Steel Making
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Module No.# 01
Lecture No. # 35
Solidification and Casting Processes

In this lecture which is the last lecture, I will be telling you about final finishing operations.From the ore - iron ore - we have cast steel through several successive methods, casting with it rolling and we got the product for a particular application.Now, the final finishing operations are needed, in order to generate or create a property, that is required for a particular application.

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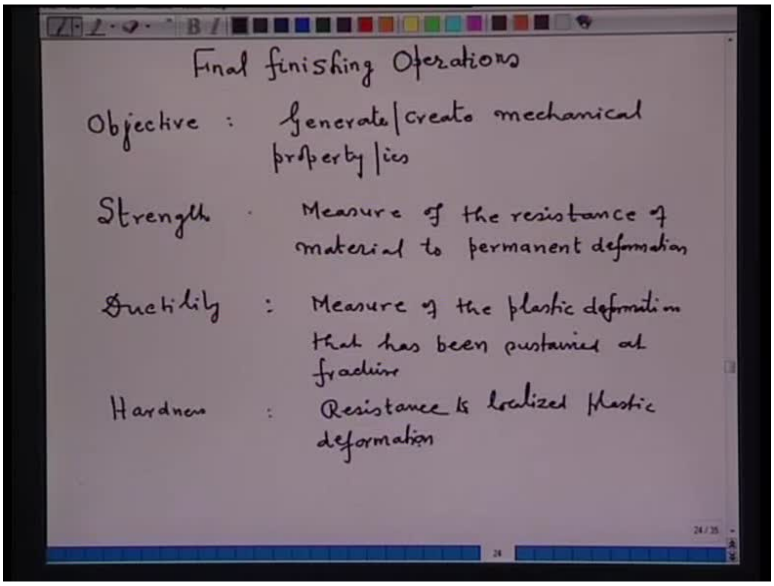

So, in fact the objective, in fact, the objective of final finishing operations is to generateor create mechanical property or propertiesis required for a particular application. Now, what mechanical properties are we looking?For example,strength - this is the measure of the resistance of material to permanent deformation; that is, we are looking a product, which should have high strength or should have high ductility.

What is ductility?The ductility is a measure of the plastic deformation, that has been sustained till fracture, that hasbeen sustained at fracture, that is what the property you are looking for. Hardness - resistance to localized plastic deformation. These are some of the properties, mechanical properties I have listed, some of the corrosion properties, some of theall, whatever properties you require for your application. In order to get those properties, final finishing operations are being done. The requirementsare in all; there are requirements for low tech industry;for example,construction industry to as I as for the high tech industry, that is the aircraft application.

So, accordingly, the finishing operations are to be carried out, in order to generate or create that property.Now, the question that comes to my mind, how I can generate or create a required property in material. I want a soft material, what should I do? I want a hard material, what should I do? I want ductile material, I want a corrosion resistive material,what should I do? Because the product which I am getting from the rolling mill, it does not meet my requirement, so what should I do? Or ratherin what way I should think or what should be my direction of thinking, in order to create or generate that property?Now, mind you, I am using the term create or generate; that means, there must be something, which can lead to creation or generation of a particular property.

How to get that?Easiest way to get that, you open a material and see what the material consist of; with that I mean, I put before you four steel samples and I say one is hard, one is soft, one is brittle, another is ductile.Can you tell me from the external appearance, which is hard, which is soft, which is ductile, which is brittle.Unless I tell you, this is this,this is this, this is this, this is, you cannot tell just by seeing the material.Then, how to create or how to generate or how to know to induce a particular property?As I have said just before youto open the material, what does it mean?You have to open the material, you have to polish it, you have to etch it and you have to see under the microscope.

All of you have gone through a course on phase diagram at phase transformation. You can appreciate if I open the material, I polish it and I see under the microscope, that could be optical or could be scanning or whatever the microscope may be.Then, you will be confronted with a different type of structures in the material.And if you analyze those structures, you will get a clue; the property which you are looking for is generated through the phases, that are present in the material.

So, what I want to say from here, that a property or an individual property that is required for a particular application, it depends upon the phases which the material consist of. In short, if you see the micro structure, you will find it consist of grains, it consist of grain boundaries, there could be small size grains and larger grain boundary, that could be larger size grains,but smaller than boundary, there could be different phases, the distribution of phases could be different, the morphology of the phases could be different.So, if I combine all the inside story of the material that is after seeing under the microscope, and if I apply to the iron carbon system, then I get the following picture.

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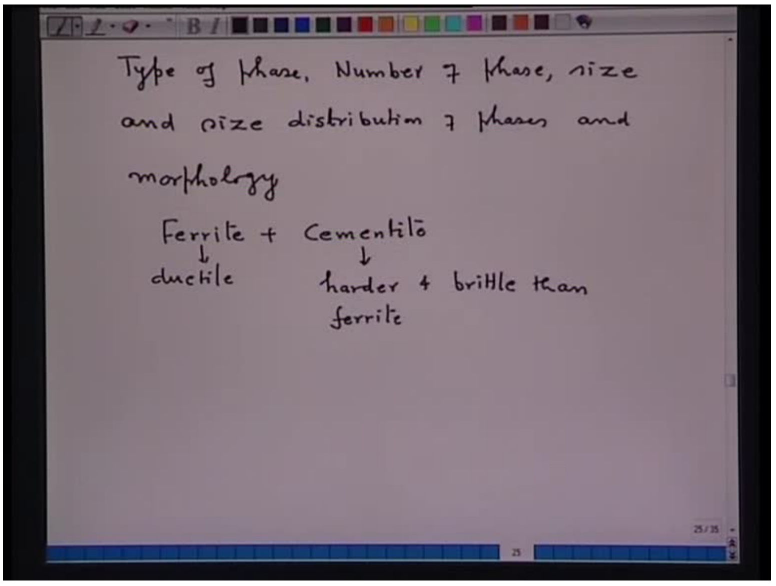

The type of phase, number of phase, size and size distribution of phases, and morphology, they constitute the required property in a given material.If I see now the iron carbon system, remember, in my first lecture I have told you, that iron carbon is a unique system to which steel belongs; it is unique in the sense, it has a capability to have some solubility for element and create that property.Now, I will show you how it can be done.

If I see now the equilibrium phase diagram of iron carbon, I notice there are two phases are present at room temperature; austenite is a high temperature phase.Room temperature, I have ferrite plus cementite; ferrite is ductile, cementite is harder and brittle than ferrite, ferrite is ductile.

Increasing the proportion of cementite in a material, what will it do? It will make the steel more harder and brittle.So, here itself I am getting a clue, that if I vary the proportion of cementite in a simple iron carbon phase diagram, I can getdifferent type of materials.

Now, imagine if I change the morphology of the cementite, imagine I change the size of the phases, I change the number of phases, by some manipulation if I am able to generate more number of phases, then very different properties I can produce it.So, let us see what are the number of phases or types of phases that can be obtain in an iron carbon system, so I am listing.

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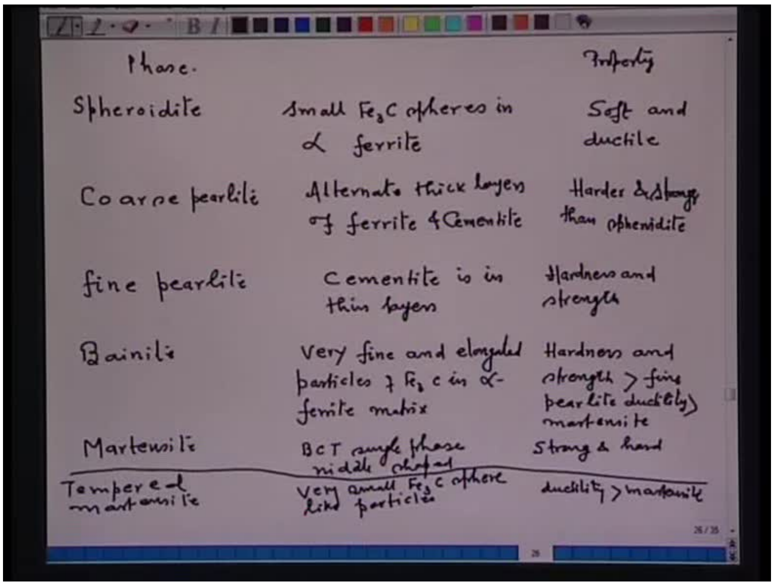

First phase, let us say spheroidite; this consist of a small Fe 3 C spheresin alpha ferrite. what I have done? I am simply modifying the morphology of cementite, getting a phase spheroiditeand this phase property is soft and ductile; so, this is the property of a phase and this is how it consist of.

Then, you must have heard pearlite, so there is a coarse pearlite. And the course pearlite have alternate layers of ferrite and cementite, this is all together a different type of phase; this is harder and stronger than spheroidite. I can further change the morphology, say I can get fine pearlite.

Now, in fine pearlite, alternative thin layers of ferrite and cementite; that means,cementite is in thin layers in ferrite. Now, this hardness and strength, they are greater than coarse pearlite.Then, another phase I can get which is called bainite.Thebainite is very fine; in bainite, you have very fine and elongated particles, with a very special structure of Fe 3 C in alpha ferrite matrix.

Now, this phase bainite has hardness and strength, it is greater than fine pearlite, butat the same time this phase has ductility, ductility which is greater than martensite.Still another phase I can have, that is the martensite. Martensite is a body central-tetragonal phase, all of you know; it is a single phase niddle shaped; this is a strong and hard and ductility is very poor.Then, I can again get another phase, which is tempered martensite.Now, here, very small Fe 3 C sphere like particles in alpha ferrite matrix. Now, this particular tempered martensite has ductility greater than martensite.

Now, you see what I have illustrated over here, I have shown you this, these are the type and number of phases that can be obtain in an iron carbon system.Do not you imagine, that in iron carbon system, it provides very large possibility to create the material of different properties, all that you should know the application.And with 100 percent confidence I can tell, there is a material which is steel.

That is what the importance of the steel as a material, because it provides a very large number of possibility.To create a particular property which is required for a particular application and that you can see, these are the number of phases.Now, you see now, at 7 or 8 number of phases, now I can vary the size, I can vary the distribution.

Also one of the phase that I have not listed is the austenite; it is the high temperature phase,but as I have said that, because of the uniqueness of iron carbon system, it has some solubility for an element; you can always find an element in the periodic table, which can retain austenite at room temperature and you can utilize the ductility of austenite, in order to create a very different type of material.So, arriving at what I want to say is that, that it is, these number of phases, their size, their size distribution, their morphology, if one can change them, then one can obtainvery different type of material.

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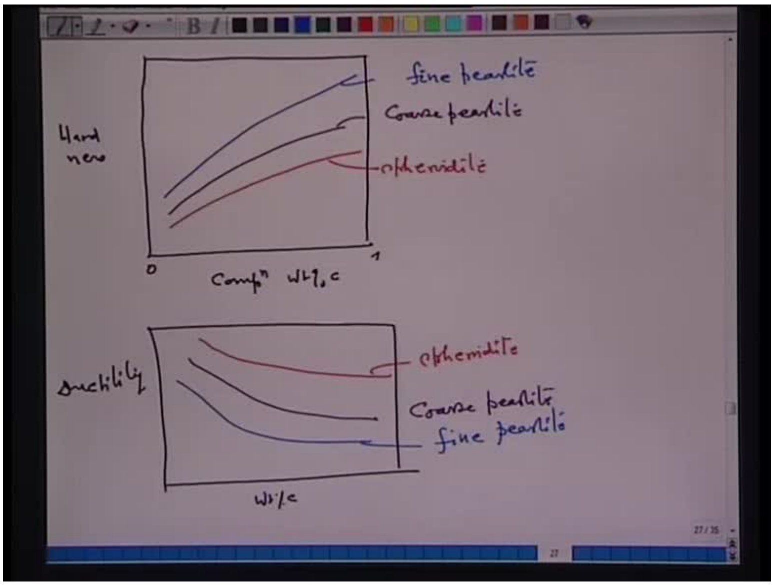

Now, just to show about the property;for example, I just to plot schematically, say for example, I take here, say a composition, say weight percent carbon - it varies from 0 to 1, and here I take for example hardness,then for say spheroidite - this is hardness is the minimum, and then if you go for coarse pearlite, this is for the coarse pearlite, and on the top, you have fine pearlite,that is what I have said also, this is how the mechanical property vary.

Now, if I take ductility,for example,if I plot here now, this scale is same composition weight percent carbon; I take here ductility, it will be reverse of this plot - say spheroidite - will havemaximum ductility; spheroidite, then followed by coarse pearlite, andthis is followed by fine pearlite.What I mean to say?Naturally, hardness and ductile they do not go together.If a material is very hard, then it will be less ductile; if the material isnot that hard, it will be more ductile.

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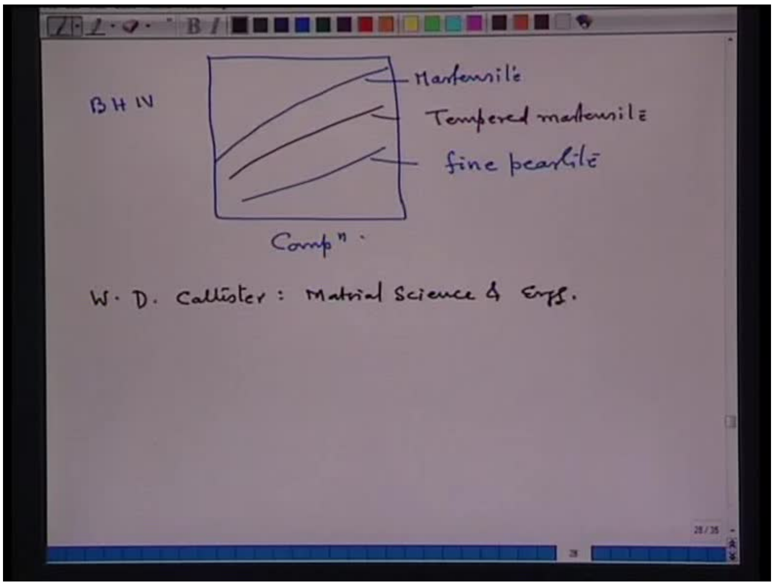

Now, also if we can see some other phases,for example,if I plot here the BrinellHardness Number against composition, then martensite is the hardest phase; that is the martensite, then this will be tempered martensite and this will be fine pearlite.Now, those are interested in more details, they can look down to a book WDCallister; I given the reference in the end, but still I will give you here material science and engineering.

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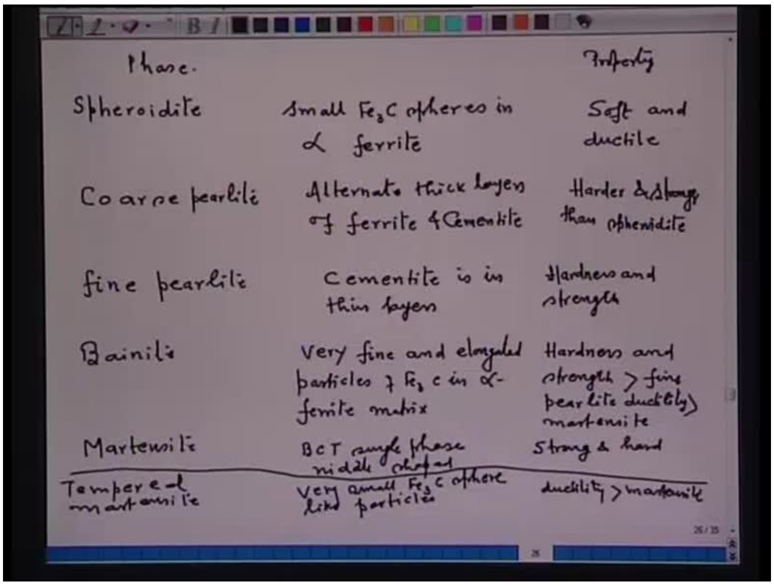

Now, with this presentation what I wanted to say is a very simple, that if you want to create a given property for a given application, the application could be anything at the moment, all that you should know, what for you want to use that material.Then, the iron carbon system, it provides a very large number of possibility.To create a property by permutation and combination of the phases which I have listed over here, you can see there is a very large permutation and combination, and if you include into that permutation and combination, size of the phase also becomes one of the importanttool to manipulate the property in a material, whether it is for low tech industry or whether it is for high tech industry.

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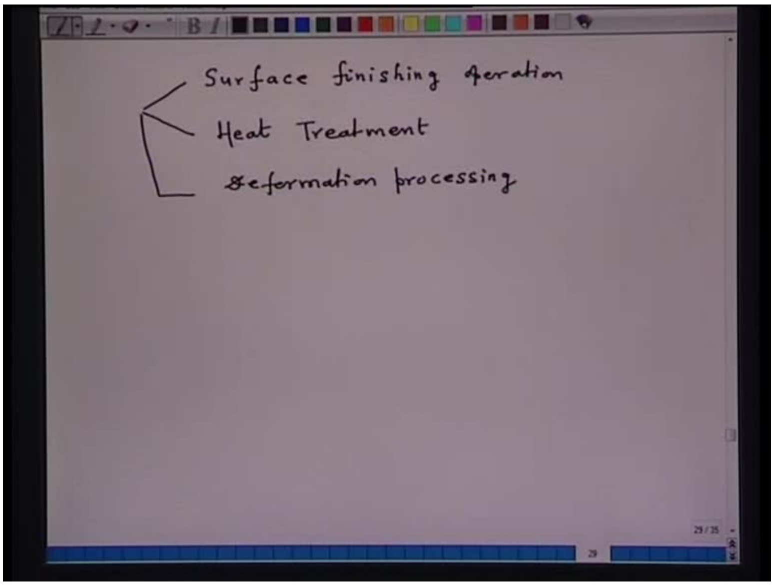

So,now, possibly you are convinced from my statement of the first lecture, that iron carbon is a unique system to which steel belongs, it has a unique property of alloying with several elements and that is what I meant over here.With this,what I want to say is that, all that you should have an application in your mind.

You will have, before you steel as a material, now all that is required and that a question must be coming into your mind, how can I generate these properties, what are the ways in which these properties can be generated or it is just simple, I have presented and there is no way is there, no, there are ways these distribution of phases can be obtained.

And now, these properties, I can classify into three types operations: one is the surface finishing operations,that is where for some applications require only surface property are to be modified; and second is the heat treatment; and third is the deformation processing.These are the three differenttechnologies which can be used to proportion, the number, size and size distribution, morphology of the phases, to obtain material for a particular application.Now, in short I will take,for example,surface finishing operations; that is, in fact, they are called surface hardening.So, first I will take for example surface hardening.

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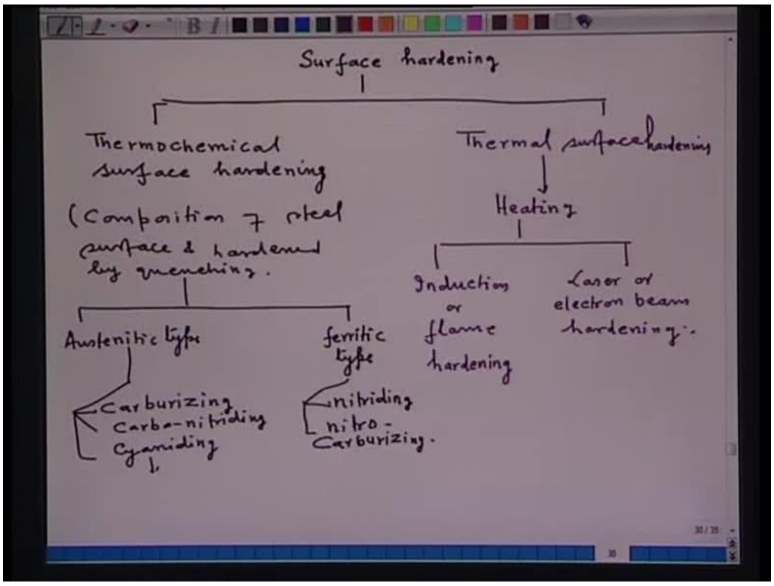

Now, surface hardening consist of two parts: one is a thermo chemical surface hardening;now, one of the important requirement in order to apply these technology is to heat the steel, so that at the heating temperature a steel should have single phase.And the temperature at which the steel will be in a single phase on heating, that one can find out on the phase diagram and which depends on the carbon contain, I want to say with this, that the steel is to be heated, so that it comes in the single phase region - that is the austenite from where the transformation to the different phases begin.

So, one is the thermo chemical surface hardening.And in this composition of steel surface is altered,and is then hardened with or without quenching; that is all that you require to heat to the austenitic temperature, and from here, there you can quench or you can any in the air or what depending on the hardness you require.

Composition of the steel surface is altered and is hardened by quenching or some other treatment.So, here, you have say austenitic type or you have ferritic type.The austenitic type, they are known as,for example,carburizing carburizing is one such method,carbo-nitriding is another method,then cyaniding is another method. In one case, you introduce carbon;for example,in carburizing, in carbo-nitriding, carbon and nitrogen, and so on.

In the ferritic type, it consist of one is nitriding,then you have nitro-carburizing. Now, here, in this particular austenitic type, the non-metallic elements usually carbon singly or in combination with nitrogen are diffused into the austenitic phase.That is why we call them, they are the austenitic type thermo chemical surface hardening method; that is, carbon and nitrogen,they are diffused into the austenitic phase. In the ferritic type, the carbon are carbon plus nitrogen are diffused into the ferrite phase.That is why, we call them as a ferritictype of thermo chemical surface hardening.

Now, another is a thermal surface hardening.Now, in the thermal surface hardening, heat alone is used to alter the micro structure without altering the composition; that is, you locally heat, it you require heating and heating can be done either by induction or flame hardening; you know induction is a very localized heating or flame hardening or you can direct the flame at the part which requires so the heated up; so, induction or flame hardening.

Another type ofthermal surface hardening could be done or by heating could be done, laser or electron beam hardening.Now, the idea of thermal in surface hardening is to heat the localize surface only, such that you for austenite to a control depth, which is then quenched in water or oil or force air to produce hard martensite phase.

As I have said in the beginning, in order to alter the number, phase, number of phases, size, size chooses morphology, and so on, the technology begins first to heat the steel to a single phase region; and in most cases, that is the austenite, that is a single phase.It is from there, depending on the rate of cooling, the different type of phases can be generated.

So,here, in the thermal surface hardening, where heating is done to a controlled surface, so care is taken.Only that controlled surface is transformed to austenite, because you want only surface hardening and depending on the hardness that is required, you have to quench it.If you quench in water, quench in oil, quench in furzier, you get a varying degree of hardness in the steel.So, that is what this surface hardening method.

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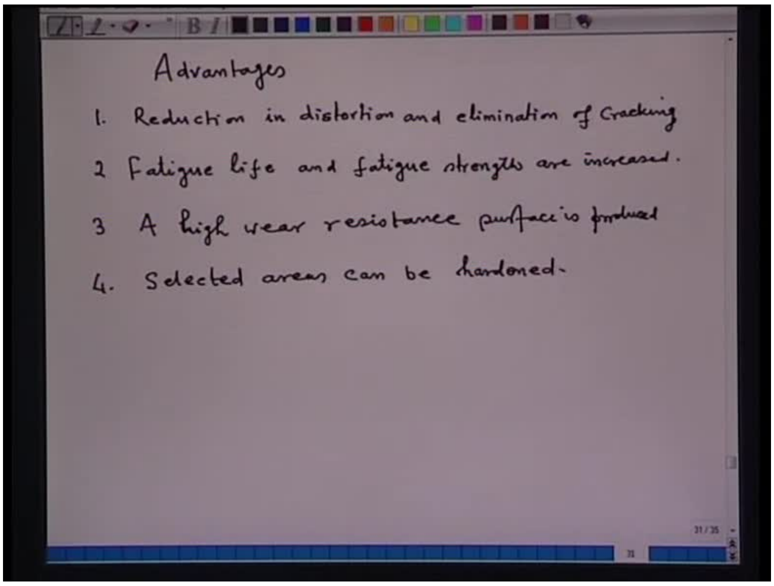

Now, the advantages over thorough hardening method is, advantages over through hardening.The one advantage is that, reduction in distortionelimination of cracking,specially in large components.Second, fatigue life and fatigue strength are increased, due to compressive stresses in the outer layers. Third, a high wear resistance surface is produced, these are the advantages of surface hardening method.Fourth, selected areas can be hardened.Now, say, these are the some of the surface hardening methods.So, next important technology is deformation processing; in the deformation processing, you have to apply the load or you have to deform the material.

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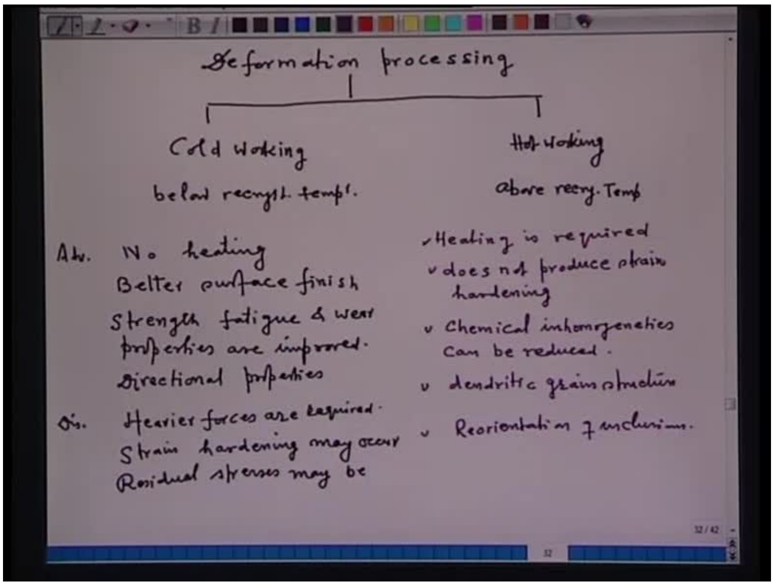

So, you have a such as cold working and hot working.Cold working is done below recrystallizationtemperature;hot working is done above recrystallization temperature.Advantages of cold working is no heating is required, better surface finish and dimensional control can also be achieved, then strength fatigue and wear properties are improved, then directional properties can be imparted.

Some of the disadvantages: heavier forces are required, because you are working in the cold stage, then strain hardening may occur - and this strain hardening requires, then toanneal them to relieve the material from stresses - then some residual stresses may be produced; some residual stresses may be obtained during the cold working operation and if air is not taken, then one may have a problem in the applicationstage.

Now, as regards the hot working, heating is required,but natural there is no need to write, heating is required.But there are certain advantages associated with the hot working; hot working, it does not produce strain hardening.Hard working can be used to drastically alter the shapes, without fear of fracture and excessive high forces, because you do not need to apply high forces.Then, at elevated temperatures, what can happen?The diffusing processes are accelerated; and as a result,certain force are there certainin-homogeneities in the material is there, they can also be reduce.

So, that means, chemical in-homogeneities can be reduced, force can also be welded up or reduce in size during deformation.Then, the dendritic structure - dendritic grain structure - small gas cavity shrinkage porosity form during solidification.In large section can be modified during hot working to produce a fine randomly oriented spherical shape grains, which results in better properties.Then, hot working also results in reorientation of inclusion, I will just put in short, reorientation of inclusions.

Now, one of this important requirement for cold working to be successful is that, the stress strain diagram of the material should show a high strain for a particular stress; that means, the material should be ductile and easily deformable; the material is brittle, then as the limited amount of force that can be applied under cold condition.

There are several operations for cold working as well as hot working: rolling, exclusion, and sheet metal working, hot rolling, all these are the operations andyou can study them and see that, you know it.

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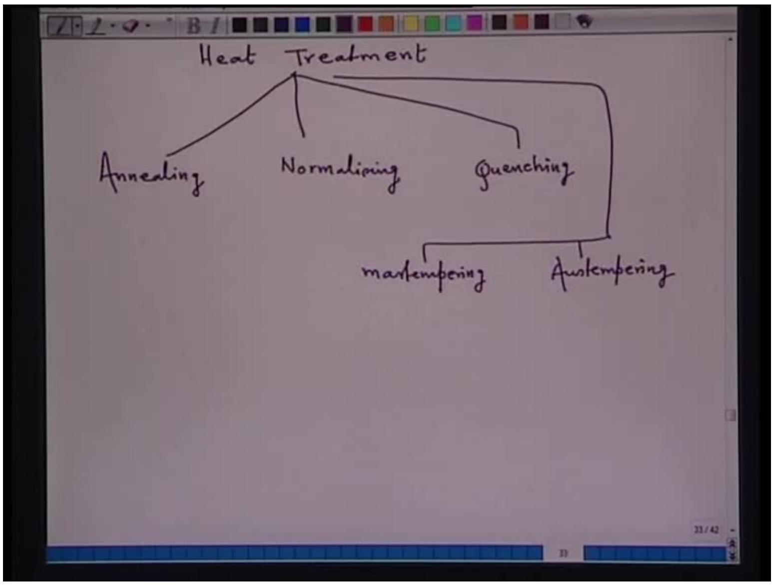

Another important technology as I said is a heat treatment.Now, heat treatment consist of heating and then cooling.Heating to what temperature?The foremost requirement for surface finishing operation or for the bulk finishing operation is to heat the material to a single phase range, that is the austenite temperature. So, the heat treatment operation consist ofheating the material to the austenite grain and from there, it is cooled at a different rate.

And they are several type of heat treatment procedures: one is the annealing that you heat and cool the material in furnaceitself; then, another treatment is normalizing, you read the material again to the austenitic range and cool in air; and third is quenching, here material is heated again to the austenitic range, then it is rapidly cooled in water.So, in all the three method, there will be different phases will form,of course, it will depend upon the carbon content also.

In between this, you can have the several modifying practices for heat treatment; for example, one is martempering, then austempering.Because you want to get a phase bainite, to makeuse of the properties of the bainite, for theiraustempering is done; then also tempering is done, say after quenching, large amount of stresses are induce in the material, then the stresses are to be relived; and for that purpose, the material is reheated.So, these are some of the technologies that belong to heat treatment.

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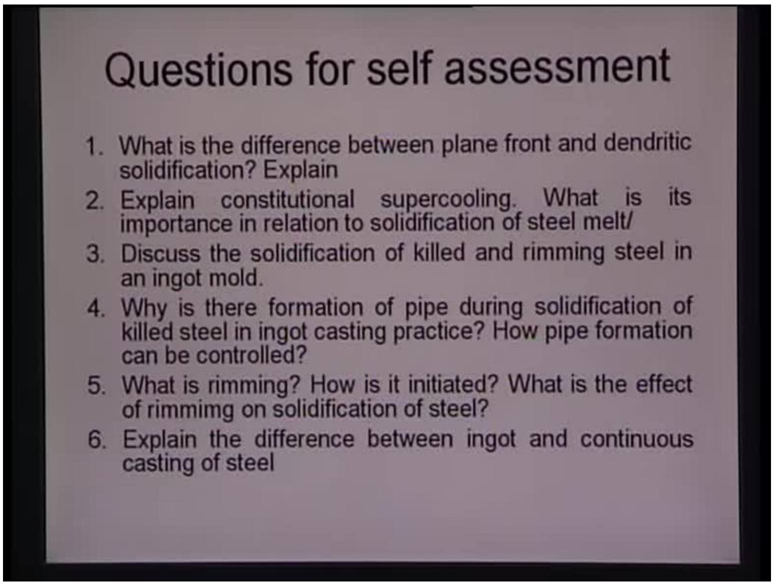

Now, I willlike to give you certain questions and references.Here are the question for self-assessment.

What is the difference between plane front and dendritic solidification, explain? I had already explained, I do not think now you want any explanation from me.Second,explain constitutional super cooling, whatis the importance in relation to solidification of steel melt?Third, discussthe solidification of killed and rimming steel in an ingot mold?Well, you have to tell here, how both types of ingot solidifies a pipe formation blowhole and so on; it would be better if you answer the question by drawing sketches.

Why is there formation of pipe during solidification of killed steel in ingot during continuous cast during ingot casting practice?How pipe formation can be controlled?what is rimming?And next question, explain the difference between ingot and continuous casting?That is, I have said already.

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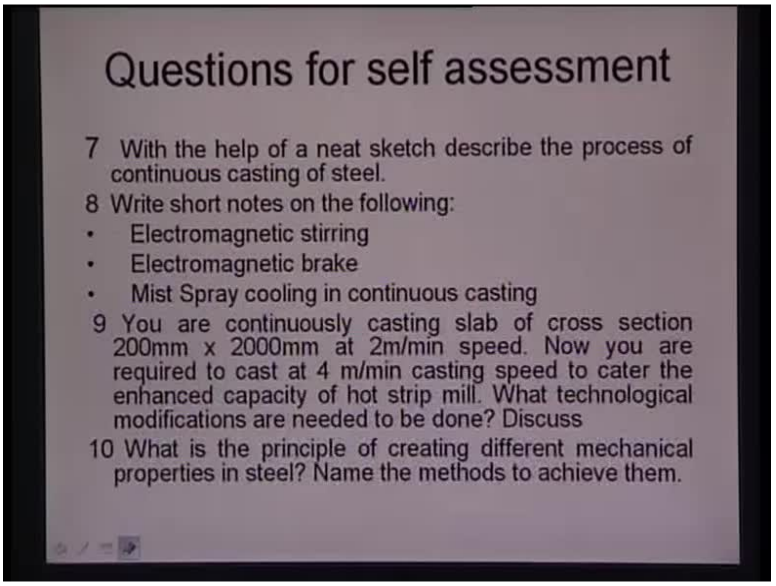

Seventh question, with the help of a neat sketch describe the process of continuous castingsteel - try to draw a sketch.Write short notes on the following: well, that has already said.

Nineth question is that, you are continuously casting slab of cross section 200 into 2000 millimeter at 2 meter per minute speed.Now, you are required to cast at 4 meter per minute casting speed to cater the enhanced capacity of hot strip mill.What technological modifications are needed to be done?Discuss. I have taken an example.Now, this question, you can modify with thediscussion that we have and you can provide the answer here, what is the principle of creating different mechanical properties in steel?Name the methods to achieve them.Right now, I discussed.And these are the references for further reading to strengthen your knowledge.

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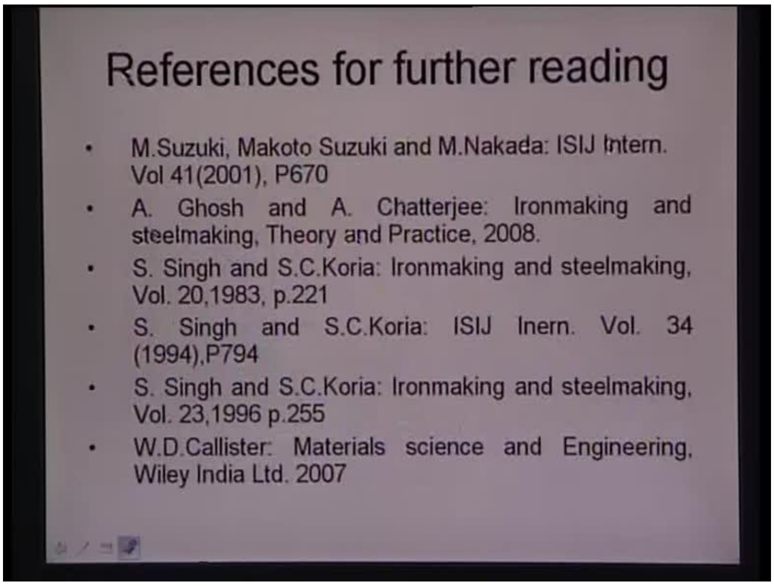

So, with this, I want to end my lecture by telling, in fact, I will be repeating my few sentences of my first lecture, where I have said, that is steel belongs to iron carbon system and iron carbon system is a unique property.And now, you are seeing the uniqueness of iron carbon system; and believe me or not, it is the creation of the nature.Nature has madeiron to be magnetic, so that it is ductile at room temperature; otherwise, it would have been hexagonal plex coarse practice structure.Do not you think, it is a wonder of the nature.

Another that, I want to say is that, as I have said also, steel provides enorm application oriented development of the material; on the top of it, nature is also given steel or nature is also made steel to be recyclable.

My dear friends, I conclude the lecture by telling, steel is a green material.

Thank you.