refractive material which may not be required. So, it is in this perspective depending on the various zones.

One can select the property of the refractory for example; the high alumina or basic refractories are used. Here also temperature varies from one eighty to as I have said 1600 degree Celsius. So, depending on the zone one can also go for a zoned concept of lining of refractory or one may line the same refractory, but lining with same refractory may be very costly. So, what I wish to say summarize this lecture is by telling is that one has to select among the available right kind of refractory for right application in order to save the cost. The objective ultimately is to have the high lining life, low maintenance at the economic rate.