Theory of Production Processes

Dr. Pradeep Kumar Jha
Department of Mechanical Engineering
Indian Institute of Technology, Roorkee

Lecture – 17
Melting and Production of Iron Castings

Welcome to the lecture on melting and production of iron castings. So, in the last lecture we discussed about the furnesses which are required for melting of castings, specially either casting may be either of the non ferrous material or it may be of ferrous material, in ferrous you have either iron or sometimes you have steel. So, these are the two main components. So, iron means the variety of grey iron or cast iron. So, in that case basically the melting temperature is less than that of steel.

So, if you look at the iron carbon phase diagram, you will see that as the carbon composition increases carbon content increases towards the right, the melting temperature comes down. So, basically if you go to the eutectic point it comes close to 11 40 degrees centigrade whereas, if you come to near the 0 degree 0 percent of carbon, it is close to 15 40 degree centigrades.

So, there is lot of difference and the iron products like gray iron or white iron or S G iron or so, they are having variety of you know proper varied properties, because of which they are mostly used in many sectors like automobile construction or so. Although the cast iron has certain limitations also you I mean properties in certain way, but then there has been advances, there has been the advent of newer type of cast irons like gray cast iron or ductile iron or tempered ductile iron or so, which has made them very very popular material as a cast product, and used extensively specially in automobile industries.

So, as we discussed you have first of all this cast iron which is your important material, whose demand is quite high mostly if we look at the machine beds, where we have the component made of cast iron. In many cases the material is made of cast iron, if you go to any shop of machine shop or heavy machinery if you look at most of the structures which are the supporting they are normally made of this cast iron. The thing is that the cast ability being better and the easy casting the structure is higher.

So, that makes it and also the properties or so, good if you control the pressure parameters in a proper way in that case it is very much useful. So, that is why it is very important material and its demand is increasing day by day, and this is a very important type of material whereas, the properties of cast iron. So, as we know it has the some inferior properties as compared to steel specially when we check it against the tensile property, but its compressive property is quite high the damping property is quite good. So, machining property is quite good. So, these are the special properties for this cast iron.

Now, in the case of cast iron we define it. So, basically in the case of cast iron what we see you have the carbon percentage more than 2 percent will be there in the case of cast iron, then you have the silicon is present. So, basically silicon will try to stabilise the graphite because in normal case the carbon may go as carbide. So, because of the presence of silicon the carbon which is there that basically will be stabilised in the form of graphite. So, in the case of cast iron the carbon is normally in the case of in the form of graphite, also you will get carbide when the amount of silicon is less, or depending upon the cooling conditions either you can get the carbide or you can get the graphite now types of cast iron.

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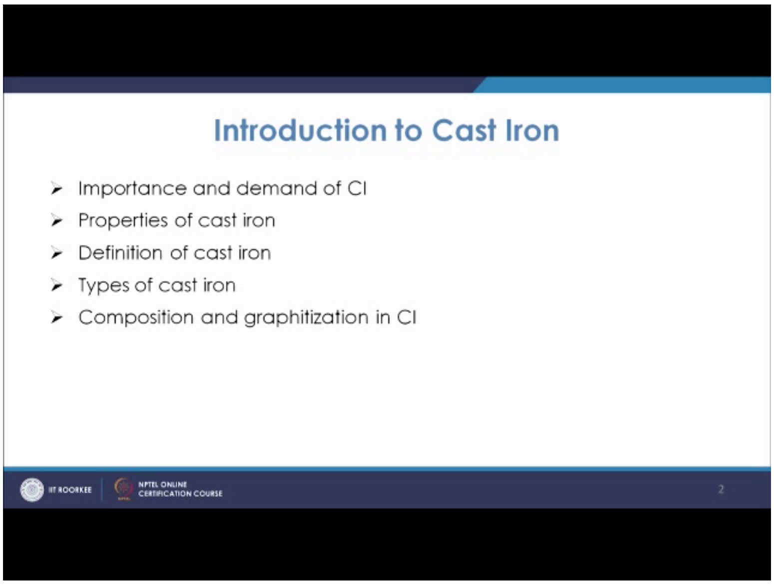

So, cast iron as we know cast iron one is gray cast iron. So, that is gray cast iron because the fracture surface is gray in colour. So, that is why it is gray cast iron, then you have white cast iron. So, the white cats iron is its fractured surface is white. So, it is known as white cats iron.

Gray cast iron has very good compressive strength, less tensile strength little bit because of the presence of flaky graphite in the case of gray cast iron.

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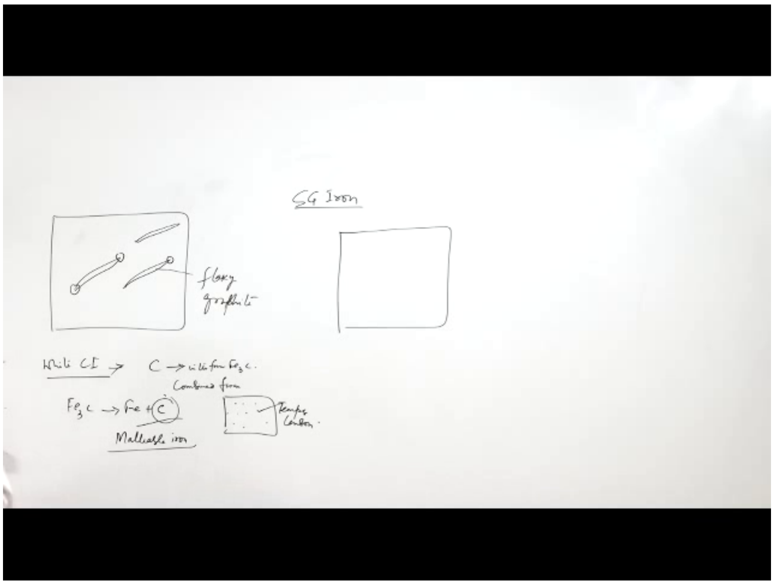

So, if you look at the gray cast iron, you will have the graphite flakes like this. So, so these are the flaky graphite in the case of gray cast iron. So, what happens this is soft. So, it gives a better damping properties, but these regions which have the pointed ends, they are the source the defect and they are the stress results. So, that is why in that in that tension state, it does not give very good property then you have another variety of cast iron is white cast iron.

So, the white cast iron in that basically the carbon is present in the form of Fe 3 c combined carbon so, combined form. Now this is basically promoted because of the lower amount of silicon in the charge, and also because of the larger cooling rate. So, in the case of cast iron you need to maintain a slower cooling rate. Now cast iron in this case even the higher even with the higher silicon content or carbon content, if the cooling rate is fast in that case in certain area where the cooling rate is fast, you can have this structure of white cast iron or the hard phases formation that is carbide formation.

So, basically depending upon the percentage of silicon and carbon especially silicon because silicon is the graphitizer. So, silicon promotes the formation of graphite and also depending upon the cooling condition you get these white cast iron. So, because of the presence of the carbide iron carbide as carbon, also carbon is in the form of iron carbide this is very extremely hard. So, it does not much of the ductility, its very very hard and normally not used for nay engineering application, expect for the places where very high it can impart very high compressive stress, it can has it has very high extremely high hardness.

So, you are normally used for steel rolls in the steel rolling mills for rolls we use this material. But then this this cast iron is important because once we do the heat treatment of this cast iron the Fe 3 c the carbon which is there in the Fe 3 c this is decomposed. So, we if we subject it to annealing at a temperature of about 950 degree centigrade, and keep it for long duration then that is known annealing. So, it is done in the furnace at high temperature and then if this is maintained at that temperature for large amount of time, then basically disintegrates and it gives you free carbon. So, this Fe 3 c breaks into f e plus c. So, that is giving you free carbon or graphite. So, then that basically appears as small nodules nodules tempered for. So, this is known as temper carbon.

So, because of this annealing treatment, this carbon comes into this shape and then this is known as malleable iron. So, because of this annealing treatment for a prolonged duration, the hardness extreme hardness goes away, softness is induced and it has it develops a very high malleability and that is why it is known as malleable iron. So, it is very much used for the automobile components and it has very good formability and it is used for to mobile applications.

But nowadays, it is many at many places because it requires very large annealing treatment. So, energy consumption is quite high. So, even the SG iron is now a days preferred for making such components, which are required to be used in automobile applications. Next kind of iron I mean popular cast iron variety is the S G iron that is also known spheroidal graphite cast iron. So, this S G iron is basically the cast iron. So, in the case of white cast iron you get this cast iron by basically doing the heat treatment.

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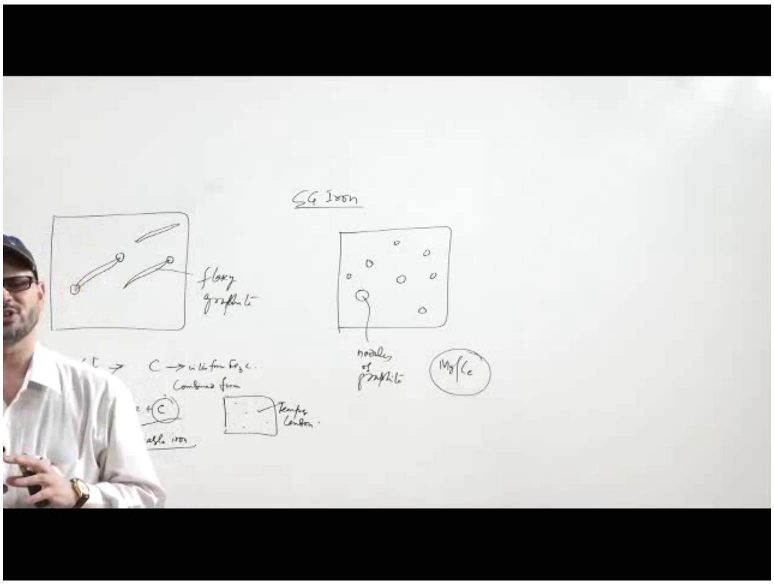

Whereas, a simply by casting, you can have the carbon as graphite nodules. So, these are nodules of the graphite.

Now, this is achieved by treatment the melt with either magnesium or cerium. So, if the cast iron melt is treated with magnesium or cerium, then what happens the first of all the sulphur content should be quite low. So, for that the M g reacts with sulphur and M g s as a slag is removed, and then the residual magnesium basically helps in changing the morphology of the graphite and it changes in such a manner that the growth of this graphite nodules is equal in all directions. So, it becomes a nodule here the growth is not in equal not equal in all the directions.

So, it becomes flaky type where as in this case because of the treatment with magnesium it becomes in nodular shape or spherical shape. So, that is how this kind of structure is obtained this is known as spheroidal graphite structure or nodular iron or ductile iron or so. So it has many name and this is known as this is the one variety which is very important variety. Apart from that you have mottled iron which is because of the freezing conditions if the part, part is freezing you know that is higher cooling part is at lower cooling rate in that case you will have the structure which is known as mottled iron. So, then you have ADI austempered ductile iron which is further treatment to ductile iron. So, what you get ADO. So, this way you have the different types of cast iron.

Now, you have the graphitization in cast iron as we discussed. So, graphitisation will be basically depending upon the percentage of carbon and silicon. So, as it will be more and also the cooling rate the cooling rate is small, then graphitisation will promote it otherwise not. So, these are the different parameters. So, solidification mechanism in cast iron, that we will discuss and these are typical microstructure in the cast iron that you get graphite, cementite, ferrite, pearlite, steadite austenite.

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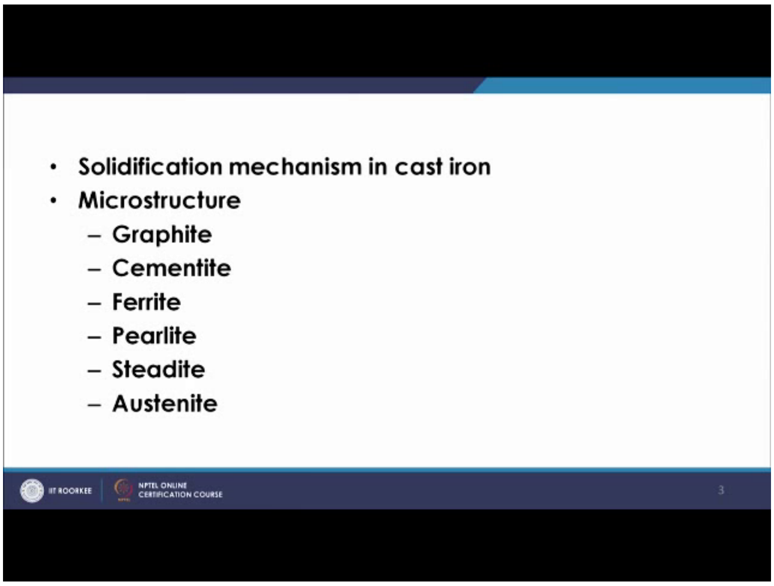

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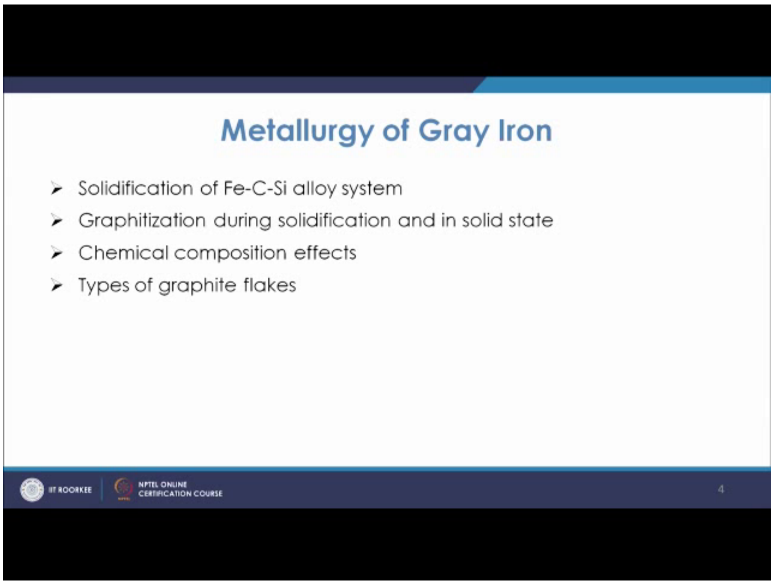

Now, we will discuss about the metallurgy of gray irons. So, how these solidification occurs in the iron carbon silicon alloy system, and then how the graphitization occurs and chemical composition effects and types of graphite flakes. So, let us see this is the you know iron carbide iron graphite equilibrium diagram.

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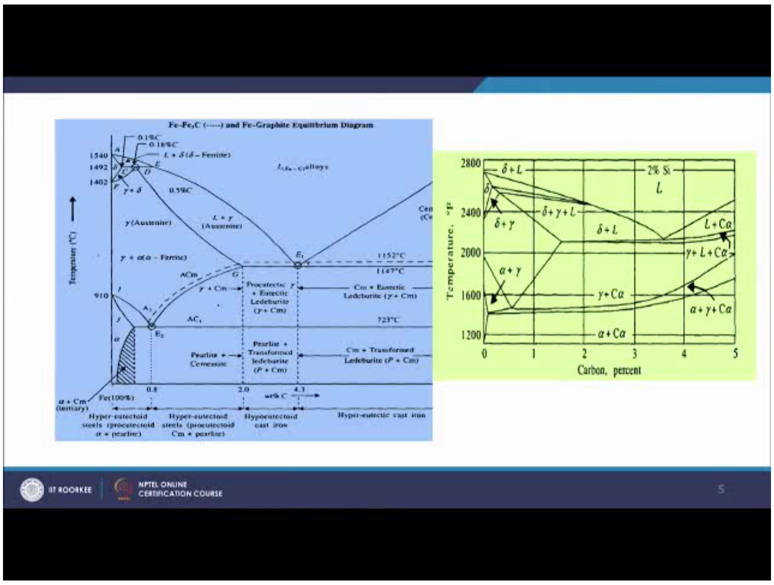

So, if you look at this you can understand that how this solidification occurs wherever composition if we take.

So, once it comes to this temperature, then this is the liquidous line this side or this side and then once the solidification starts, once you come to this zone suppose it is hypo eutectic you know cast iron in that case here it will come. So, you will have one as here. So, austenite will be of this composition whereas, you will have. So, ultimately you have the liquid as well as the austenite. So, liquid will be there and austenite will be there, and then from here once it comes at this point. So, one will be following this line. So, one will be here and then another point will be here.

So, from here once it comes down this is the eutectic point. So, once you go below that you have if you look at this side you have the cementite. So, ultimately you will have the in this side you have cementite plus eutectic, in this side you have pro eutectic austenite plus. So, because the austenite is formed before the eutectic points, it is pro eutectic austenite plus eutectic ledeburite. So, that is here this point. So, in this zone we have pro eutectic austenite plus eutectic ledeburite; ledeburite is the discomposition. So, that is what you get gamma plus cementite.

And as we come down to again this temperature so, further you have the conversion of this austenite, and then austenite will further change to the pearlite and cementite. So, you I hope that you are conversant with this iron carbon equilibrium diagram, which talks about the solidification mechanism, that as you come down at any place you have two basically two basic rules; one is the lever rule and is the tie line rule. So, that one talks about the amount of you know amount of liquid or solid which is there or two phase at any point, and then composition of the phases. So, amount will be basically done by this lever rule. So, that whoever it touches as per the lever rule, you are going to find the amount of the two phases, and then the tie line will talk about the composition.

So, as we see in this case what we see here that, once the silicon content is basically increases, in that case the you know this eutectic point is shifted towards left. So, that is basically known as the carbon equivalent value. So, in that case what happens that percentage carbon plus percentage silicon by 3, that talks about the carbon equivalence. So, if you have 3 percent of silicon and 3 percent of carbon that is basically carbon equivalent is 4 percent. So, that way it is or 3 percent of silicon and four 3 percent of carbon and 4 percent of silicon. So, that will reach at this 3 percent carbon itself you will have the eutectic point instead of 4.3 percent because 4 by 3 is 1.33.

So, that gives you 3 percent carbon itself will have the eutectic point. So, this is the point which should be kept in mind because the silicon is promoting the graphitization and it will basically shift this point towards the left side.

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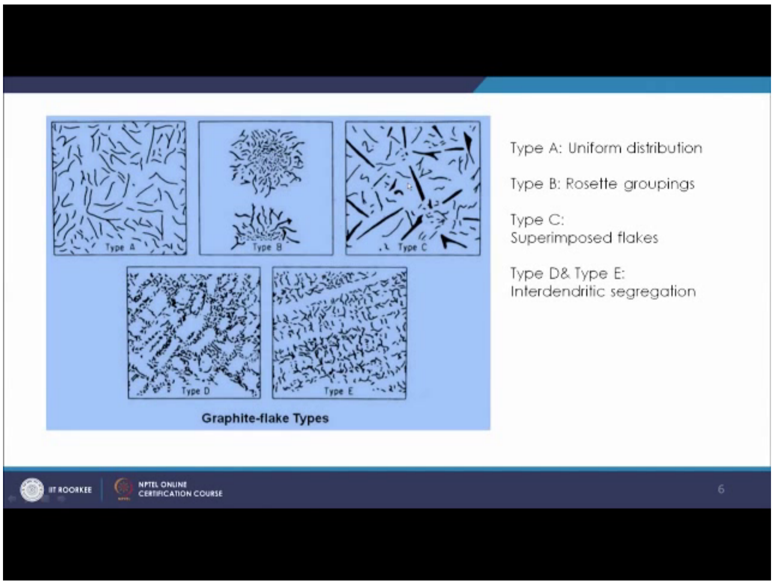

Now, this picture talks about the different kinds of you know graphite flakes distribution inside the matrix, and the type a graphite uniform distribution is the most preferred one, apart from that you have the different varieties different kinds in which the graphite may be distributed inside the domain, and this is type B is rosette type, type C is super imposed flakes, type 4 D and E they are inter dendritic segregation.

So, type a normally is the most preferred type of you know flake distribution, inside the matrix. Next we are going to study about the moulding related aspects of the casting of these iron based materials like gray cast iron or S G iron or even the white cast iron.

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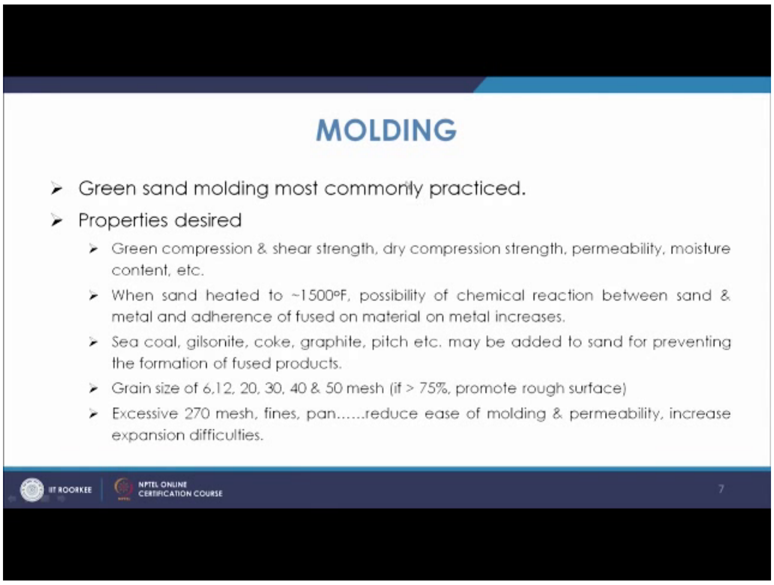

So, for that green sand moulding is normally used, you require the green compression and shear strength, dry compression strength permeability moisture content, it is a adequate in the moulding material. The sand when it is heated to about 1500 degree Fahrenheit, then there is possibility of chemical reaction between sand and metal and there may be adherence of fused material on the you know metal.

So, you now you use sea coal gilsonite coke graphite pitch, it may be used in the sand for the prevention of the formation of these fused products, which are because of the reaction between the sand and the metal. Normally the grain size which is used is 6, 12, 30, 40 and 50 mesh. So, if you take more than 75 percent, then they promote the rough surface. Excessive two seventy mesh or fines as you know when the number I mean if the fine numbers mean higher fine mesh means higher numbers. So, if you take more then they reduce the ease of moulding and also permeability.

So, basically permeability is reduced because of the very fine particle; increase also expansion properties like the collapsibility is affected in that case then what are the foundry properties of the gray cast iron that we will discuss.

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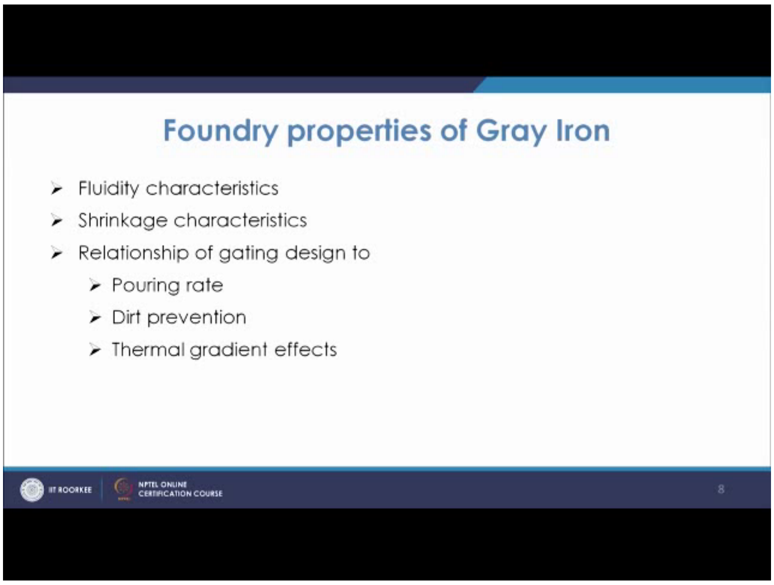

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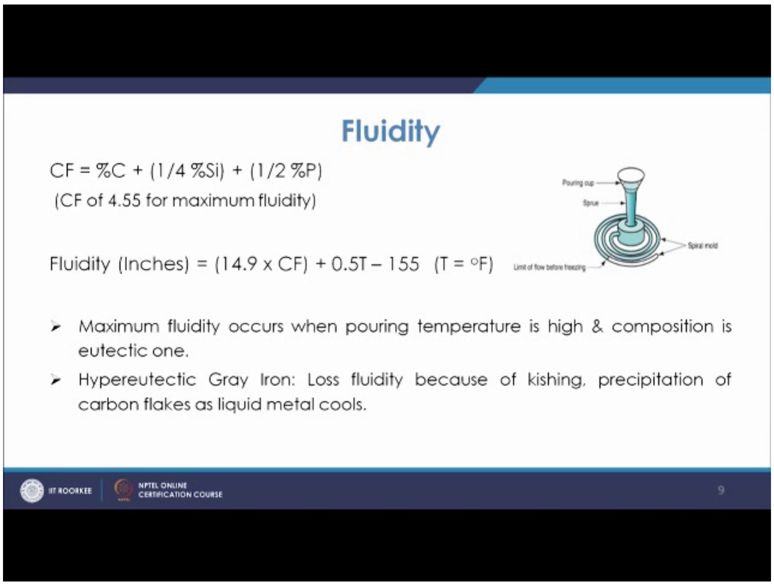

So, fluid life that fluidity. So, fluidity is basically depending upon the percentage of carbon, silicon and phosphorous. So, phosphorous basically it gives the phosphorous and phosphor eutectic, because of that the fluidity also is increasing because of the presence of phosphorous. So, that is why phosphorous also comes into picture. So, if you carbon percentage silicon percentage and phosphorous percentage, then fluidity inches also fluidity will be affected because of this silicon and also the phosphorous content. So, that is why composition factor will be percentage carbon plus half 1 by 4 percentage silicon, plus half percentage phosphorous. And composition factor of 4.55 is said to have maximum fluidity. So, once you have the composition factor known, you can have the fluidity inches according to this formula 14.9 into CF plus 0.5 T minus 155. So, T will be at temperature affording in kelvin. So, in Fahrenheit.

Now the maximum fluidity is occurring when the pouring temperature is high and the composition is eutectic one, and hyper eutectic gray iron. So, for that basically there is loss of fluidity, because of the kishing of the or the precipitation of carbon flakes as liquid metal cools. So, in that case basically you know the flakes come up. So, that is how this fluidity is also you know affected, fluidity becomes less even for hyper eutectic type of gray iron.

So, for eutectic you will have maximum one, it will be less even for hypo eutectic side also for hyper eutectic side, because of the kishing effects.

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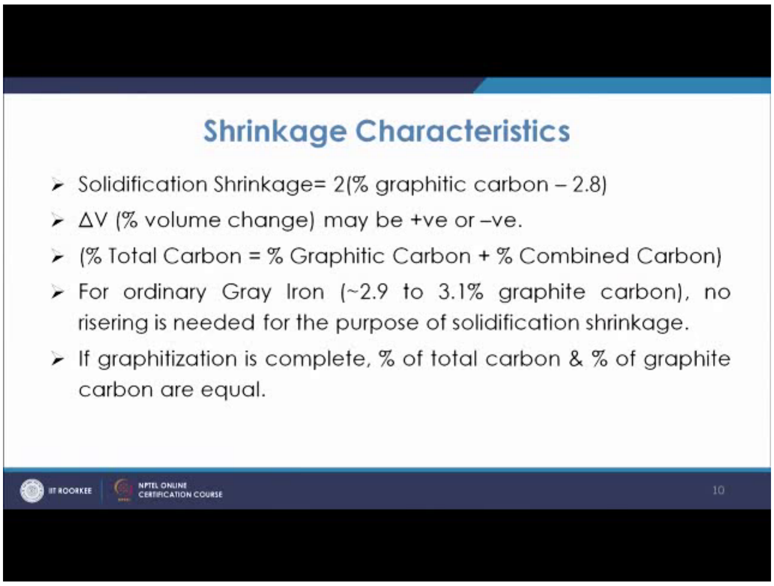

Shrinkage characteristics as we know in the case of gray cast iron, this is one of the advantage of cast iron that is since the graphite is transferred from carbon and this graphite has the lower density. So, basically there is expansion. So, shrinkage basically many times that is why it is very much good in castability because here that requirement arises many a times may be very very less. So, solidification shrinkage in normally two times percentage graphitic carbon minus 2.8o.

So, delta V it may be plus or positive or negative depending on percentage of graphitic carbon now. So, total graphite carbon will be I mean total carbon you can take it either as the graphitic carbon plus combine carbon. So, you have two types of carbon, one is carbon in the graphitic form and another is in the form of combined one. And if you have as you see from the figure if you have the shrinkage, if you have the graphitic carbon is more in that case if you look at delta v will be positive.

So, in that case you know no rising is needed. So, for 2.9 to 3.1 percent of graphitic carbon you do not have even the requirement of riser. So, that is how its shrinkage property is different than the other metals, where in most of the cases you have delta V as negative change is volume is there if there will be shrinkage always, but in this case that is you have riser less type of solidification very much defined in the case of cast iron.

So, if though graphitisation as occurred percentage of graphitite carbon is 0. So, that is how it is defined and depending upon that you will certainly you will have different kinds of micro structures.

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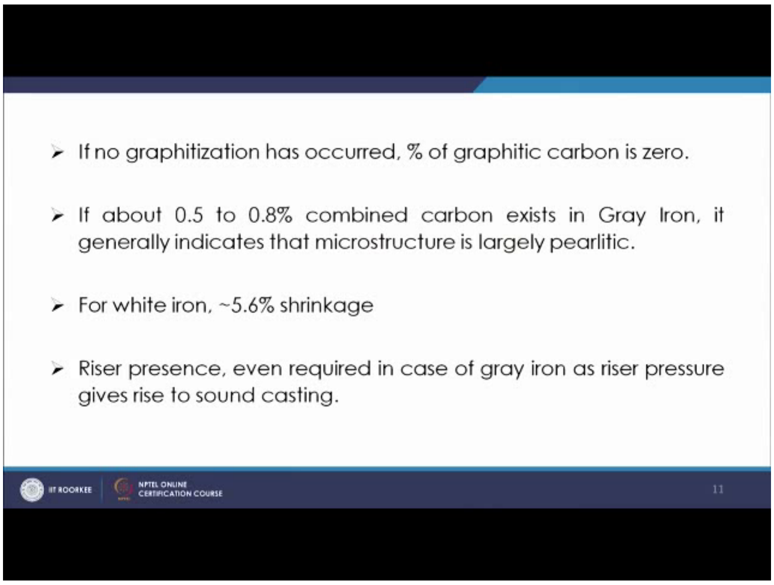

Now for white iron you have normally 5.6 percentage of shrinkage, because there is no graphitisation in that case where whereas, wherever there is graphitisation you will have less shrinkage or sometimes the shrinkage requirement is not to be when compensated by the riser.

So, further you have some times the pressure purging is there also in the pressure in the opposite side also. So, because of this pressure, because you know riser pressures even required in case of gray iron. So, riser pressure gives rise to a strong casting. So, that is also is there because of that you get the strong casting in quality of casting is better.

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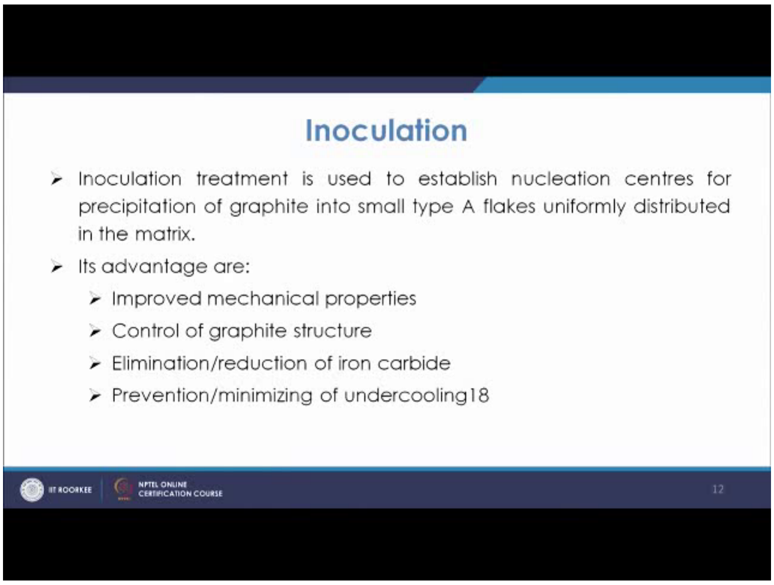

Inoculation treatment is normally used and this is used to establish the nucleation centre for the precipitation of graphite into small type a flakes uniformly distributed in the matrix.

So, normally the inoculation treatment is practiced. So, you have the inoculant, which go into the melt which is given into a melt. So, that you get a better flaky graphite structure a type of flaky graphite structure you are getting. And its advantage is that you have improved mechanical property, control of graphitic structure, elimination or reduction of iron carbide and prevention or minimising of under cooling. So, these are the you know advantage of inoculation.

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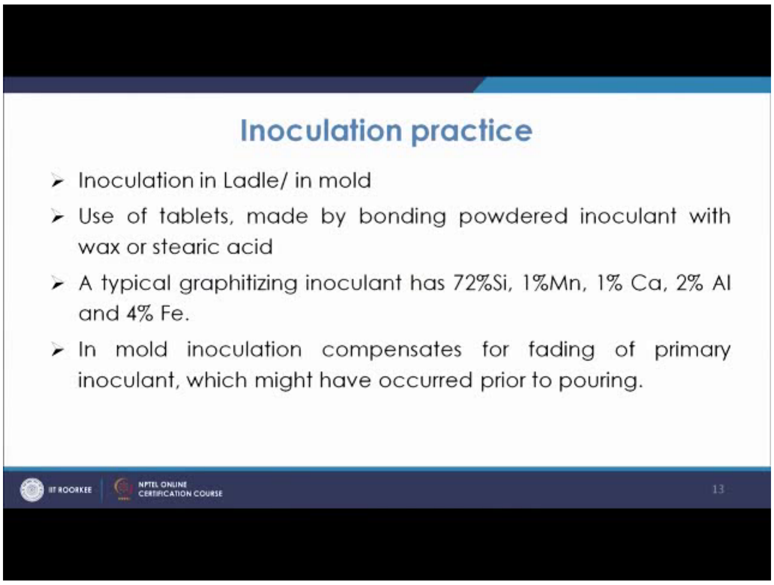

The practice is that, it is in the ladle or in the mould you can use you can use the tablets. So, which is made by bounding powdered, inoculant with wax or stearic acid and you have a typical graphitising inoculant used as 72 percent silicon 1 percent manganese, 1 percent calcium, 2 percent aluminium or 4 percent and 4 percent iron. So, normally these inoculants are used in the during the casting and it gives a better properties.

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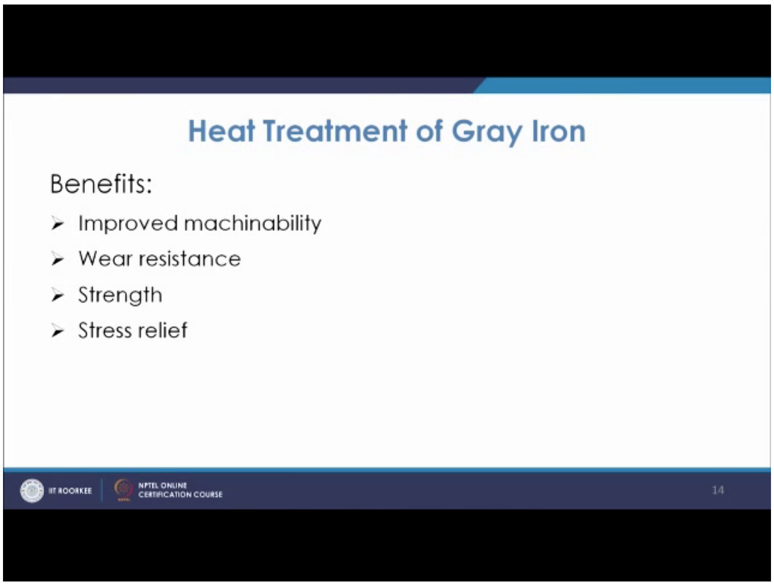

Now, you also do the heat treatment of gray iron for improving its properties, like machinability wear resistance strength and stress relief.

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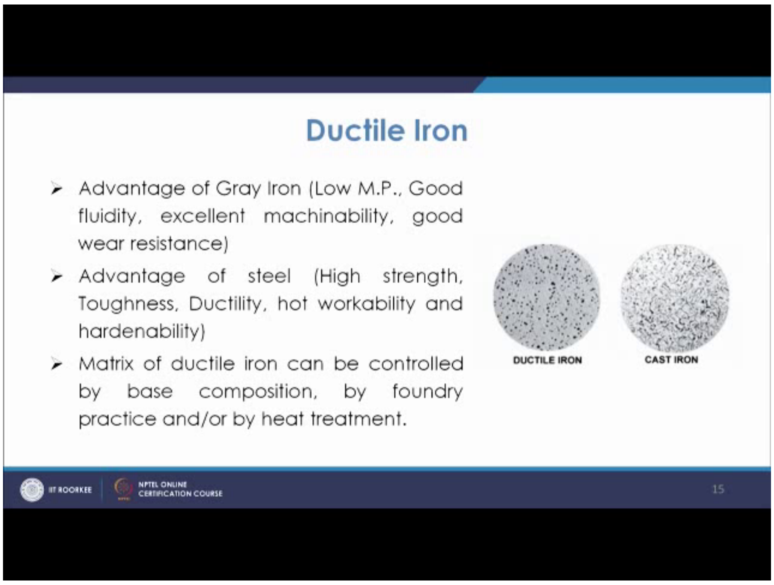

So, then another variety is the ductile iron. So, ductile iron as you know you the gray cast iron has certain disadvantages, that is basically compensated in the case of ductile iron, which is made by treating that material with the magnesium.

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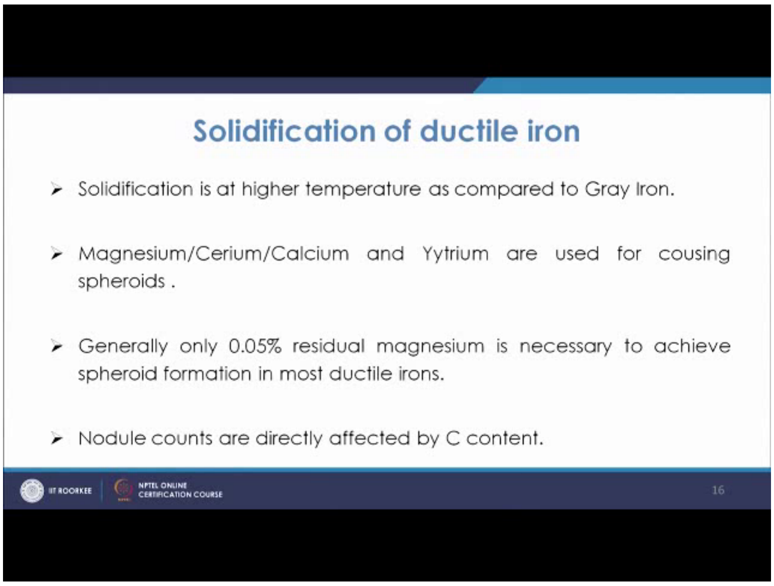

So, solidification is at higher temperature as compared to gray iron in this case, magnesium or cerium or calcium and Yytrium they are used for causing the spheroids, then you have only some amount magnesium is required to achieve this spheroid formation and nodule counts are directly affected by the carbon content.

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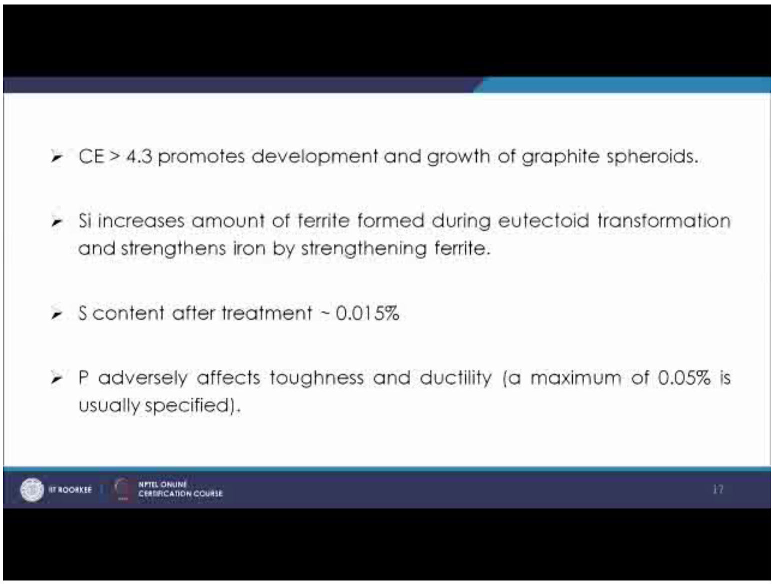

Now, if the carbonic equivalent is more than 4.3 the if it promotes the development and growth of the graphitic spheroids. So, you must see that this carbon equivalent should be more, for that you do a carbon and silicon content should be more.

now the sulphur content after the treatment has to be very very limited, because that affects because once there is sulphur the magnesium is mostly consumed, because of the this sulphur. So, sulphur is very much deleterious for this formation of nodular graphite, and p also is adversely affection the toughness and ductility. So, you will have to limit the amount of p as well.

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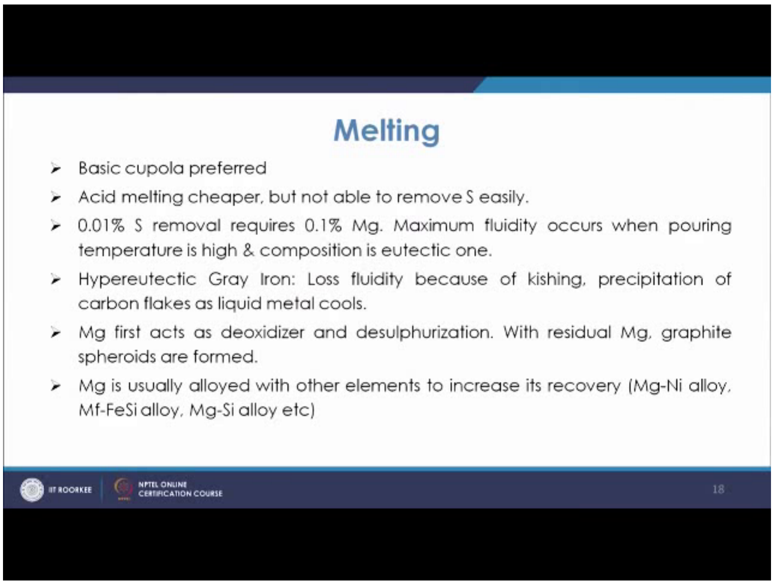

For melting the basic cupola is preferred acid melting is cheaper, but now acid melting is not preferred because it will not be able to remove the s sulphur, and sulphur is deleterious for this nodular iron.

So, you will have to see that you go for basic cupolas which is preferred; you know that when the sulphur is there and you put the magnesium first of all this magnesium is consumed by this sulphur. So, and also maximum fluidity is occurring when the pouring temperature is high, and the composition is eutectic one that is what we have seen when for the gray iron n and you have some fluidity losses, because of the even hyper eutectic side. So, M g will first act as de oxidiser and de sulphurisation will take place. So, first of all it will react with sulphur and make the M g s, and with residual M g itself graphite spheroids are formed. So, that is how you get and M g which is used is normally as the ferro alloys like you have the different alloys. So, that is M g nickel alloy or M g Ferro silicon alloy or. So, so this way these are treated.

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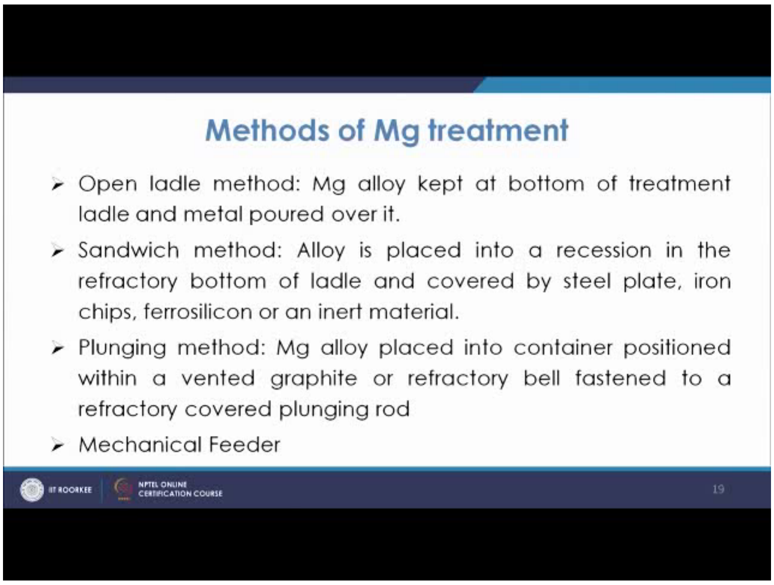

You have different methods of M g treatment like you have ladle method sandwich method plunging method, and mechanical feeder and the purpose is that it will go into the melt and slowly it will go because it is explosive in nature. So, you have to put it there you have to have a sandwich type of method or you have in the corner you have somewhere slowly metal will go and it will react with that. So, that it does not create vigorous reaction with vigorous you know noise or so, and quietly it should mix. So, that one slowly it will go, and it will react and make the graphite spheroids.

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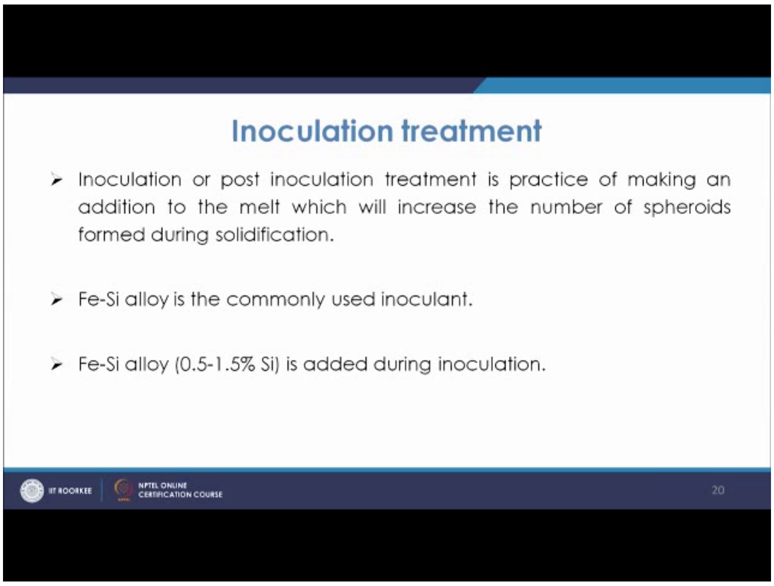

You also do the inoculation treatment to increase the number of s spheroids form during the solidification. So, ferrosilicon alloy is normally used as inoculant and ferrosilicon alloy that is 0.5 to 1.5 percent silicon is added during the inoculation, then you have also the foundry process controls.

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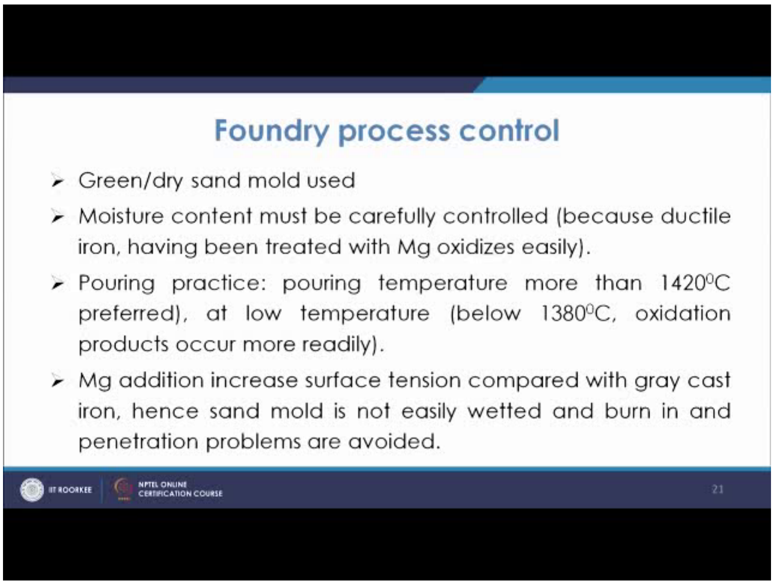

So, in that during the casting you as we have discussed you must have certain process control like you have to use the green or dry sand mould, in moisture content should be basically proper properly controlled, because the M g will oxidise easily then pouring practice. So, pouring temperature should be more than something like 1420 degree centigrade. So, that is proffered at low temperature the oxidisation products occurs more readily. So, that is the case in this melting of or production of nodular iron.

So, that needs to be seen then magnesium addition also increases the surface tension compared with gray cast iron. So, sand mold is not easily wetted and burning and penetration problems are avoided. So, this is the advantage in the case of casting of the nodular iron.

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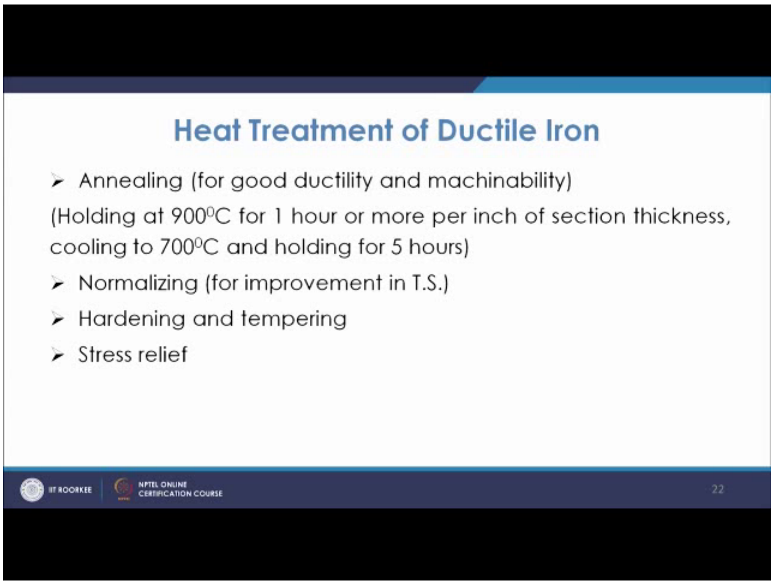

Then you have also the heat treatment of ductile iron, that is annealing is also carried out for good ductility and machinability. Normalising is done for improvement in tensile strength hardening tempering and stress relief is also carried out to improve the mechanical properties.

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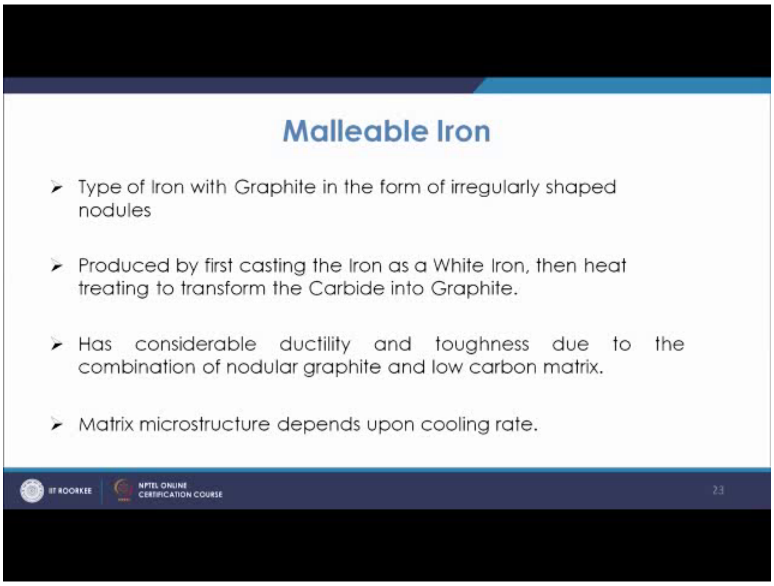

Another variety of cast iron is malleable iron where the curve the iron which has the graphite in the form of temper form, and it is a as we discussed it is formed y the heat treatment of cast iron I mean in white cast iron that is annealing for a quite larger time, in the furnace itself which is increasing its ductility and toughness.

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So, that is how you get the malleable iron this is the structure of malleable iron.

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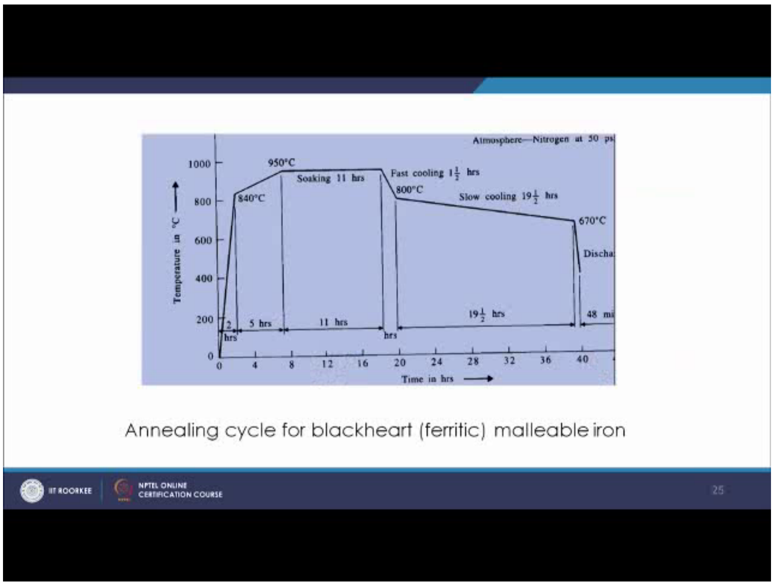

This is the annealing cycle of malleable iron which we get.

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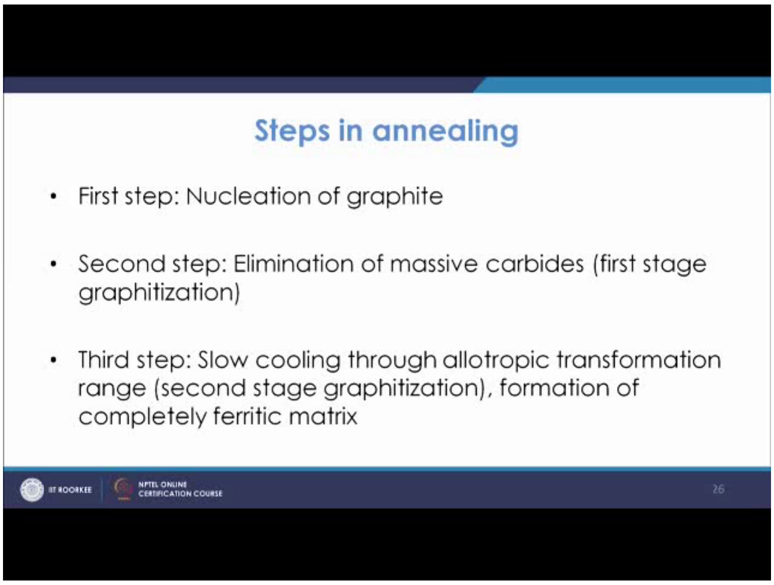

And these are steps like in the first step there will be nucleation of graphite, second step you will have elimination of massive carbides, in the third step you have slow cooling through allotropic transformation range. So, this way what we see is that carbide structure is removed and you will have depending upon the situation either ferritic or paralytic matrix of.

Thank you very much.