Hydration, Porosity and Strength of Cementitious Materials
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Lecture - 21 & 22
Mineral Admixtures

Hi good morning to one and all. I am K. V. Harish, Assistant Professor Department of Civil Engineering, IIT Kanpur. You are watching MOOC lecture course on Hydration, Porosity Strength of Cementitious Material.

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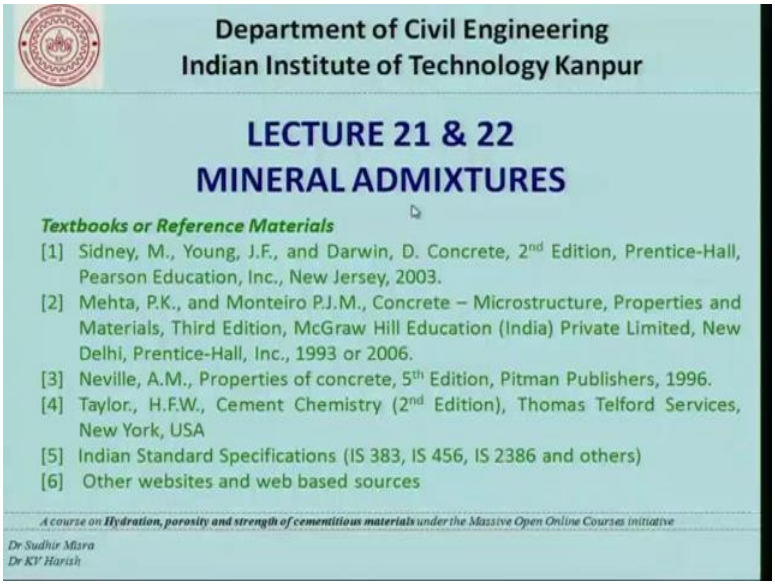

Today we will see lecture 21 and 22. And just brief information about what we have seen in the previous lectures. For example, in lectures to 11 to 20 which is Portland cement based paste systems. We have seen the different hydration reactions hydration compounds; we have also seen how the compounds are developed with a curing period. We have also seen the morphology and microstructure of both hydrator and un-hydrated compounds and then we went to the volume changes that happen (Refer Time: 01:10) concrete some create crystal pressure some does not create crystal pressure and how the compounds increasing volume.

And all these things we have seen through models developed by power and other people and in addition to that we have also seen that the hydrated cement paste contains pores, pores solution unhydrated cement compounds and several others and again in pores we

have seen the different type of pores like capillary pores gel pores entrain air voids entrapped air voids and several others their size properties and several other micro structural features.

In addition to that the importants of specific micro structural parameters like gel to space ratio degree of hydration and the relation of the micro structural parameters with porosity strength permeability etcetera. And also the relationship between porosity and permeability of concrete through under by understanding the mercury intrusion porosity cemetery curves and several others; and we have also seen how gel to space ratio is related the prob specific properties like strength of Portland cement based paste systems.

In addition, in these in these lectures we have also seen that Portland cement based paste systems or design based on 3 criteria application based factors performance based factors and economy based factors. And remember that all these factors are based on the design for the existing situations and existing condition.

So, what we have not seen is these Portland cement based system have not considered the future, which means whether the concrete will last long and cause any problems for the future generations and all those things. So, understand that we need to know about sustainability and other factors. In addition, last 2 lectures 19 and 20 we have seen the importance of heat of hydration, and that was and lectures were are given by professor Sudhir Mishra, were you would have seen that the heat of hydration is developed at the paste level because of the exothermic reactions of several compounds in Portland cement based paste systems.

And when it comes to concrete again the heat may be a very important factor or may not be a important factor depending upon the volume of concrete that is produced. And if the thickness and volume thickness of the members' concrete members and the volume or bigger than in that case you have heat of hydration being a critical parameter because it causes thermal expansions and concrete and since concrete and Portland cement based paste systems or a week intension they may result in thermal cracks. So, all these things we have already seen in the previous lectures previous set of lectures from lecture 11 to 20.

Now, in lectures 21 to 30 we will see about mineral admixtures. As I already mentioned in the previous 10 lectures we have seen designing concrete only for the existing needs.

So, under mineral admixtures what we will see in lecture 21 and 22 is the importance of sustainability, what is sustainability? What is sustainable development? What is sustainable design? How to understand sustainability? What are the environmental issues related to cement and concrete production? And what are the strategies to account for sustainability. So, that the concrete that we design today takes care of the needs of the future generation tomorrow. So, all these things will be covered in lecture 21 and 22. And then we will step on to the introduction to mineral admixtures and several others.

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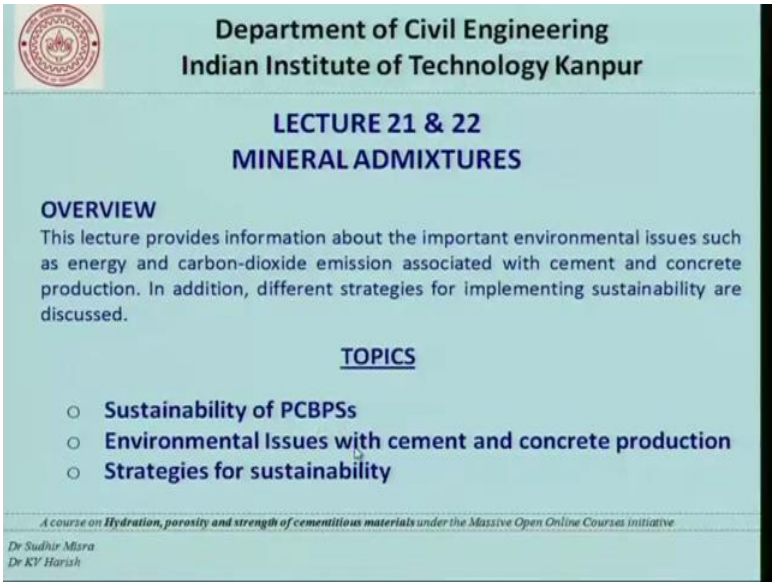

So, the text books or reference materials they are shown in this. And the topics that will be covered or sustainability of Portland cement based paste system. Environmental issues with the cement and concrete production. Remember that the environmental issues with cement primary primarily include the high amount energy that is required during the production process. It may also include the liberation of carbon dioxide substantial amount of carbon dioxide is liberated to the atmosphere. And it also includes continues depletion of natural resources for the production of the cement.

So, there are several environmental issues and we will deal these things in this lecture. And remember that when it comes to concrete not entire issue sustainability issues of cement is cement goes to concrete, primarily because the portion of cement that is used in concrete is substantially lower. So, we will also see if there are any environmental issues with concrete production also or not. And then we will move to how we can

incorporate important strategies to make sure that the concrete that we design is sustainable that is which will take care of the future needs.

So, the overview of the course is as follows this lecture provides information about the important environmental issues such as energy and carbon dioxide emission associate with cement and concrete production. In addition, different strategies for implementing sustainability or discussed.

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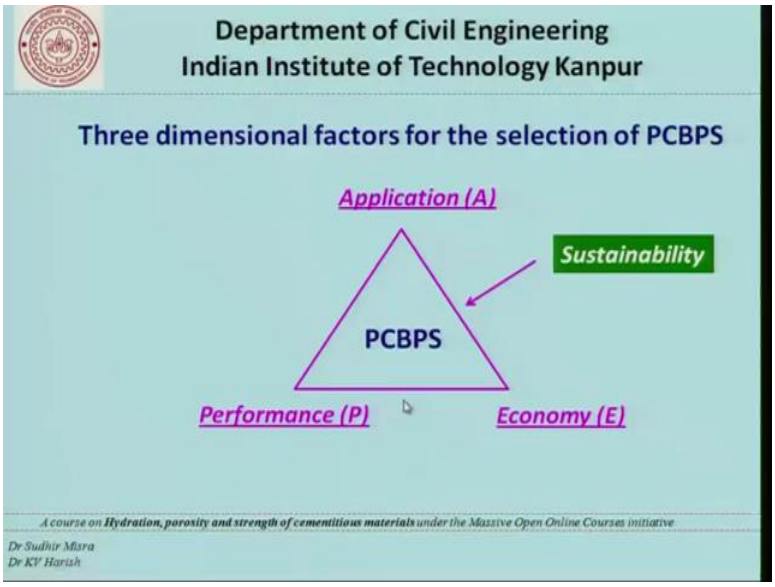

Now, in the lectures which were delivered in the past some between lectures 11 to lecture 20 you would have seen that there are 3 dimensional factors when it comes to selection of Portland cement based paste systems, application performance and economy. And in this lecture the application factors are denoted by the letter A performance factors by P and the economy factors by E. So, make note of it because whenever we use it in the lecture it will be easier to follow.

And we have also seen in the previous lectures that sustainability acts as provides fourth dimension to the selection of Portland cement based paste systems. And in this topic we are giving significant importants to sustainability.

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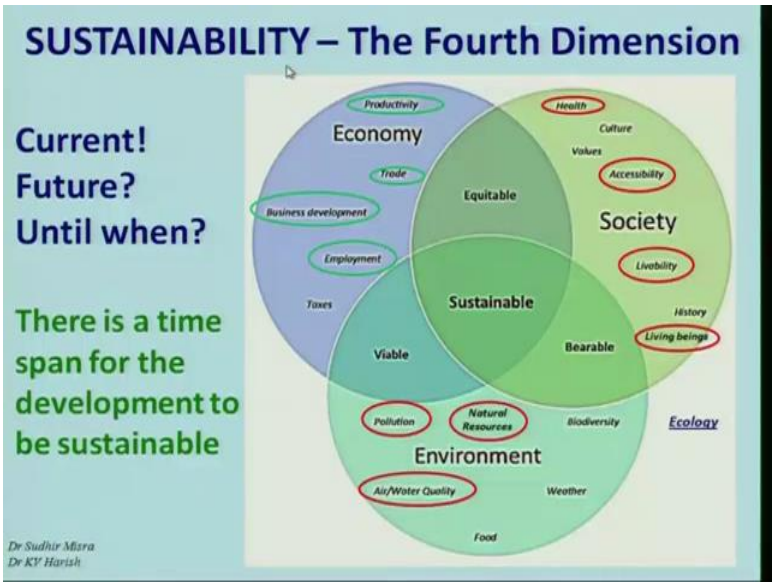

Now, as I already mentioned sustainability provides a fourth dimension to Portland cement based paste systems. And what you see in this figure is the 3 important principles or components or face heads of sustainability which is generally discussed in many conferences and many other places. So, the main 3 factors include economy society or social society related factors and the third one is environment and you see that you also have overlap of economy and society which comes under the factor of equitable and economy and environment together comes under the heading as viability, and society and environment some overlapping features called as bearable and sustainability is something that is actually overlapping of all these 3 factors or 6 factors together; economy equitable society bearable environment viable, so all everything inside accounts for sustainability.

Now, the purpose of showing this is primarily to make the audience focussed about what are the important economic factors environmental factors and a societal factor that governs sustainability remember that sustainability is a very broad terminology. And economy is one important aspect of sustainability.

Remember that economy is also used in the 3 dimensional factors that we have described here, but there is a significant difference between this economy and this economy. So, the economy here primarily in case the restrictor to the application the where when

whenever we use Portland cement based paste systems, we make sure that the selection of materials or composites is based on these 3 factors.

So, the economy here is very confined to the application. Whereas when we discussed economy in sustainability it includes a lot more parameters such as productivity whether that are trade related parameters whether you have business development in that employment taxes and several others. So, economy here is described at a much larger scale. And the other 2 that is in that are there our society and environment where environment place a little more important role. And in the relationship between society and environment primarily living beings and natural resources they are both connected together by a terminology called ecology. And many times the ecological balance is required, but in our case ecology is not at present important what is a largely important will be discussed at a later stage.

So, sustainability includes 3 these 3 main phases. And when whenever we design anything for sustainability we should make sure that it satisfies the current needs and whatever we design should also be for the future. So, what we have seen in the previous 3 factors is that the application performance and economy. They usually do not consider the future. So, these consider primarily the current requirements and not the future requirement the moment you incorporate sustainability it takes into account the future requirements also.

So, the question arises are we designing for the future also. And the other question is that until what time or until what period we are designed. So, let us first get into the definitions broader definitions of sustainability to get a little more overview of what is sustainability all about.

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Now, under sustainability you have several simple terminologies. So, one is sustainability the other one is sustainable development and sustainable design basically, it is good to know the difference between these 3 and primarily the sustainable development and sustainable design comes from the word sustainability. So, let us see each one of the definitions for clarity.

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So, sustainability is the property of the system to remain diverse and productive indefinitely. This is a very general definition of sustainability and if you carefully see the

words used like for example, system diverse productive and indefinitely all these are very broad definitions. And with regard to concrete you can visualize system to be something like a building or the bridge structure or a something like that. So, in general we can assume the system to be something like a structure.

In the case of diverse that primarily indicates the multi functionality. So, and likewise productive indicates that whatever you built like here in this case we are assuming or visualizing it a visualizing the system as a structure, in that case the structure should yield something to the society. So, productive is seen from that angle. And indefinitely means substantial period of time continuously during from the start of it is construction until it is service period. So, indefinitely means the time is infinite.

So, the basic definition of sustainability is that it is defined as a property of the system to remain diverse and productive indefinably. So, we have to think about the future sustainably, that is what basically sustainability indicates. Coming on to the definition of sustainable development it is defined as the development that meets the needs of the present without compromising the abilities of future generations to meet their own needs.

Remember here there are 2 important things that are present. One is meeting the needs of the present. So, the present conditions are also important, but at the same time when you design or when you develop any product you have to make sure that it should not compromise the abilities of the future generation to meet their own needs which means, for example, if you are if you are building a structure and for the present condition assume that there are certain loads that the structure have to with stand and for a certain period of time usually the age of the structure is assume to be somewhere between 50 to 75 years

So, we have to make sure that we built the structure for a substantially longer period of time. So, that the future generation do not have any problems with a structure that is built today. So 2 components that are that are present here or the present scenario and the future scenario; if you do not consider sustainability or disregard sustainability, then it goes back to the 3 factors that we discussed only application performance and economy all satisfying only the current needs, and we are not looking into the future. So, sustainability is largely a factor to include the present as well as the future.

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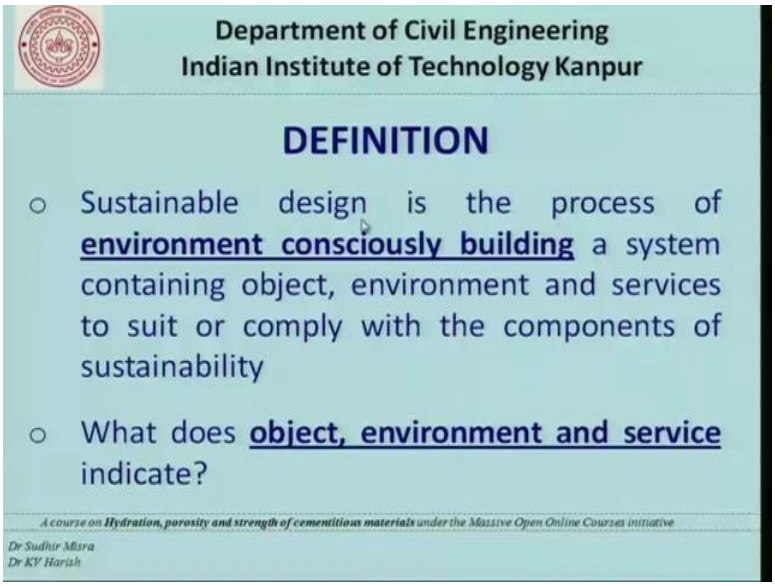

So, that is about the sustainable development and let us moves to the third definition which is sustainable design. Sustainable design is the process of environment consciously building a system containing object environment and services to suit or comply with the components of sustainability. This is a very important definition in the sense that whenever we use sustainable design, the emphasis is largely on the environment consciousness about the building. So, in this case we are considering system to be more like a building and what is mentioned by sustainable design is that we need to care for the environment and make sure that we do it in such a way does not become difficult for the future generations to carry on.

So, in this definition what you find that you find 3 parameters one is object the other one is environment the other one is services. So, how do you understand this in in terms of structure, or something primarily we want system to be a structure because for civil engineering largely we use a structure we try to construct buildings all these come under the broad terminology of structure. So, we consider the system to primarily involve some building or structure.

So, with regard to a system like building object directly reference to the building that we are constructing and environment reference to the environment outside the building and primarily the environment will try to affect the building either positively or negatively depending upon the environmental conditions. So, if you actually get back to some

lectures which were discussed the under next design, you will see that environmental conditions come under durability that plays a very important role.

And the third one is service. So, service may include the loads that are acting on the structures, it can also include the at a later stage the durability and all other factors which comes under the broad terminology of serviceability. And also the deflections the buildings or subjected to and many others.

So, object environment and service are critical terminology is used to explain sustainable design. So, sustainable design by terminology focuses more on the environment consciousness and if you again get back to the broad dimensions under a sustainability what sustainable design refers to is that compare to these 2 factors the environmental factors become very important.

So, this is something about sustainability sustainable development and sustainable design. And remember that in all these thing the word sustainability comes together just to indicate that all 3 should have all these 3 phases.

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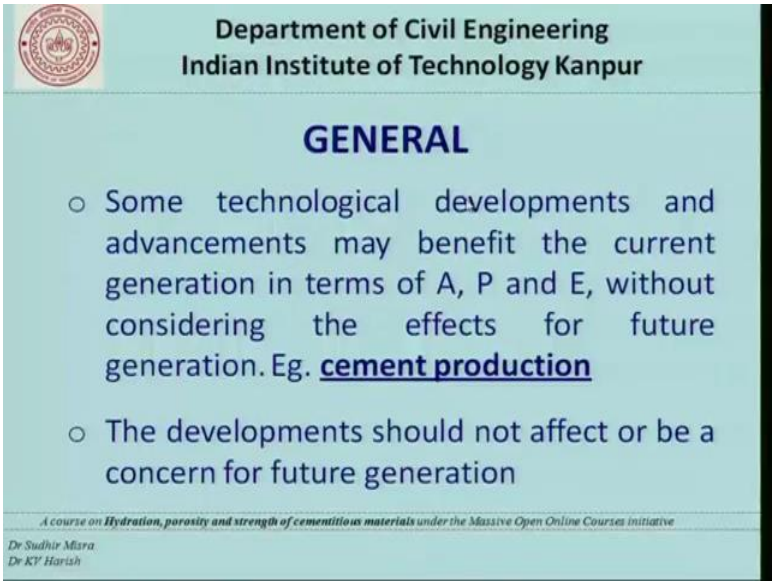

Now, let us take an example of say cement production because we have excessively see in this topic in the past especially in lectures say 4 to 10 we have seen cement production process, what types of compounds are formed during the production and several others. And we have also seen that lot of heat is involved during the cement production process

because the temperatures are higher and lot other information. So, let us see cement production from a sustainability stand points. So, that it will be much more clear what are the limitations of cement production and others from a environmental stand point.

Some technological developments and advancements may benefit the current generations in terms of application performance and economy without considering the effects for future generation. So, it is a very important line. Some technological developments and advancement finally, we are see in cement production as a technological advancements and this has huge benefit is for the current generation in the sense that concrete is very popular products from cement production and extensive use of concrete largely increases their production of cement, and hence it largely takes care of the current needs in terms of application performance and economy.

The developments should not affect or be a concern for future generation. So, if we have to ask our self a question whether cement production takes care of the future generation does it causes any problems in the future, then we need to again get back to some of the sustainability factors. So, this is little bit information about sustainability and in the next broad topic we are seeing a environmental issues with cement production.

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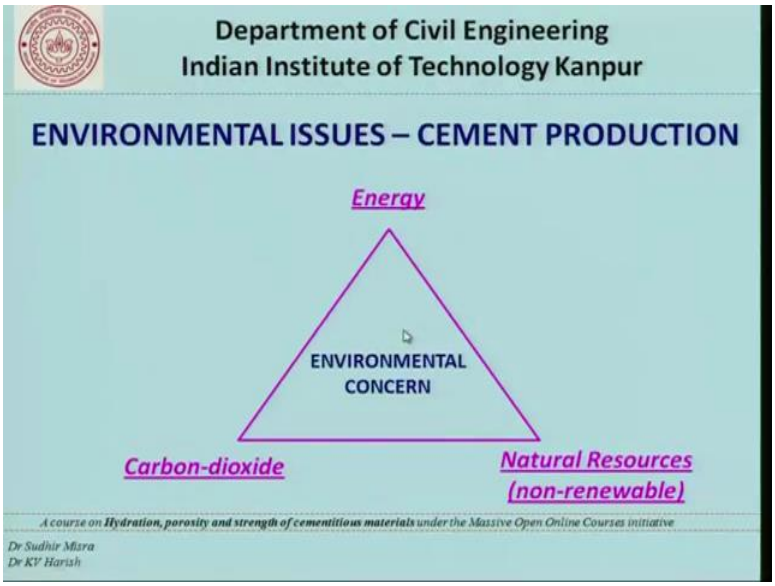

Now, there are 3 key issues with the cement production one is energy that is used in cement production the other one is the amount of carbon dioxide that is evolved or emitted during the heating process in the (Refer Time: 21:48) use in the cement

production and you also have the third important environmental issue is that constantly we are using cement constantly, we are using cement because constantly we are using concrete and the requirements of concrete have extensively increased over the years.

And hence when you use more and more cement you tend to use more and more natural resources. Remember that natural resources are used in the cement production in 2 ways. One is that in the row materials we use limestone clay and other sources all are natural resources and all are non-renewable in nature. Those row materials are directly used. In addition to that since very high temperatures are used in the production process, we also need fuels primarily the fossil fuels again non-renewable resources for the burning process.

So, typically what we use is coal for burning or oil or petroleum for heating the natural resources to a very high temperature. So, all the natural resources both used for heating as well as the row materials they are non-renewable in nature, and in the past say 30 40 years before when cement was introduced in our India 30 40 50 years before, we find that of this came as a new technology and surpassed many of the existing building materials. So, at that time sustainability was not a key issue primarily because we have substantial amount of natural resources especially the row materials and other non-renewable sources.

But during the last 20 to 30 years you concrete has been extensively used because of the high development in our country and we see that the natural resources have being depleted over time.

So, the environmental issues that we have with cement production currently includes use of very high energy, use of liberation of very high amounts of carbon dioxide and constant use of natural resources.

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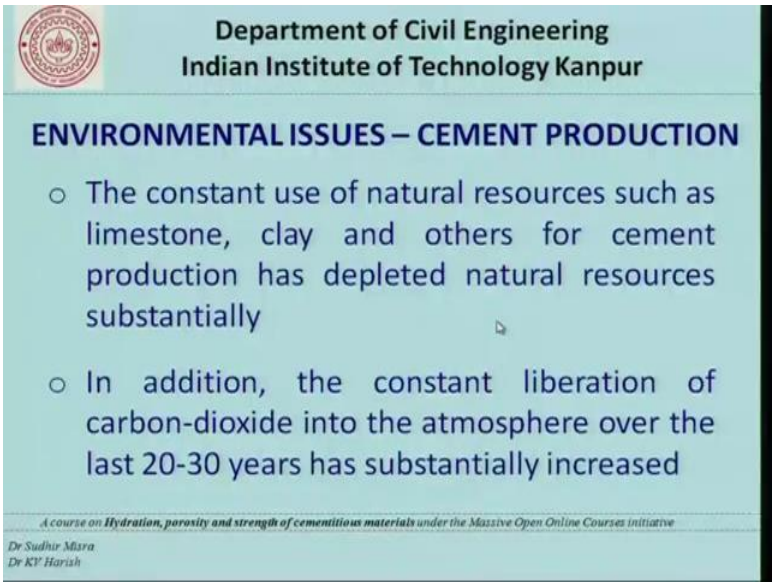

Now, little more information constant use of natural resources such as limestone clay and others for cement production has depleted natural resources substantially. In in addition the constant liberation of carbon dioxide in to the atmosphere over the last 20 to 30 years has substantially increased. This is a very important factor, but if you get back to the previous one. So, what is the problem with the liberation of carbon dioxide? Primarily because the carbon dioxide is a greenhouse gas; so basically it increases the percentage of greenhouse gas and reduces the amount of ozone that has present on the atmosphere there by causing environmental concerns. I just repeat the second point in addition the constant liberation of carbon dioxide in to the atmosphere over the last 20 to 30 years has substantially increased.

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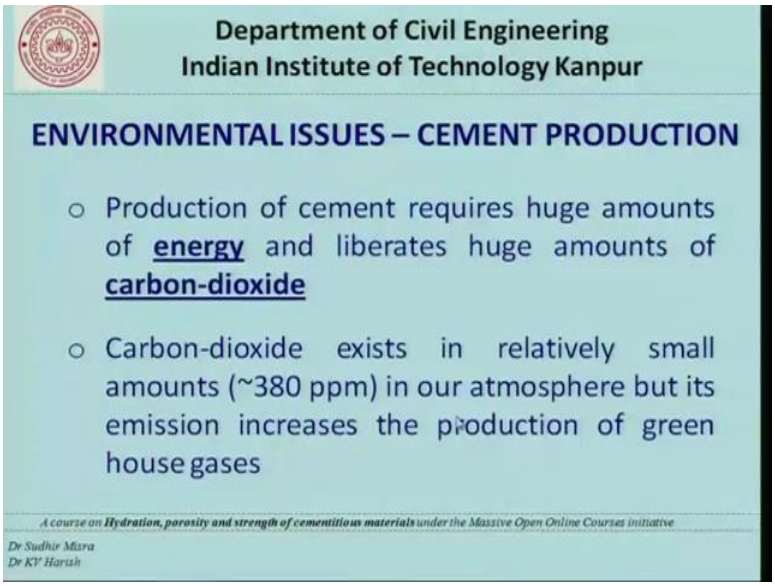

Now, the production of cement requires huge amounts of energy as already discussed and liberates huge amounts of carbon dioxide. Carbon dioxide exists in relatively small amounts approximately 380 ppm this is a very important value 380 ppm approximately. Primarily because one should know what is the general amount of carbon dioxide that is in the present at atmosphere, but it is emission increases the production of greenhouse gases.

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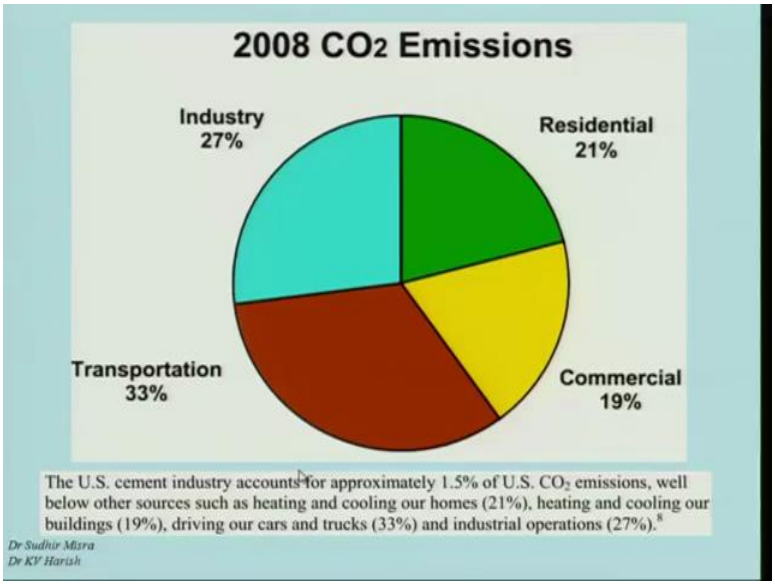

If we generally consider the carbon dioxide emission what is happening in the country and estimate is provided remember that this is not an updated one this is only a 2008 estimate the values of these or might have a changed, but this will give some approximate idea about which industry is producing more carbon emissions compare to which industry.

So, this is basically US industry data and what we find is that the carbon emission basically is from 4 different sources, one is from the industry, and other one is from the resident other one is from commercial and the final one is from transportation. And largely we see that the transportation and industry they concede the maximum carbon dioxide emission. And remember here industry refers to not just cement industry, it may include many other industries; so approximately to 27 percentage of carbon dioxide or emitter from the industry.

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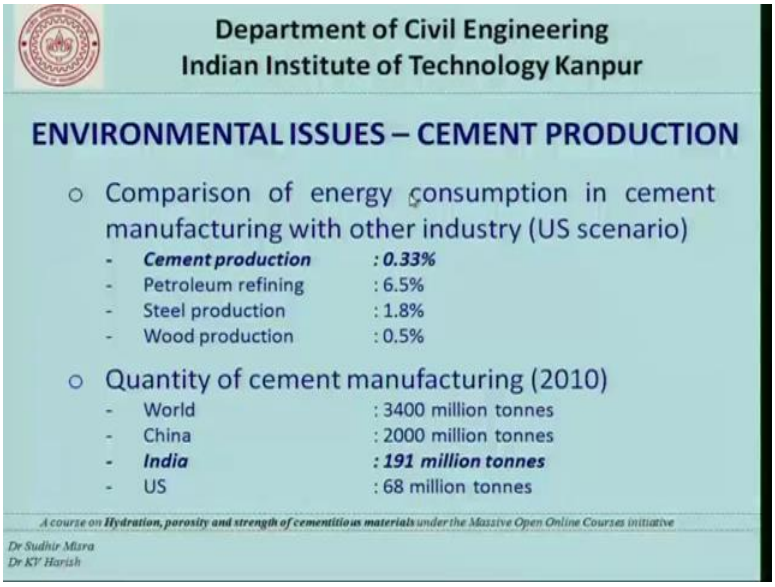

Now, if you want to go little more into the details some are provided here. Comparison of energy consumption in cement manufacturing with other industry is provided. So, if you take cement production approximately it constitutes 0.33 percentage petroleum refining 6.5 percentage steel production 1.8 percentage wood production 0.5 percentages this this is the approximate idea about the energy consumption that is required for each and every for 4 different industries.

Now, if you see the quantity of the cement manufacturing and remember that this is a 2010 data it is not latest data, but still it is sufficient for this course just to get some approximate comparative idea about what is the situation globally. So, in case of quantity of cement in the world, we are typically using 3400 million tonnes of which china manufactures 2000 million tonnes and India manufactures approximately 191 million tonnes even US this is a developed country manufactures only 68 million tonnes. So, you can see the relative cement manufacturing quantities.

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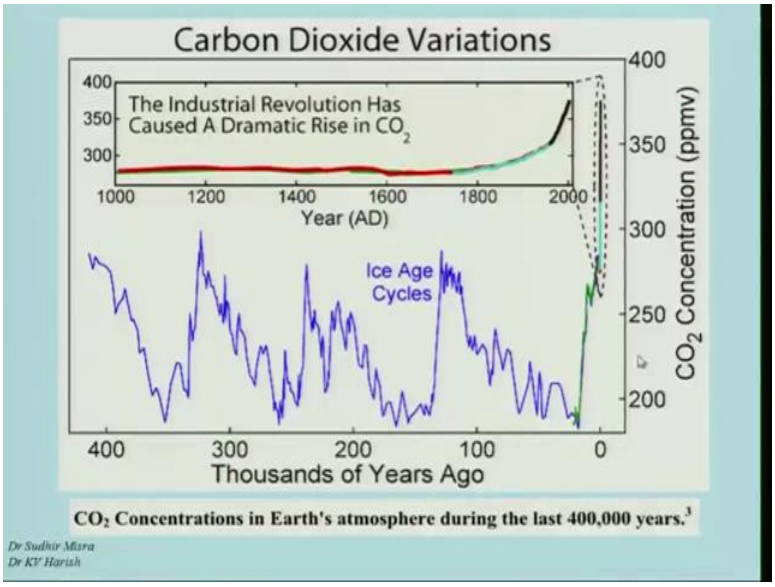

And another figure is shown just to give you some idea about a how the carbon dioxide in the atmosphere changed from olden days and primarily the change the change because of the industrial revolution.

So, what is shown in this figure is basically 2 graphs, one is in which we have thousands of years ago taken in the x axis and carbon dioxide concentration is taken in the y axis. And there is one more graph that is shown inside this graph, which again gives the year approximately in AD. And also in the y axis same carbon dioxide variation or concentration is taken remember that this is in ppm v parts per million terms of volume.

Now, let us first see the smaller graph and then understand the bigger graph in the smaller graph what you find is that the AD ranges from say 1000 AD to about 2000 AD. And what you find is that constantly in the olden days it from 1000 to say about 1800 the approximate amount of carbon dioxide concentration in the atmosphere is somewhere

between 150 to 180. There has been constantly maintained the moment the industrial revolution came in to picture, what you what we see is that there is an exponential increase in the carbon dioxide quantity. And you find the at about say 2000 you find that the value is approximately 380m which is discussed just while before here 380 ppm.

So, likewise you also refer in the ice age the relative concentrations are much lower and nowadays it is much higher, it ranges from somewhere between say 280 to as high as 380.

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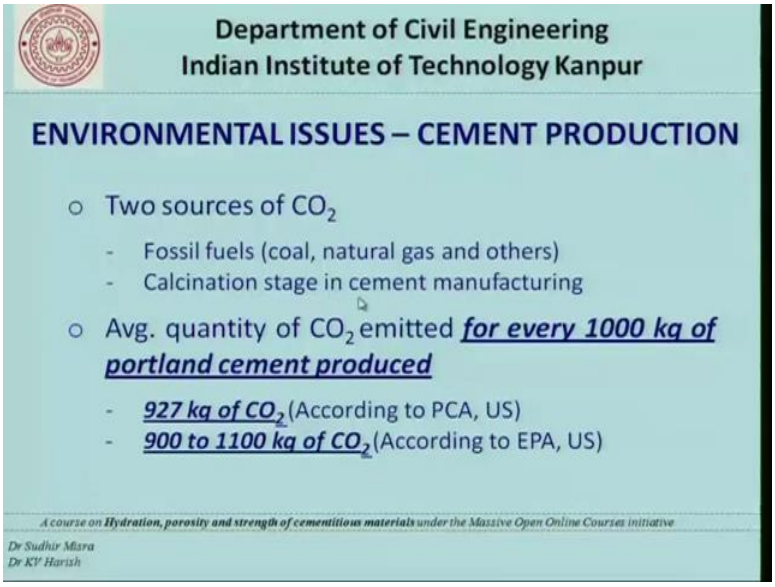

Precisely when it comes to cement production what we find is that there are 2 sources of carbon dioxide, one is as already mention from fossil fuels we use coal natural gas and others and also in the calcination stage we use and carbon dioxide is also emitted in the calcination stage of cement manufacturing process.

If you want to know the approximate quantity of carbon dioxide that is emitted during cement production some values are given remember that these values are critically important even from course stand point. So, the average quantity of carbon dioxide emitted for every thousand kg of Portland cement produced. They are just making it constant to 1000 kgs. So, the average quantity of carbon dioxide emitted for every thousand kg of Portland cement produced is approximately 927 kg of carbon dioxide. And 900 to 1100 kg of carbon dioxide these are from 2 different sources.

So, on an average what we can generally assume is that of thousand kg of Portland cement produced thousand kg of carbon dioxide is liberated. Just to approximate all these factors. We can assume that thousand kg of Portland cement produces thousand kg of carbon dioxide which creates lot of problems to the environment.

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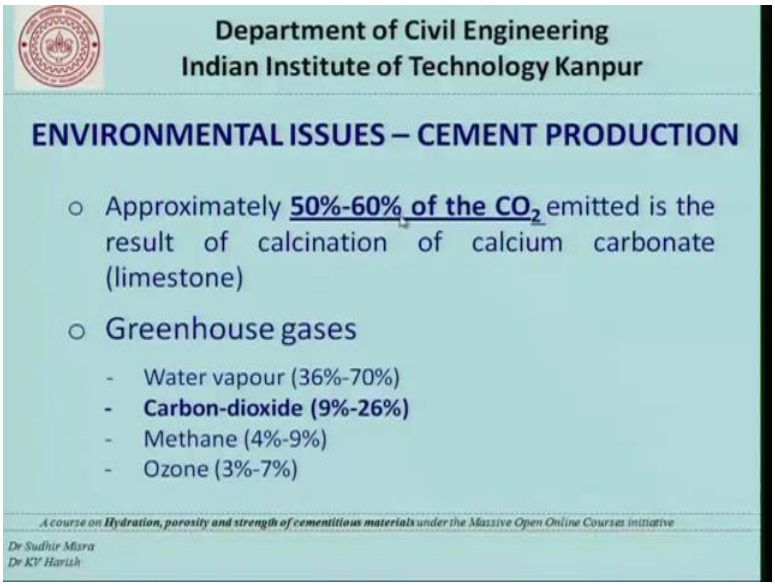

Now, approximately it is estimated that 50 percentage to 60 percentage of the carbon dioxide produced is the result of calcination of calcium carbonate that is limestone. So, in the heating process basically we 50 percentage to 60 percentage of carbon dioxide is liberated, and for heating we use fuels and the remaining carbon dioxide is primarily because of burning of those fuels.

And some more information about greenhouse gas compositions are also given, this includes water vapour carbon dioxide methane and ozone. So, you generally find that the water vapour is usually the largest 36 percentage to 70 percentage carbon dioxide is much lower 9 percentage to 26 percentage methane is 4 percentage to 9 percentage and ozone has typically 3 percentage to 7 percentage. So, the composition of green house gasses also important from the context of carbon dioxide.

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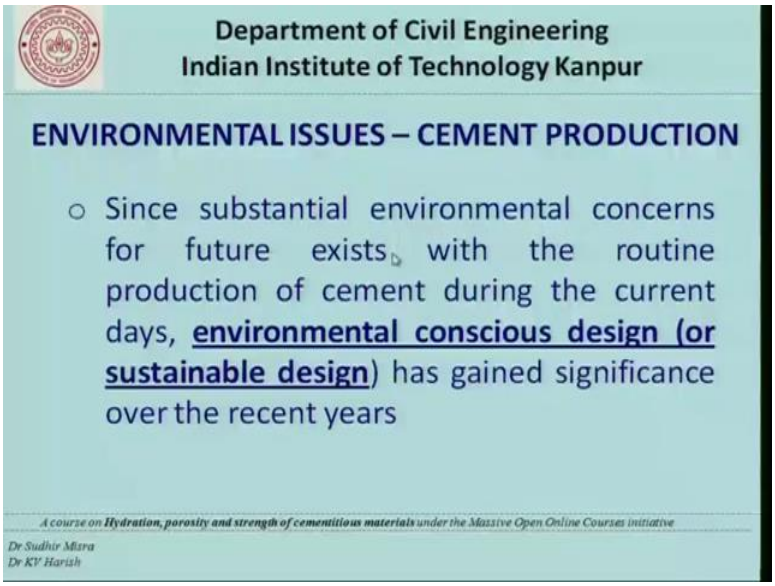

Since, a substantial environmental concern for future exists with the routine production of cement during the current days. Remember that in the past sustainable issues were not really present for the simple reason, that cement came as a new product to the industry and the substantial natural resources were already present 30 40 years before whereas, the same situation does not prevail now. So, environmental conscious design in other words called as sustainable design has gained significance over the recent years.

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Now, when we talk about technological development the technological developments or advancements could be either at the plant level or at the standard testing and certification level or at the application level or at other levels. So, of these each level is equally important, but many times people try to address the sustainability related issues at the application level. So, when we go to subsequence slides more important is information is providing about this.

Developments in technology are again diverse in nature in construction field. So, depending upon the type of construction depending upon the application the developments in technology vary substantially, but generally it can be grouped under 4 different heads plant standard testing and certification application and others stages.

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At the application level the use of appropriate strategies can help in providing desired performance and economy. The moment we say appropriate strategies you can recall that we have in the past we have already gone through mixed design strategies at the macro level, and also in a lectures 11 to 20 we have gone through the micro level parameters. So, at the application level the use of appropriate strategy can help in providing desired performance and economy.

In Portland cement based application remember that always multiple strategies exist for any simple problem. For example, again in the mixed design strategies we have seen that if you if the workability is low then you have 5 or 7 different strategies to achieve that

workability. Likewise, if you want higher strength again you have 3 4 or 5 different strategies again if you have durability you can use all those strategies.

So, for one issue you have multiple strategies and what is important for a engineer is first to identify what are the strategies that are available, and use multiple strategies or one strategies based on the requirement, but when you use those strategies use should make sure that you considered sustainability as also a factor. And this will help in addressing issues for the future. Remember sustainability is largely for the future, but without compromising today's needs. We are trying to make sure that the current requirements are satisfied and the future requirements are not compromised.

Now, this is about the cement production. Now we go to the next level where we will see energy and carbon dioxide required for concrete.

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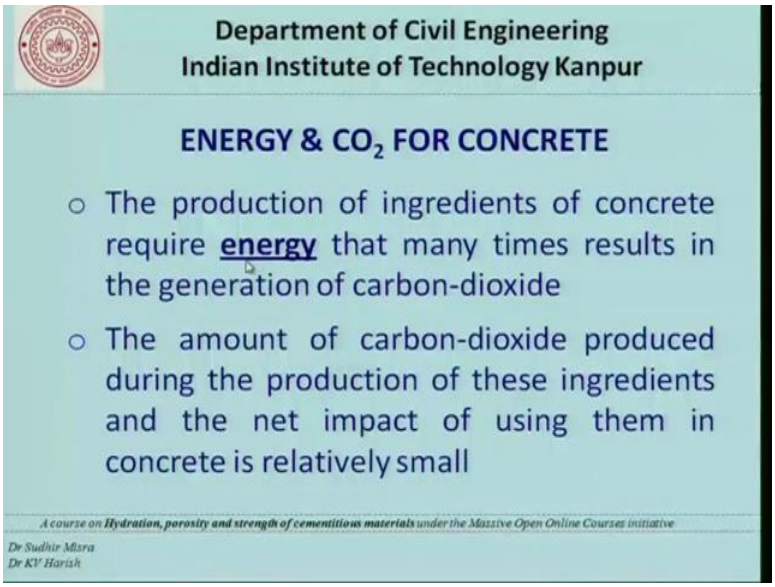

Now, the production of ingredients of concrete requires energy that many times results in the generation of carbon dioxide. So, when we see concrete again concrete does not contain just cement data also contains water is also containing fine aggregate it also contains course aggregate. So, the moment we say the production of concrete it includes cement as one part, and you also have production of fine aggregates and course aggregates are the other end.

So, although we see that the energy and carbon dioxide emissions or much higher or cement production can, it be the same for concrete also. Because recall that cement is only a small portion by volume in concrete. So, it is important for us to know; what is the energy that is required to produce concrete so that we can understand whether the environmental factors for cement should also be considered for concrete or not.

The amount of carbon dioxide produced during the production of these ingredients and the net impact of using them in concrete is relatively small. This is a very important line just to indicate that even though huge amount of carbon dioxide is liberated into the atmosphere because of the cement production process, if you take unit volume of concrete in which cement place only a minor role, the amount of carbon dioxide if you calculate for volume of concrete the net impact is usually low or relatively small.

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Water sand stone or gravel and other constitute approximately 88 to 90 percentage of concrete mixture. So, other than Portland cement typically you have 88 to 90 percentage other ingredients, and this a evaluated by weight. The process involved with other ingredients that can emit or consume carbon dioxide or mining sand and gravel crashing stone combining materials in concrete plant transporting concrete to construction site.

So, what is here is that some of the process that are involve when you are dealing with the production of other materials such as water sand stone gravel and as a whole as a composite concrete, there is still some amount of carbon dioxide that is emitted. See if

you take mining sand gravel or crushing stone or typically in this process or there is some or the other equipments like drilling or excavation or other things are used and the because of that fuels are used. And the carbon dioxide is also if you consume fuels for these applications carbon dioxide is also a part of it. So, carbon dioxide is a emitted because of all these process.

So, we able have to know whether the amount of carbon dioxide because of these processes is high or low.

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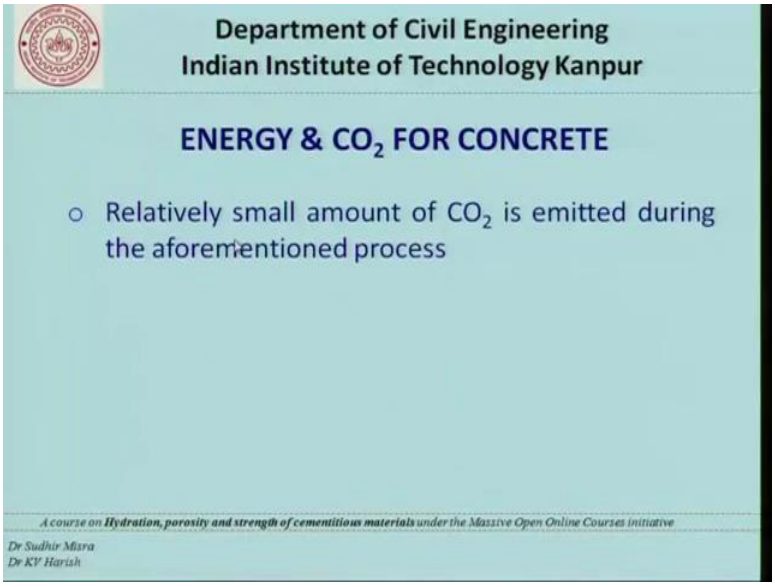

Now, relatively small amount of carbon dioxide is emitted during the aforementioned process. So, all these process even though involves use of fuels and other things finally, the carbon dioxide that is used for all these process is comparatively low when you understand it with regard to cement production.

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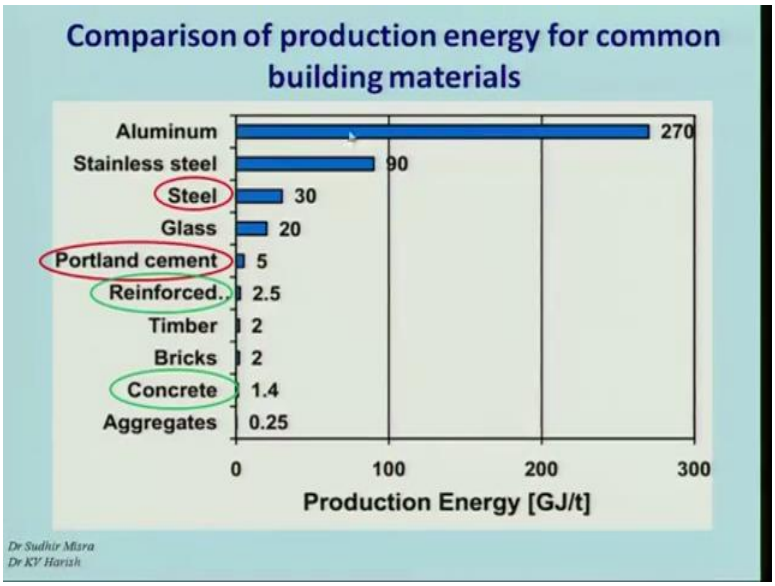

Now, this will give approximately. So, now, we have seen in the previous slides about carbon dioxide. And now we go to the energy production energy. In this figure what is shown is in the x axis you have production energy varying from 0 to 300 and energy is expressed and giga joules per ton. And here in the y axis we are taking different civil engineering materials, and comparing what is the production energy for each one of them. So, right from aluminium stainless steel glass Portland cement reinforced concrete timber bricks concrete and aggregates or provided and all these are some way of the other use for some or other civil engineering application. So, if you start from say aggregates you see that the production energy is very low in terms. So, a for aggregates is only 0.25.

Now, if you take concrete it will little more surprising that it is not substantially higher it does not size 1.4 giga joules per ton. And if you take bricks it is lightly higher than concrete and remember that this is one brick a while in the part if you actually seen the load bearing walls were very popular, and a say about 40 50 years before and that time for cemented concrete was not really invented. So, people preferred bricks structure and prefer bricks to take forge and the main can notering walls were constructed based on that. Once the cement and concrete were invented they basically surpassed the load bearing structure.

And finally, whatever structures that we have these days' frame structure. Where the walls basically do not take load only the columns beam slabs and foundations take load. So, when you compare bricks and concrete you see that the energy required for concrete is relatively low compare to bricks. And likewise if you take timber and bricks approximately have the same energy, and if you go to reinforced concrete it is slightly higher than conventional concrete primly because you use steel reinforcement. And if you carefully look steel has a higher production energy primarily because in the production of steel basically the (Refer Time: 42:23) melted to a very high temperature. So, lot of energy is involved

So, some element of that actually comes to reinforce concrete. That is why you find that a production energy for reinforce concrete is higher than conventional a Portland cement concrete. Now if you nearly take Portland cement you will see that it is substantially higher compare to all other products discussed below. And it is approximately 5 giga joules per ton. And if you take glass steel stainless steel and aluminium they are a extremely higher, and you need lot of energy to produce it. And remember that in our conventional applications glass steel stainless steel and aluminium is not very often use. Of course, steel is use very often, but that is usually used in the form of reinforced concrete structure or reinforced concrete members. So, this figure approximately gives an idea about a fact that the energy that is use in concrete is relatively lower compare to Portland cement or steel or other things.

Now, coming to the next important topic do we have any strategies for sustainability and what are the important strategies. So, we have seen in the recent slides the important of sustainability. And we have also seen that we should design the moment we say sustainability we should look into the future and make sure that nothing is compromised for the future. So, do we have any strategies for sustainability, which can take a current day needs as well as satisfy to some extend the future needs.

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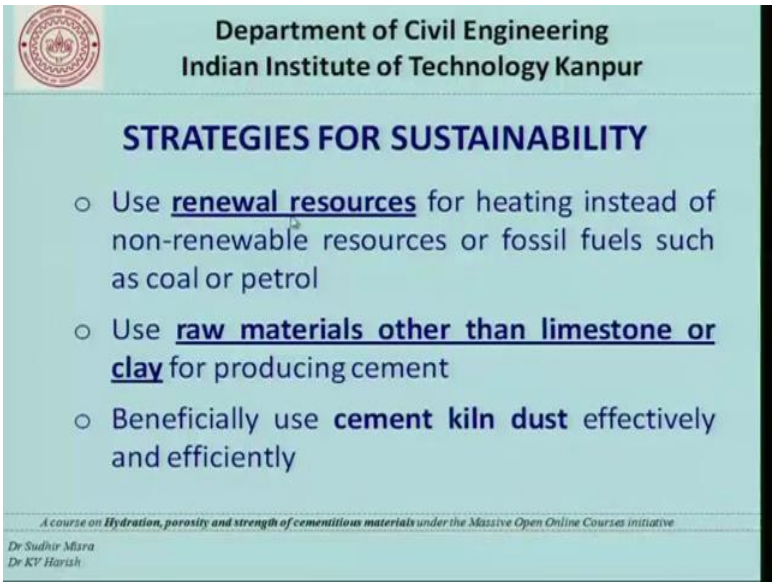

So, some of the strategies are discussed. One is the use of renewable resources for heating instead of non-renewable resources or fossil fuels such as coal or petrol. So, for the as we have already seen for the burning process most of the times we use fossil fuel such as coal or petrol. So, is it possible to use renewable resources? So, that is one strategy to make sure that the carbon dioxide liberation is much lower, and thereby it can help in a not polluting the environment.

Now, the second one is use raw materials other than limestone or clay, because limestone and clay are the principle raw materials used and since we have been using it during the last 30 40 years. Do we have any other source of limestone or source of calcium or alumina in this world? So, we can use those sources. So, that these sources can be preserved the third strategy is beneficially use cement kiln dust effectively and efficiently. Since cement production has been going on for the last 5 decades we also find that whatever fossil fuels are burned we also find the dust from the fossil fuels. And these are also in huge amounts and can those be effectively used in for a use for construction purpose. So, that is another strategy that will help to design for sustainability.

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The fourth one is lower the cement usage, very important as much as possible which will reduce the use of natural resources. So, lower the cement usage is a very important part of sustainability. And it gains significant importance primarily from the fact that many waste materials or industrial waste materials can be used in concrete; however, in this case we are seeing a 2 different levels, one is the plant level weather you can lower the cement usage and also at the application level. So, in the plant level the materials such as limestone can be interring ground.

Remember limestone is a use as a raw material in the production process and basically what we do us limestone a is basically crush into fine powders and it is mixed with other ingredients and finally, the in the kiln it under goes heating process. So, that is one stage that we have already seen here what we are seeing is that this limestone itself can be use at a later stage along with a clinker instead of making it in to fine powders and heating it we are making it to fine powders after we make the clinker. So, that will actually reduce the carbon dioxide a mission as well as help in protection of the environment.

So, at the plant level a what is also thought about is whether the limestone can be added along with clinker at a later stage and inter ground and then made into a cement more like a sustainable type of cement and at the application level what is also thought is that weather limestone can be added as a blend material. Remember this point has nothing to

do with a industrial waste. So, industrial waste is a separate strategy that is discussed at a later stage.

And the next strategy is continuous innovation and product improvement that leads to reduced environmental impact. This is generally said in a very broader sense and the next one is prescriptive to performance specifications for concrete.

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This is a very important point and at this level you should know what is prescriptive and performance specification. In simple sense prescriptive we have seen when we discussed in Portland cement and other things are that, the chemical compositions or specify. For example, if you see the oxide compositions like a for example, specific oxides like magnesium oxide free calcium oxide and other things or basically restricted in cement. Not only that even if you take the simple chemical composition that is an oxide composition of cement you have calcium oxide silicone oxide aluminium oxide iron oxide and several other oxides, which have to be in a specific range for to qualify as a proper ordinary Portland cement. And we have discussed it is extensively in under the head physical and chemical requirements. So, prescriptive means basically prescribing physical and chemical requirements and saying that if it meets then it can be used if it does not meet it can be used.

In the case of performance as the prescription of the physical and chemical requirements are lower, and what is more concentrated is the performance characteristic such as

workability strength durability for that particular application; that means, that a particular material need not be prescriptive in the sense that it does not have to satisfy any physical or chemical requirement, as long as it satisfies the performance. The purpose of providing prescriptive and performance has it is own advantages, but currently or during the previous year's prescriptive specification have been followed and people preferred to move to performance based specifications primarily from the stand point of sustainability.

And why do you want move primarily because industry would preferred to use different materials that are available. It could be industrial waste it could be several other materials, and they could come up with a new specification which need not be a prescriptive type, but it could be a performance type in the sense that it may not satisfy the physical and chemical requirements of conventional mixtures, but it will have the performance that is required for that particular application.

So, performance specifications provide more flexibility for concrete producers to optimize mixtures for intended performance that will reduce environmental impact or carbon dioxide emissions. Now the final thing is use of industrial by products or waste materials which are abundantly available as a supplement for cement, this is an extremely important part primarily, because when the we will see in the next lectures that mineral admixture largely has fly ash slag and silica fume and all these are industrial by products and they extremely help in improving the properties of Portland cement based paste system.

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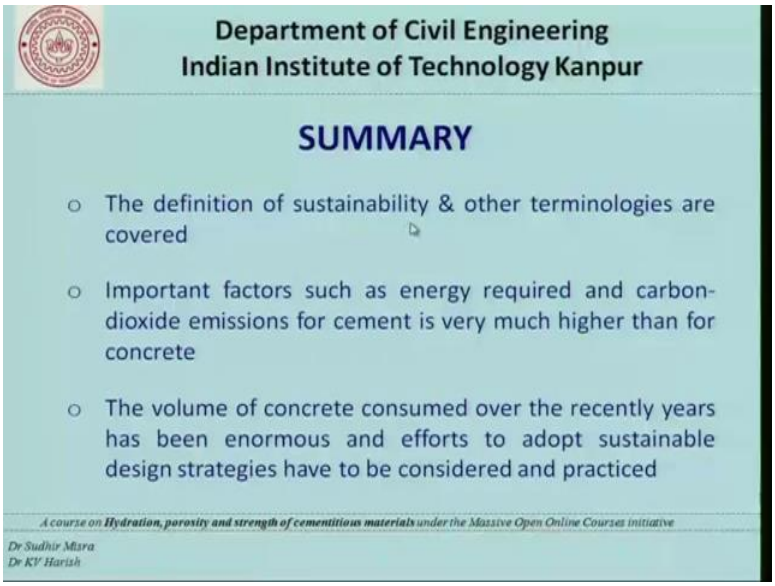

So, use of for industrial by products an always leads to sustainability, and in summary what we have seen is the definitions of sustainability and other terminologies. We have seen important factors such as energy required and carbon dioxide emission for cement. These are generally higher compare to that of concrete. The volume of concrete consumed over the recent years has become enormous and efforts to adopt sustainable design strategies which we have discussed just now have to be considered and practiced.

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The use of industrial by products or waste material is one important strategy that will help in providing an effective solution for sustainability.

So, in the next few lectures we will see about industrial by products or waste such as fly ash slag and silica fume, how it is chemical composition other and others can affect the properties of Portland cement based paste system from the angle of sustainability as well as from the angel of a performance including workability strength durability and economy with is this lecture is getting over.

Thank you.