Principles of Casting Technology
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Lecture - 38
Heat Treatment of Castings
Heat treatment of cast iron and non ferrous metals and alloys

Welcome to the lecture on Heat Treatment of Castings, in this lecture we will discuss about cast iron and non ferrous metals and alloys. So, we have discussed about the different kinds of cast iron and when we cast the varieties of cast iron, we need to go for the different kind of heat treatment so that we can get the desirable properties.

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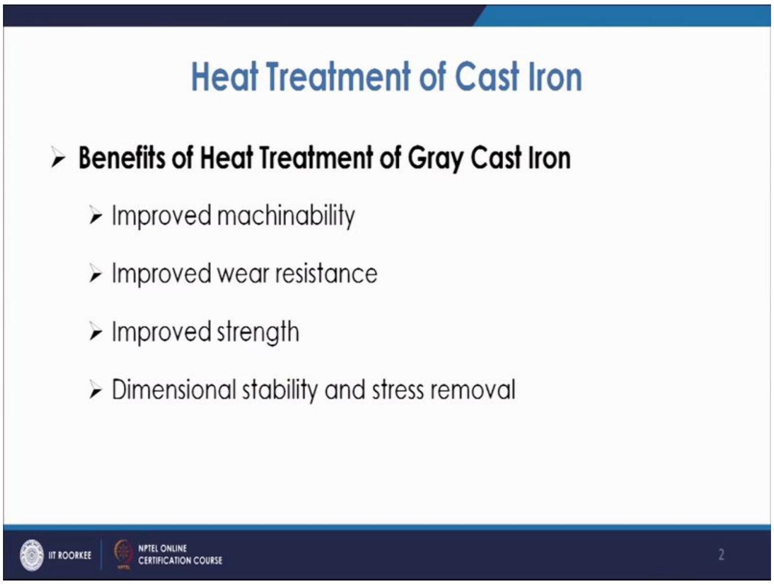

So coming to the variety of caste iron that is the grey cast iron; the grey cast iron if you want to have here improved machinability, or improved weird styles, or improved strength or the stress removal, because once we do the casting, we know that we will have the chance to go for a certain heat treatment, because there will be stresses inside it because of the thermal radiance which is there during the cooling process, also although grey cast iron has the good machinability, because of the presence of graphite flakes, we still may think of having the grey cast iron better machinability.

In many cases we feel to have the improved weird resistance like when the gray cast iron are used for the rings of the piston, in that case you need to have these or cylinder liners in those cases, you need to have the weird assistance to higher degree, so that its life is longer. Similarly for improving the strength of the grey cast iron, so that its strength is increased also the dimensional stability and stress removal. So, for these reasons, you have different kinds of heat treatments which is required on the cast product.

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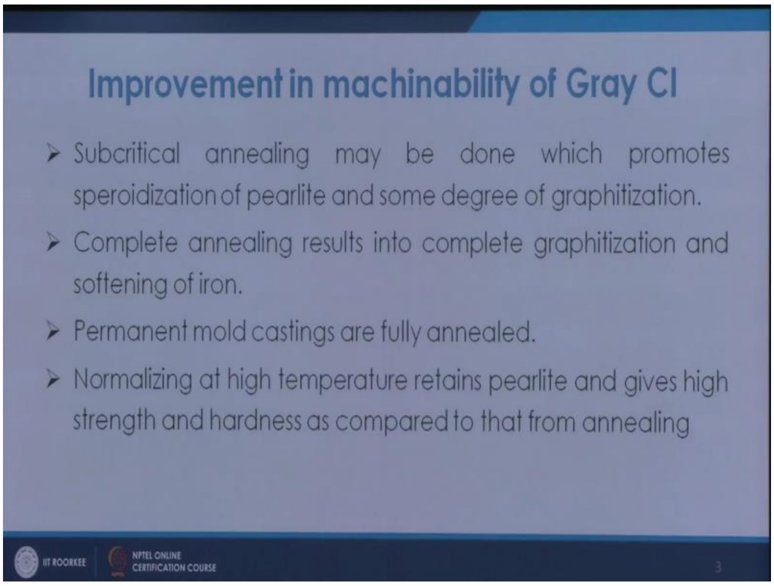

Now, improvement in the machinability of grey cast iron. So, we know that for improving the machinability, normally we go for annealing process. So, in that case the subcritical annealing may be done which promotes speroidization of pearlite and some degree of graphitization. So, in this case the lower critical temperature below that. So, may be about 600 to 700 degree C of heating and holding temperature that is sub critical annealing. So, if we do that basically holding for larger amount of time, that leads to the formation of (Refer Time: 03:17) of this pearlite that is known a speroidization of pearlite. So, and that basically improves this machinability, and also you have some degree of graphitization. So, some graphite's are also formed at the expense of the carbide or carbon. So, the subcritical annealing is one of the methods by which the structure is (Refer Time: 03:44). So, there will be speroidization of pearlite and the improvement in machinability of the gray cast iron.

Then we can also do the complete annealing. So, if you do the complete annealing for that, we are going above the critical temperature. So, we are going about 900 degrees centigrade or 9 to 950 degree centigrade, and then we are basically cooling at the farness very slow rate in that case. So, we are going into the (Refer Time: 04:18) range and then we are very slowly cooling. So, certainly when we talk about grey cast iron, in presence of graphitizes like silicon. So, under that slow cooling, all the complete graphitization will take place, and that will make the iron very soft and in that case it will result into soften structure as well as it will improve the machinability of the structure.

Permanent mold castings are fully annealed. So, that is normally the requirement because in the permanent mold casting, the heat transfer rate is normally higher than in the case of sand molds. So, here you need to go for full annealing. So, that there is complete graphitization taking place, and the grey cast iron becomes softer. If we do the normalizing, we are doing the annealing full annealing, we are going through that temperature of 900 degree centigrade, and then we are cooling at a very slow rate in the furnace, but if we cool in the air then that is slightly a faster cooling rate than in that case of annealing, in those cases some pearlite is retained.

So, retention of pearlite gives the higher strength, because of the fast cooling rate the complete graphitization does not takes place and because of that pearlite is retained and that gives more strength and hardness as compared to that in the case of annealing. So, these are the methods, so in this case you will have improved machinability, as well as you will have the improvement in strength as well as in hardness, and in these cases you will become completely soft and it will have a very high degree of machinability.

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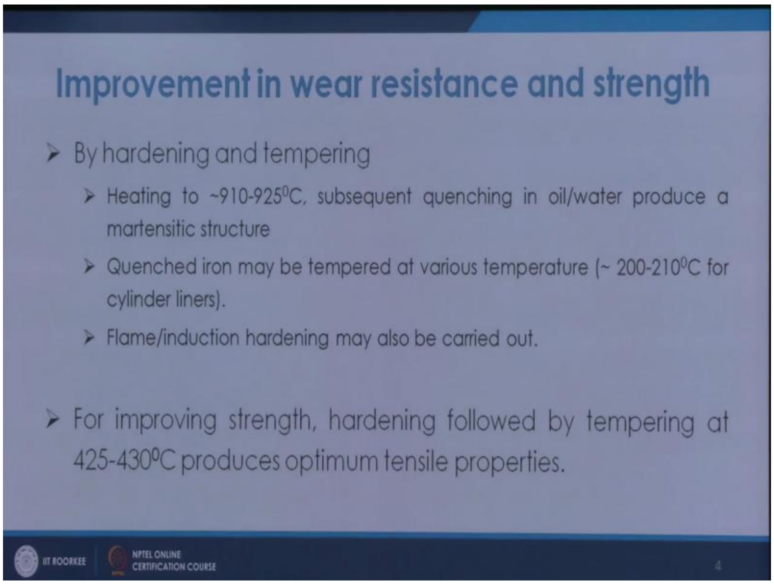

Now, in the improvement in the wear strength, wear resistance as well as strength. So, we have the treatment like hardening and tempering. So, we know that when we go for hardening, in those cases the strength is increased, hardness is increased. So, for that we are going to about 910 to 925 degree centigrade, and then we are quenching into oil or water, to produce martensitic structure. So, that is a simple principle of hardening in which we are going to the austenitic range, and then we are quenching drastically into oil that is (Refer Time: 07:06) but we can also go for water or bright solution and that results into fully martensitic structure that increases the hardness.

Now, in those cases because hardness is quite large, and the martensite formed is extremely little. So, basically you do some softening and that is why you go for tempering. So, tempering will be done at various temperatures. So, suppose in the case of cylinder liners, you see that you first make it hard and then further you temper it at the temperature of 200 to 210 degree centigrade for some time. So, that way you are basically giving some softness in the phases that is completely beetle phase that is basically tempered. So, that martensided phase is tempered, you also do, you can also go for claim or induction hardening. So, these flame or induction hardening, they are the surface hardening methods, in that the core is remaining soft, but only on the surface you induce the hardness. So, that improves your resistance. So, your resistance is improved at the surface, and for that you have flame or induction hardening, which is a verity of surface hardening that is carried out.

For improving strength, hardening followed by tempering at this produces at. So, if your tempering temperature is higher, basically that improves the tensile strength. So, at lower temperature if you are doing the tempering that basically makes the phases soft, that basically. So, you have the extremely beetle phase formed, it is the beltlines is minimized. So, for that you take the lower temperature, but if you go for little higher temperature then that produces the optimum tensile properties.

Stress relief. So, the name indicates that you this is a process for relieving the stresses which are related during the casting process, or during the machining, or during its use. So, during that many a times it also changes its dimensions.

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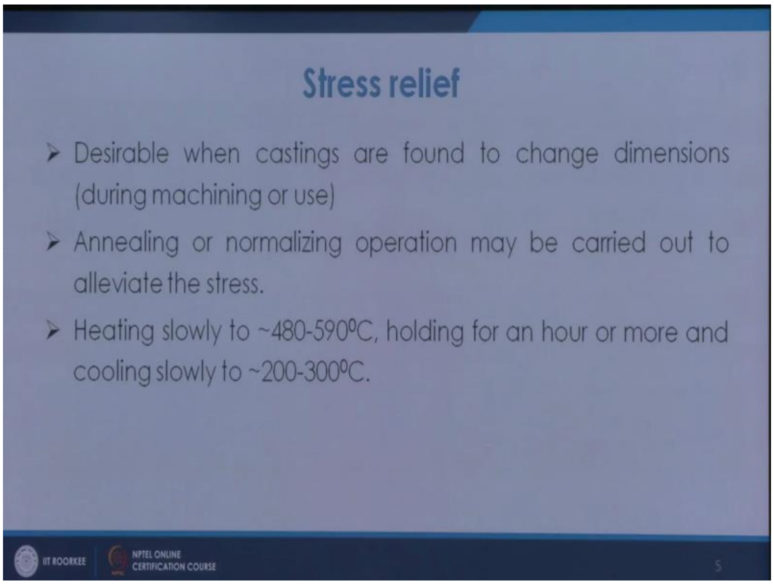

So, because of the stresses which are generated, and if that stress is basically more than the strength of the material then material may change its shape, there may be deformation taking place. So for that annealing or normalizing, may be carried out to alleviate the stress. So, for that you we are heating slowly to 480 to 590 degree centigrade holding for an hour or more, and then cooling slowly to 200 to 300 degree centigrade. So, this way also you try to alleviate the stress, either you go for normalizing or annealing or you may go in this range, heating and then further cooling. So, that basically relieves the stresses.

Coming to another variety of cast error that we have already discussed; so the variety of cast error is this white cast error, which is converted to malleable cast iron by the annealing process and we know that since white cast iron is of no use for the engineering purpose, other than wherever we need the extremely high degree of hardness. So, in otherwise to get the malleability, we are annealing this white cast iron for long hours so that the carbon which is combined form, it is converted to the free carbon or tempered carbon.

So, this annealing heat treatment for white cast iron is done in 3 steps. So, as we know we are hitting to a temperature about 900 degree centigrade or 850, and then we are holding the air for a very large amount of time. So during that holding first of all when we are hitting to a very high holding temperature. So, during the early periods there will be a nucleation of graphite taking place.

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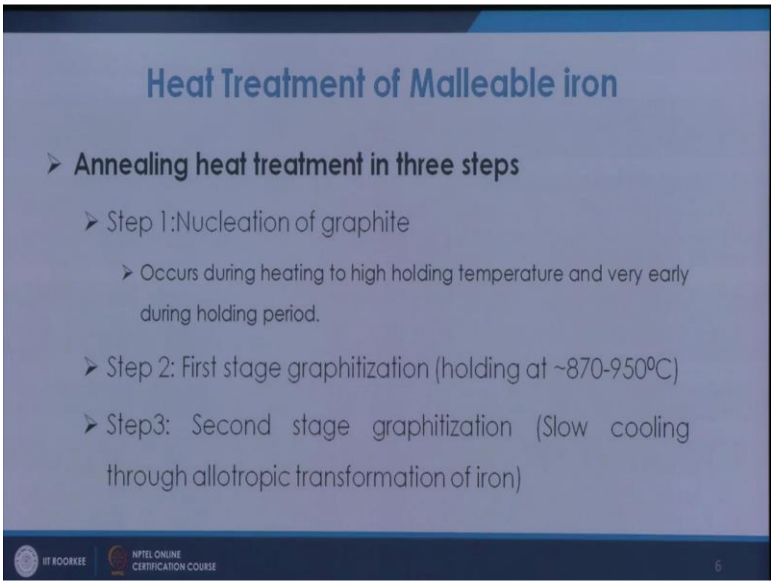

So, basically this annealing is occurring in 3 steps or 3 stages, first stage is nucleation of graphite means, the graphite will nucleate during the holding period early holding period. So, when we are hitting and going to the holding temperature during the early period or during that period, this nucleation of graphite takes place. Now when we are keeping that at that temperature for very long hours 40 to 50 hours, during that the graphitization will take place. So, that is basically dissociation of all these combined carbon into iron plus carbon. So, that is (Refer Time: 12:12) we will dissociate into iron plus carbon that is free carbon and this is known as first stage graphitization. So, the first stage graphitization basically is responsible for the conversion of these massive carbides into iron, plus graphite or free carbon.

Then the second stage graphitization during the annealing process is basically during the slow cooling through allotropic transformation range of carbon of iron. So, basically when we are cooling slowly through the allotropic transformation range, during that process, the formation of matrix, what kind of matrix will be formed that is governed. So, in that basically all the carbon further is removed and you get the ferretic type of matrix. So, that type of matrix that is ferretic matrix is completely ferretic matrix formation that takes place during the second stage of graphitization, during the slow cooling through the allotropic transformation range. So, that is known as second stage graphitization or SSG, this is known as first stage graphitization that is FSG.

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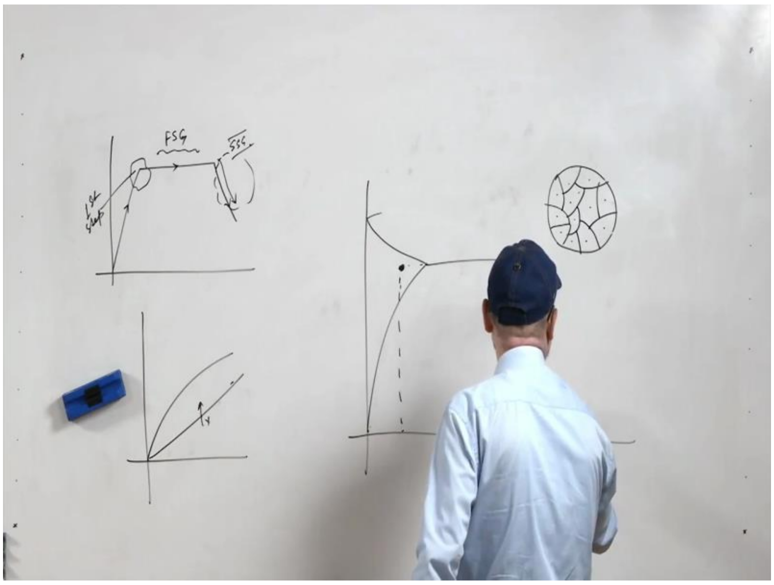

Then you can have the paralytic malleable iron. So, what we have understood that during the annealing cycle of the white cast iron, what we see is, we go here and then we are cooling it slowly. So, as we know this is the first stage, in this case this is the first step. So, this is the first step that is nucleation of graphite taking place and then during this range, this is known as FSG. So, that is first stage of graphitization and then during the second in this process in this time, all the carbides are basically dissolved and they are giving you iron plus free carbon and then that during this stage your secondary stage graphitization takes place, and it that further graphitization during the slow cooling that basically gives you completely ferretic structure.

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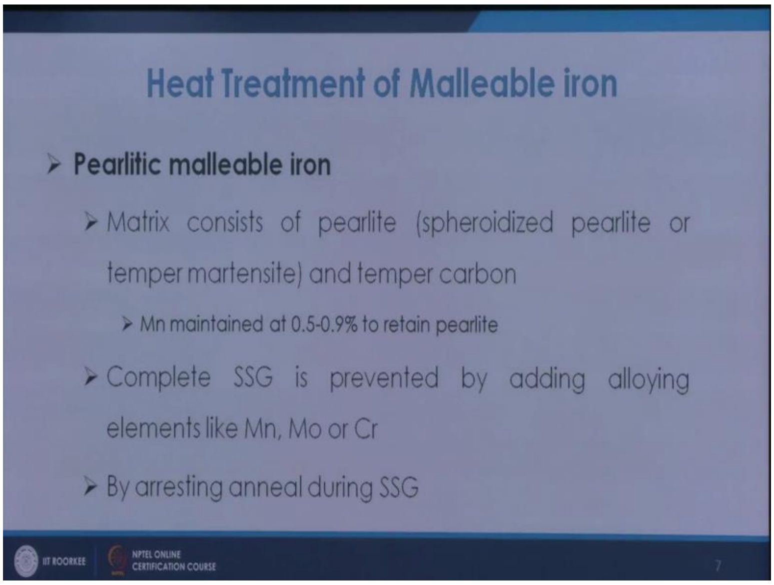

Now, if we want to have the matrix of pearlite, that is spheroidized pearlite or temper martensite, and then temper carbon modules in those cases, you have there are certain treatments and for that basically you have to see that the secondary stage graphitization that has to be prevented. So, during the secondary stage graphitization basically, your result of SSG is the formation of the ferretic structure. Now that is to be prevented, and then if that is prevented, if the cooling rate is fast in these cases if you go and if you further heat it and then further cool fast, in those cases you are getting the paralytic matrix. So, basically if the cooling rate is slow, in the slow cooling the ferretic matrix is obtained; however, if that is prevented this SSG is prevented you get the paralytic metric that gives you more strength also you are giving the (Refer Time: 15:54) so, (Refer Time: 15:56) if it is maintained at the 0.5 to 0.9 percent. So, in that case it retains the pearlite.

So, complete SSG is prevented, also by adding alloying elements manganese (Refer Time: 16:09) or chromium. So, if these alloying elements are there, they try to go for giving you the paralytic matrix. So, one is that you arrest the anneal during the second stage graphitization, another is that you are preventing the second stage graphitization where otherwise you could have got the ferretic matrix, you are getting the paralytic matrix, because of the position, because of the position which is having the manganese (Refer Time: 16:43) or chromium and that gives you a paralytic matrix.

Then the other variety of cast iron as we have discussed is, the ductile iron. So, ductile iron we know that ductile iron is obtained by addition of magnesium or cerium or yttrium in the cast iron melt, and that basically that basically converts this flaccid graphite into the nodular shape of graphite. So, in this case, you have the structure of (Refer Time: 04:19) and spheroidal graphite.

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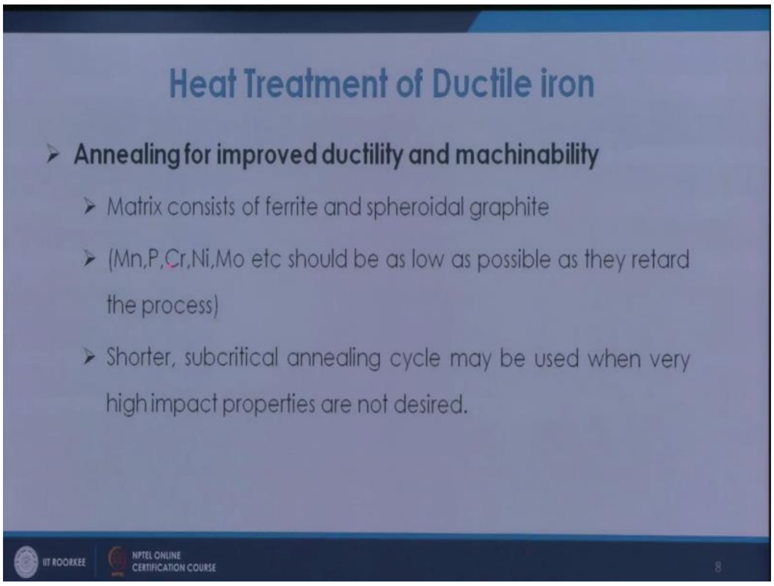

So, manganese phosphoresce chromium nickel molybdenum should be as low as possible as they retard the process. Now shorter subcritical annealing cycle may be used when very high impact properties are not desired. So, basically you can go for some heat treatment for ductile iron and these when these high impact properties are not desired, you can go for shorter subcritical annealing cycle. So, that gives you the desired properties.

Now, if you discuss about the heat treatment of ductile iron, you can go for normalizing of the ductile iron. So, again normalizing means you are going into the range of 900 to 950 degree centigrade and further holding for some time and then, you are cooling in the normal air or atmospheric air. So, that results into homogeneous structure of fine pearlite and improvement in tensile properties.

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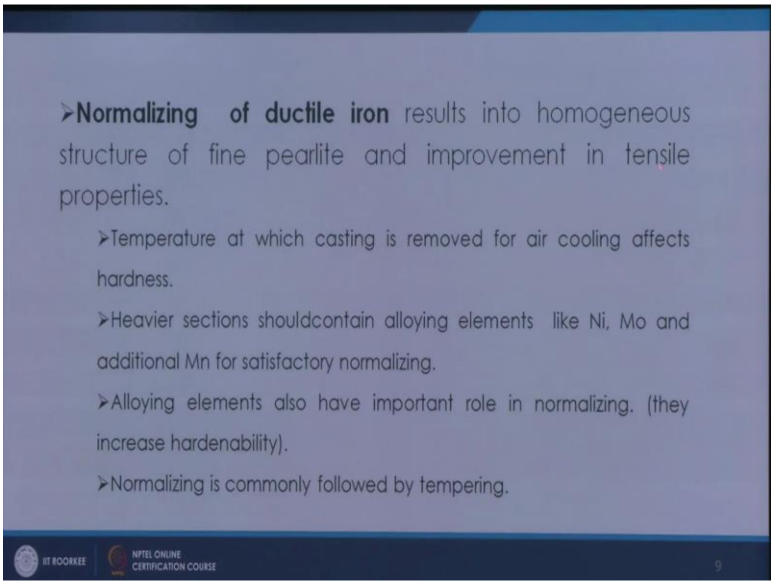

So, suddenly if you are going for normalizing and you are not cooling very slowly, in those cases instead of (Refer Time: 18:36) you get the fine pearlite matrix. Temperature it at which the casting is removed for air cooling, affects the hardness. So, the thing is that if you are removing the casting and letting it into air, if it is below 850c that will be basically affecting the hardness. So, you have to maintain a temperature, you must not go below certain temperature or below some somewhat like 850 degree centigrade. So, that temperature is one of the temperature at which you have to take it from the furnace and alloy it to cool from the air.

Heavier sections should contain alloying elements like nickel molybdenum, and additional manganese for satisfactory normalizing. So, that is one of the conditions should have this alloying elements. So, that has important role in normalizing, because they enhance the harden ability of the material and normalizing is normally followed by tempering. So, tempering done. So, tempering will be done to a temperature may 200 to 400 degree centigrade, and holding for some time and then cooling. So, that will be essential once we go for normalizing treatment.

Hardening and tempering of ductile iron. So, as we know if we want to have higher hardness or higher strength, you go for hardening.

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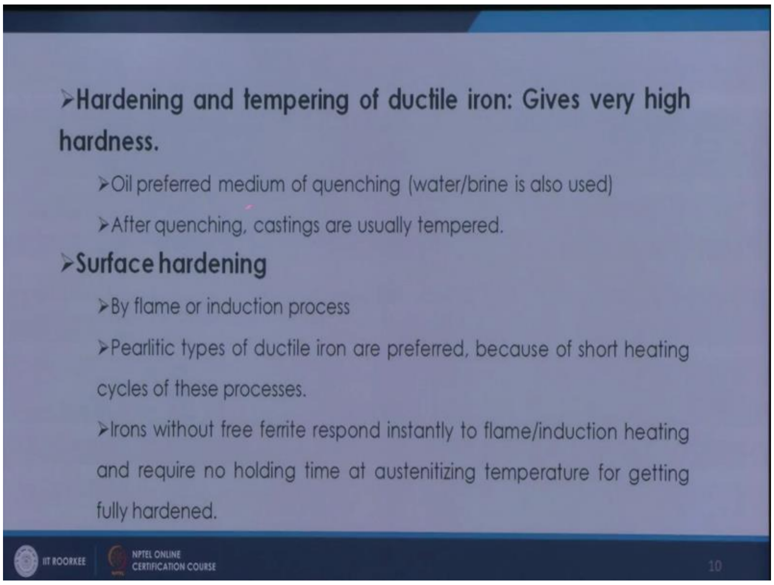

So, if you do this hardening treatment, it gives very high hardness and oil is the preferred medium of quenching all though water or brine is also used, then after quenching casting is normally tempered to induce some softness into the very hard physics which are formed. We also go for surface hardening processes. So, less flame or induction processes are used, which gives the hardness up to certain skin depth, the surface becomes very very hard.

Pearlitic types of ductile iron are preferred because of short heating cycles of these processes in the pearlitic cases; you need to give only short cycle of heat treatments so that is preferred. Irons without free ferrite respond instantly, to flame or induction heating and require no holding time at austenitizing temperature, for getting fully hardened. So, this point tells that if it is there is no fully ferrite matrix in that case, you go to the austenitic range and without much of the holding; you can further cool, so that you can get sufficient hardness. So, that is why we have seen that these pearlitic types are preferred over the ferretic type of ductile iron.

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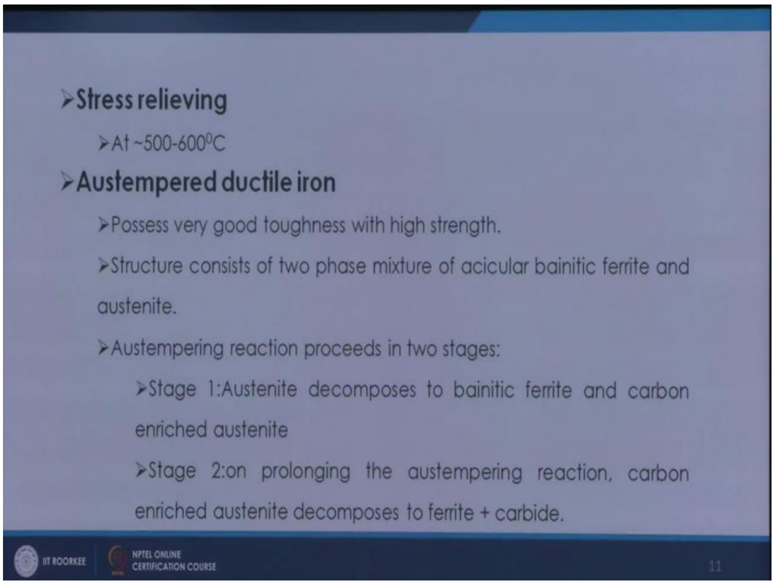

Then we also go for stress relieving, which is done normally at 500 to 600 degree centigrade. So, on that you retain for some time and then cool slowly. So, that basically stress relieves the material.

One of the very important varieties of the ductile iron is the austempered ductile iron, which is formed by a proper type of heat treatment that is austempering type of heat treatment. So, that product is known as austempered ductile iron. So, austempered ductile iron is having the properties as compared to steel or for steel. So, because its strength is as compared to that of forged steel, although you can see that its melting temperature is small. So, by cost in cost wise calculations it is cheaper, but the strength is as compared to steel. So, it is having very good toughness, with very very high strength its mixer I mean structure, consists of two phase mixture of acicular bainitic ferrite and austenite.

So, as we have seen in the case of austempering treatment, we are hitting coming below the nose of the sea curve, and then we are holding. So, that we are getting the benthic structure. So, same thing is followed here also, we are pulling fast, but we are holding it at a temperature, I mean after the point of sea curve about 3 to 400 degree centigrade, then we are holding it at that temperature. So, holding that gives you acicular bainitic type of ferretic structure and austenite. So, basically that gives a large amount of toughness in the material a very good strength.

So, it is occurring in 2 stages, in the first stage it decomposes to bainitic ferrite and carbon enriched austenite. And then in the second stage, we are prolonging the austempering action, carbon enriched austenite decomposes to ferrite plus carbide, which is in the form of needles into the ferretic matrix, and then that basically gives a large amount of strength as well as toughness. So, ADI possesses very good quality.

Heat treatment of non ferrous metals and alloys: So, we have so far discussed about the heat treatment of ferrous materials, in that we discussed about different varieties of steel, carbon steel and steel and then we also discussed about different varieties of cast iron heat treatment, then we also need to discuss about the heat treatment of non ferrous metals and alloys. Now in the case of non ferrous metals and alloys, normally non ferrous materials are used in terms of alloys, because whenever we talk about pure non ferrous materials, they are only used when we need specific properties like very high conductivity or. So, otherwise mostly they are used in form of alloys.

Now, in the cases of non ferrous materials, there are heat treatment processes like homogenization. So, what we see, since mostly we have the alloy, and in case of alloys due to non equilibrium cooling, there is a kind of problem which occurs in the case of solidification, and during the non equilibrium cooling, we have the coring type of structure.

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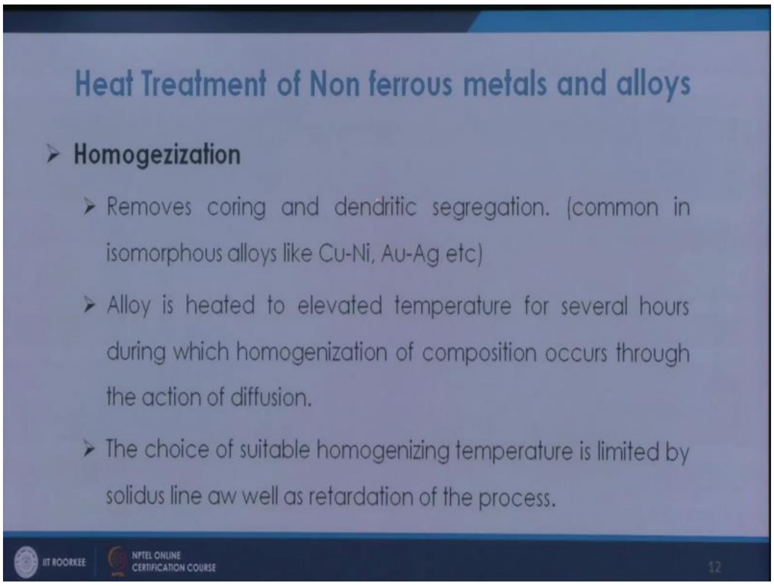

So, that is because of this range of solidification, and because of the non equilibrium cooling, this coring or this is the basically variation or gradient in the composition. So, because of that, you have coring and dendritic segregation that is normally observed in the case of non ferrous materials, or for any material, which is basically a solidification range and which goes while solidification if you cool it under the non equilibrium condition, then this coring dendritic segregation is obvious.

So, that basically is required to eliminated; so that is basically because of the compositional variation, and also we know that there are phenomena like (Refer Time: 26:18) super cooling. So, there are many things that lead to this coring and dendritic segregation. So, for that normally you have isomorphous type of alloys, you have this coring and dendritic segregation which is normally observed. So, that is removed by this homogenization process. So, in that basically the alloy will be heated elevated temperature for several hours. So, if you heat then what happens the composition becomes homogenized, and the composition becomes thoroughly same, and because of the action of diffusion. So, it becomes homogeneous.

And the choice of suitable homogenizing temperature is limited by solidus line as well as retardation of the process. So, we cannot go above a certain temperature, because if you have a solidus range, you cannot go above this because the melting will take place, and if you go below that too much temperature less, I mean below this then at lower temperature there may be less rate of diffusion. So, that is why it is written that, this suitable temperature has to be taken. So, that it is high enough. So, that there is quite good degree of diffusion taking place. So, that composition is homogenized, it is by the diffusion process is the composition is homogeneous, and also the diffusion rate is somewhat higher and it should not go beyond this line, because then there will be melting of one of the phases. So, that should be avoided.

Then the treatment is solutionized, quench and age treatment. So, this is basically in the case of such alloys where on cooling, one of the phase has limiting solubility, in those cases this age treatment is given, which is known as aging. So, this treatment is given to alloys, which is solute components having decrease in solubility with decrease in temperature.

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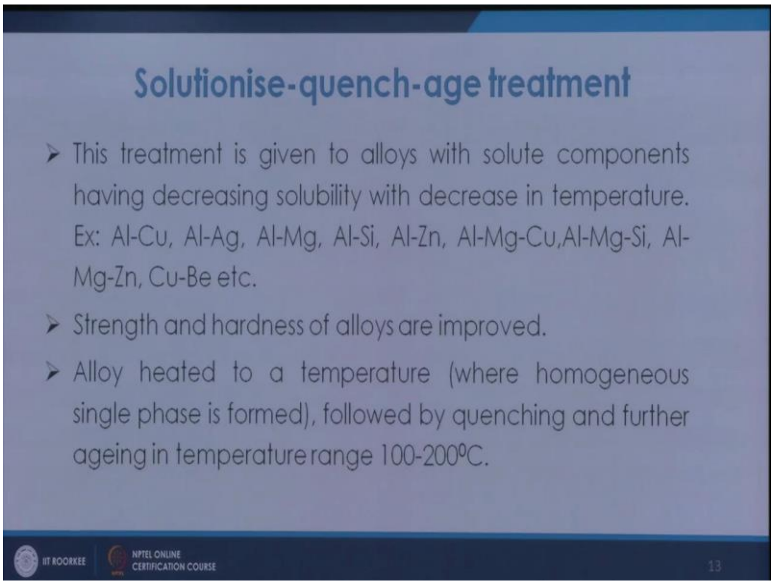

So, in most of these alloys like aluminum copper system, aluminum silver system, aluminum magnesium system, aluminum silicon system, aluminum zinc system, aluminum magnesium copper system, aluminum magnesium silicon system, all these systems basically as the temperature comes down, the solute components has the decreasing solubility with temperature. So in most of the cases what you will see that, with temp temperature decreasing there will be something like many cases.

So, as you further go this is. So, there will be different kinds of phases. So, as we see that once at one temperature if you go, the solubility at this temperature is this much, and once we come down then what happens? As we come down the solubility goes on decreasing. So, for those cases what happens? You basically cool fast. So, that this much amount is basically retained into the mixture and then it becomes a super saturated solution at this temperature, and what happens that, they try to come out because the celebrity is less, so that will be coming out as a coherent phase.

So, the strength and hardness of alloys are improved, because of the formation of the coherent or the semi coherent particle. So, what happens, when in the matrix, what happens once you are trying forcibility? So, this composition of this component once it is retained, in that case what happens? They try to come out as the temperature increased further, so slowly what happens, you have the formation of precipitates will be coming up slowly. So because your solubility was quite low here; so, once we increase further the temperature little bit and hold for some time, then this coming of this (Refer Time: 31:01) precipitates they try to come out. So, solutionize means you are going to a high temperature, then you are quenching.

So, quenching we will do, fast quenching, or fast cooling. So, that you are taking this much of salute, that is arrested in that matrix and then (Refer Time: 31:25) solubility is less. So, it will try to come out of it, and then that basically comes in the form of coherent or semi coherent particles. So, that gives an interface and basically that indeed the dislocation movement.

So, that is basically concept of strengthening in the case of non ferrous metals and alloys. So, that is known as aging. Now if we are living it in the natural atmosphere for the long time, then that is known as natural aging; otherwise if you are aging to a certain temperature, so we are hitting to certain temperature, and holding for some time, in that case the sizes of this precipitates the growth. So, that is known as precipitation hardening. And then once we age for larger time or larger temperature, then sometimes they overage, so that is normally the concept of strengthening because of the precipitation in the case of non ferrous metals and alloys.

So, in the case of over aging you have incoherent particles which are formed, and there will be incoherence see because of that the strength decreases. So aging basically depends upon the temperature and time function, and that is normally the concept of aging in the case of non ferrous metals and alloys. So, that is aging is done in the hundred to 200 degree C range. So, this is normally the heat treatment procedure, normally in the case of non ferrous metals and alloys.

Thank you.