Basics of Mechanical Engineering-2

Prof. J. Ramkumar

Prof. Amandeep Singh Oberoi

Department of Mechanical Engineering

Indian Institute of Technology, Kanpur

Week 02

Lecture 07

Heat Treatment

Welcome to the next lecture on Heat Treatment. This week, we are trying to cover Crystal Structure. Then, the third lecture is on Heat Treatment. Heat treatment is a very important process because, when you try to process, for example, when you try to machine a workpiece, when you try to deform a workpiece, or when you try to join a workpiece, the material property plays a very important role. So, in the last lecture, towards the end, we saw the iron-iron carbide diagram.

In the iron-iron carbide diagram, you could see how the microstructural changes happen with respect to temperature and composition. Heat treatment is one in which it can change the mechanical properties. Sometimes, it can also change the hardness of the surface. It can do all through a treatment, or it can do only on the surface. So, heat treatment is a very important process in which you can change the behavior of the material.

Sometimes, you might be given a situation where you cannot change the shape or the size of the material or of the part, but you want to improve their mechanical properties; then, heat treatment is the only option. I have a shaft or a pen. The surface of the pen is getting worn out. I have to do some surface treatment such that I can prevent the wearing. Then, surface treatment is part of heat treatment.

Contents

- Heat treatment: Introduction
- Purpose
- Classification
- Stages
  - Heating
  - Soaking
  - Cooling
- Type of heat treatment process
- Benefits
- Recapitulate

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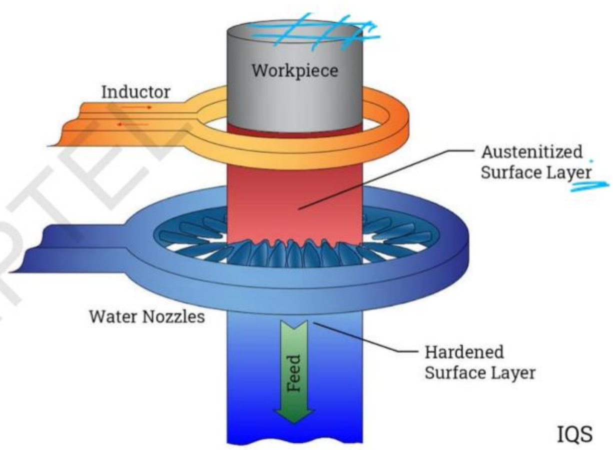
So, in the content, we will see the Introduction, then Purpose, then Classification, Stages of heating, soaking and cooling, Different types of heat treatment processes, Benefits, and their Recap. Heat treatment itself can run to 42 lectures. If you try to take a material science course, one full unit will be heat treatment. Here, we are trying to give you a superficial understanding such that you can appreciate the heat treatment process.

Heat Treatment

- Heat treatment is an important operation in the manufacturing process of many machine parts and tools which imparts higher mechanical properties to steels.



https://www.iqsdirectory.com/articles/heat-treating.html

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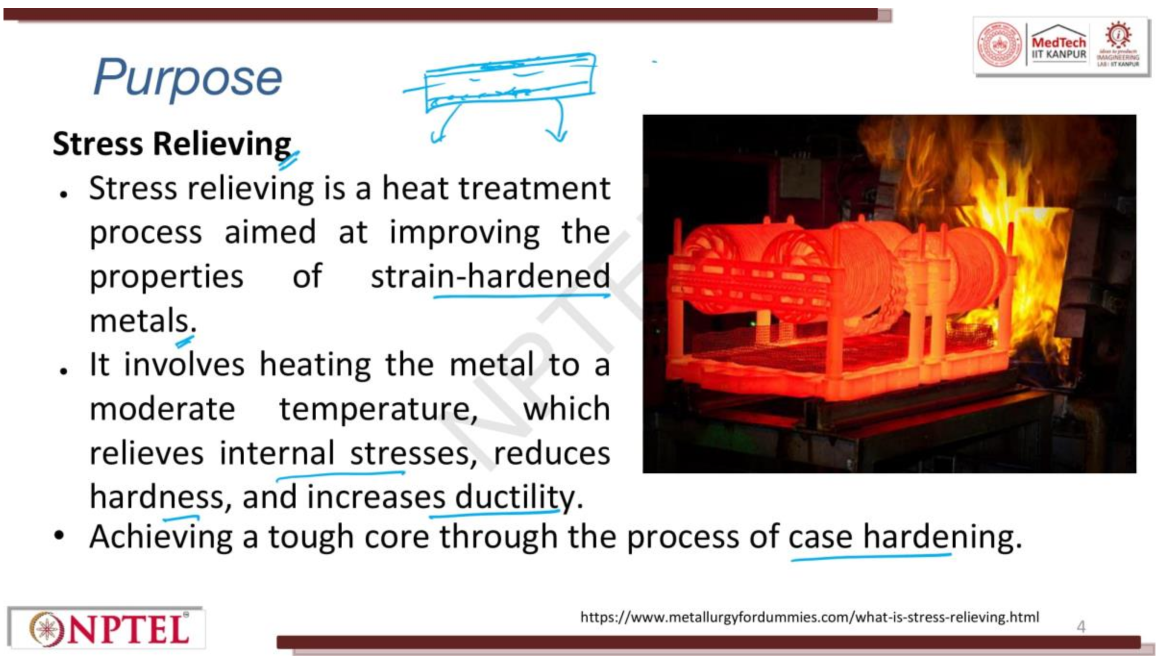
Heat treatment is an important operation in the manufacturing process of many machine parts and tools, which imparts higher mechanical properties to steel.

So, you take a workpiece like a shaft. This shaft is now getting heat treated. By doing the heat treatment, you can try to play only on the surface. Only on the surface, you can try to do a heat treatment, or you can try to do the bulk. You can do it all.

The full properties can be changed. You can try to bring an austenized surface layer. So, for austenization, you can go back and refer to your iron-iron carbide diagram.



Stress relieving is also part of heat treatment. You are trying to deform your material. When you try to deform a material, a shaft is present. When you are trying to deform the shaft, you are attempting to bend it. So here, there will be tensile stress. Here, there will be compressive stress. Now, in the shaft itself, you have two different stresses being introduced.

I wanted to relieve these stresses. Then, what do I do? I perform stress relieving. Stress relieving is a heat treatment process aimed at improving the properties of strain-hardened metals. It involves heating the metal to a moderate temperature, which relieves internal stresses, reduces hardness, and increases ductility.

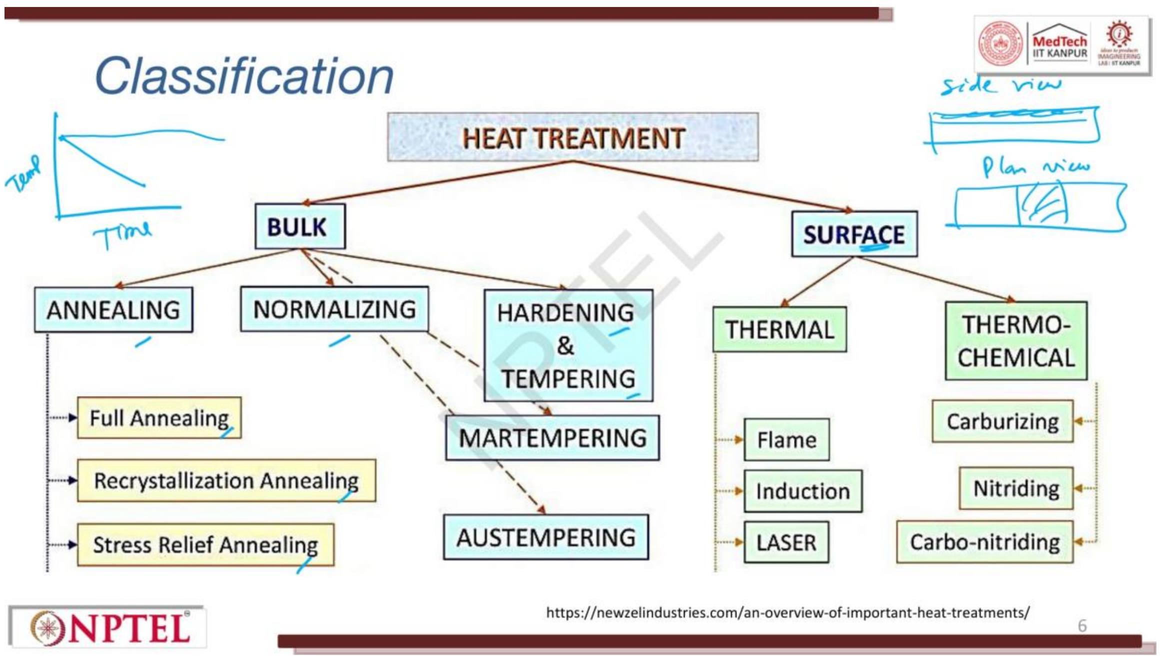
Achieving a tough core through the process of case hardening is also possible, wherein only the surface is hardened, not throughout.

Purpose

- Enhancing the mechanical characteristics of a material, such as hardness, tensile strength, shock resistance, ductility, and corrosion resistance.
- Improving machinability while minimizing brittleness. Alleviating internal stresses in metals caused by hot or cold working processes.
- Modifying or refining the grain structure. Augmenting magnetic and electrical properties. Increasing both corrosion resistance and wear resistance.
- Enhancing the surface hardness of the material. Boosting the fatigue limit of medium and small components, including gears, wrist pins, and shafts.

So, what is the purpose of heat treatment? It enhances the mechanical characteristics of a material, such as its hardness, tensile strength, shock resistance, ductility, and corrosion resistance. So, if you want to enhance any of these properties, you can experiment with heat treatment. Improving machinability while minimizing brittleness.

Elevating internal stresses in metals caused by hot and cold working processes. It also helps in modifying or refining the grain structure. If you want to make a smaller grain structure, you can do it by heat treatment. Augmenting the magnetic and electric properties, increasing both corrosion resistance and wear resistance, are possible through heat treatment. It also enhances the surface hardness of the material, boosting the fatigue limits of medium and small components, including gears, wrist pins, and shafts.



When you consider heat treatment, it is classified into two categories. You can treat the entire material, which is called bulk treatment. If you want to treat only the surface, you can focus on the surface layer. If you want to treat only a specific portion, that is also possible. This is from the side view.

This is from the plan view. If you want to treat only the center portion of the shaft, you can do that. So, bulk and surface are two categories of heat treatment. When discussing bulk treatment, we have annealing, normalizing, hardening, and tempering. We also have martempering and austempering.

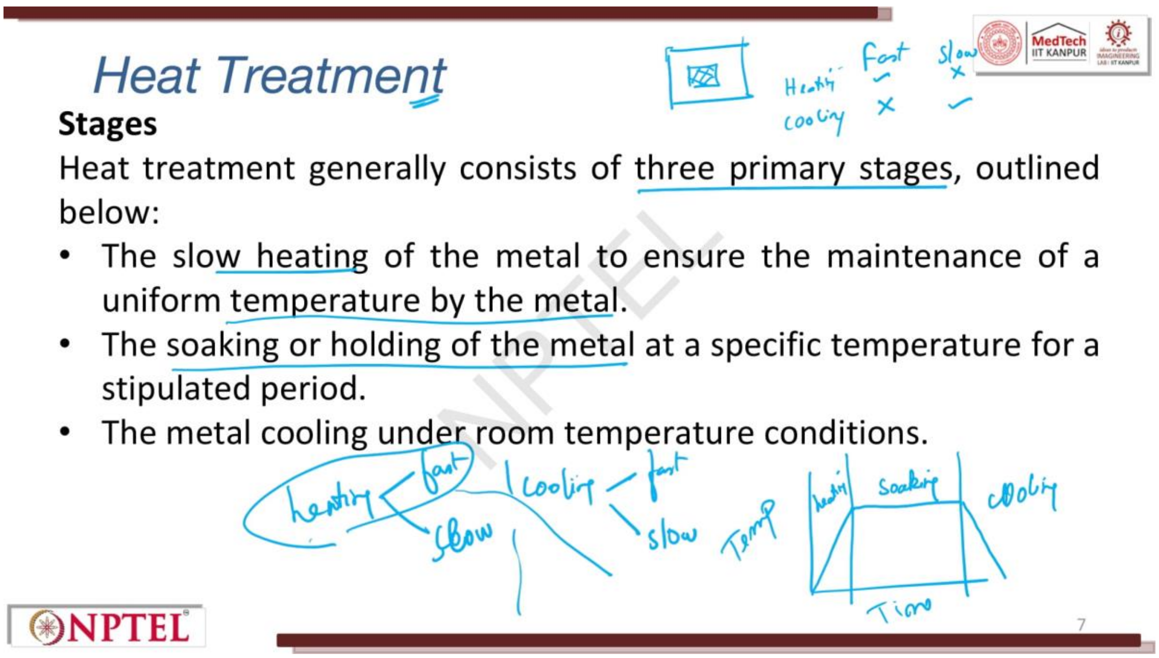
Annealing, normalizing, hardening, and tempering. These are the classifications under bulk. And again, in annealing, you have full annealing, recrystallization annealing, and stress relief annealing. When we go towards the surface, you have two properties. One is thermal, and the other one is thermochemical.

Thermal means you can do flame, induction, or laser. When we try to talk about thermochemical, it is carburizing, nitriding, and carbonitriding, a mixture of these two. So here, surface flame hardening. So when we try to introduce flame heating on the surface, you can try to do bending or you can try to relieve stresses. You can try to play with this.

So this is the major classification of heat treatment. Now, annealing, normalizing, and hardening, you cannot change the shape and size of the material. So all you can do is play with the temperature and time. That's all. So putting this inside a furnace, now I try to play with the temperature, time, and see what is the response or achieve what I want.

So here, it is going to be a temperature versus time plot. So I heat it to a certain temperature. Then, I quickly cool it. I slowly cool it. Or I heat it and then instantly quench it into water or something.

So all these things are now going to be used for bulk heat treatment. The fundamental is this.



Heat treatment has multiple stages. So let us understand the stages. Heat treatment generally consists of three primary stages.

Slow heating of the metal ensures the maintenance of a uniform temperature by the metal. If I do not do slow heating, if I do sudden heating, then what will happen is the core will be very soft or it will not have anything. The surface will try to take the hard values. Slow heating of the metal ensures the maintenance of a uniform temperature by the material.

The soaking or holding of metal at a specific temperature for a stipulated period is called soaking or holding. So, what I am trying to say is, I will slowly heat it. This is temperature. This is time. I will slowly heat.

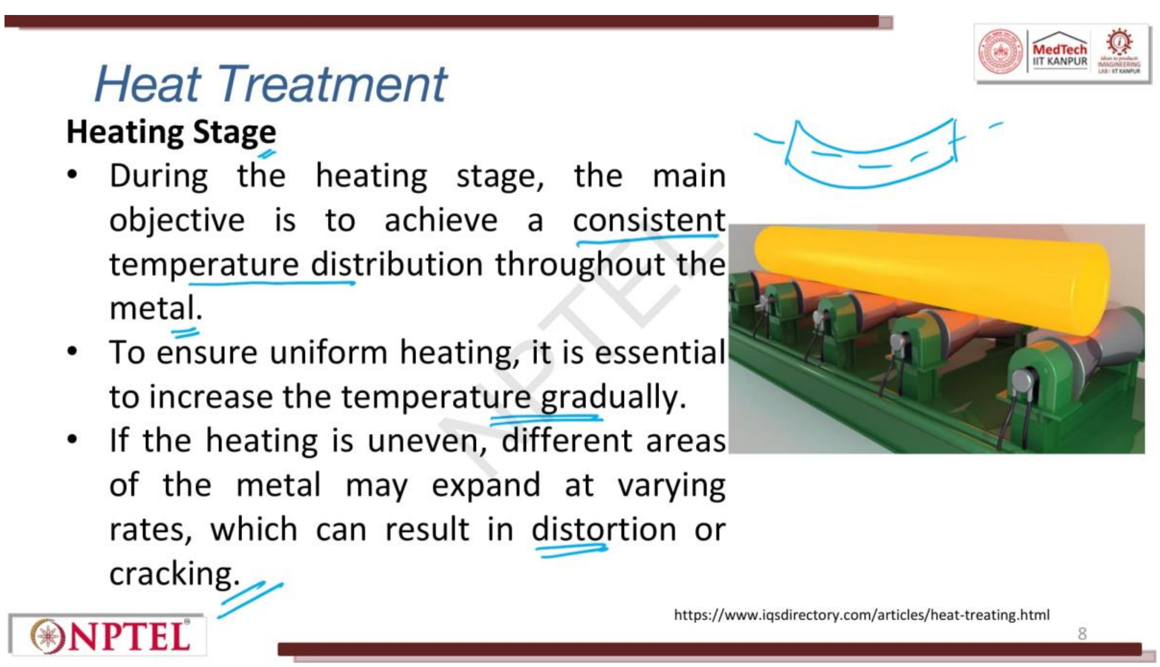
Then, I maintain it at a certain temperature. Then, I slowly cool it. So, these are the stages. So, the first stage is going to be heating. The next stage is going to be cooling.

And, this is going to be soaking. Okay. So, heating and cooling are there. You can have heating. You can have again two things. You can have fast.

You can have slow. The same way you can have cooling, you can have fast and you can have slow. Each of them has its own response. You can have fast heating and slow cooling. It is possible. So if I put fast, slow, heating, and cooling, you can have fast heating and cooling.

Then, slow is possible, and you can have a combination of these two, depending upon your requirements. And, you know very clearly, since you have gone through the iron-iron carbide diagram, the temperature has a clear response on the microstructure being formed. The microstructure, in turn, has a direct response on the mechanical properties. So you can have slow heating, so that the entire material is heated. You can do soaking or holding. Soaking or holding is this.

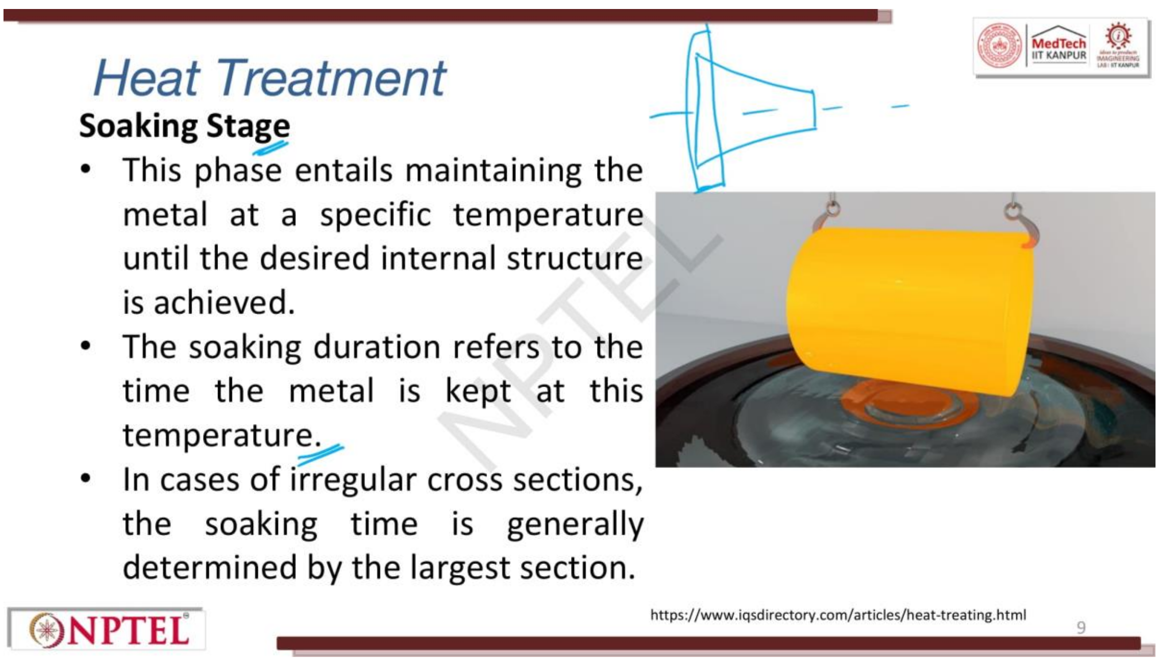
So, wherein the temperature at a specified temperature is maintained, so that the transformation in the microstructure can happen. And then, you have metal cooling under room temperature conditions.



Heating stage. During the heating stage, the main objective is to achieve a consistent temperature distribution throughout the material. If there is improper distribution of temperature, then you can have thermally induced stresses. So these thermally induced stresses can cause the material to warp.

The shaft, whatever is there, can warp like this. Because there is not much distribution of temperature, the metal can cool. It ensures uniform heating. It is essential to increase the thermal gradient. If the heating is uneven, different areas of the metal may expand at varying rates, which can cause distortion or cracking.

When the gradient is very steep, there can be cracks. There can be distortions. So generally, uniform heating is essential to increase the temperature gradually.



In the soaking stage, this phase entails maintaining the metal at a specific temperature until the desired internal structure is achieved. So you want martensite, you want austenite.

You want pearlite. You want ledeburite getting mixed in this. So here, what you do is, you try to soak and keep it for some time, such that the internal structure is transformed to get what is required. The soaking duration refers to the time the metal is kept at a constant temperature. In the case of irregular cross-sections, the soaking time is generally determined by the largest cross-section. For example, you have something like a funnel. So this area dictates the soaking time.

Heat Treatment

Cooling Stage

- The cooling technique employed can differ depending on the specific type of metal and may utilize a cooling medium such as a liquid, gas, or a combination of both.
- The rate at which cooling occurs is affected by both the metal itself and the selected medium, making this process vital for obtaining the desired properties of the metal.

https://www.iqsdirectory.com/articles/heat-treating.html

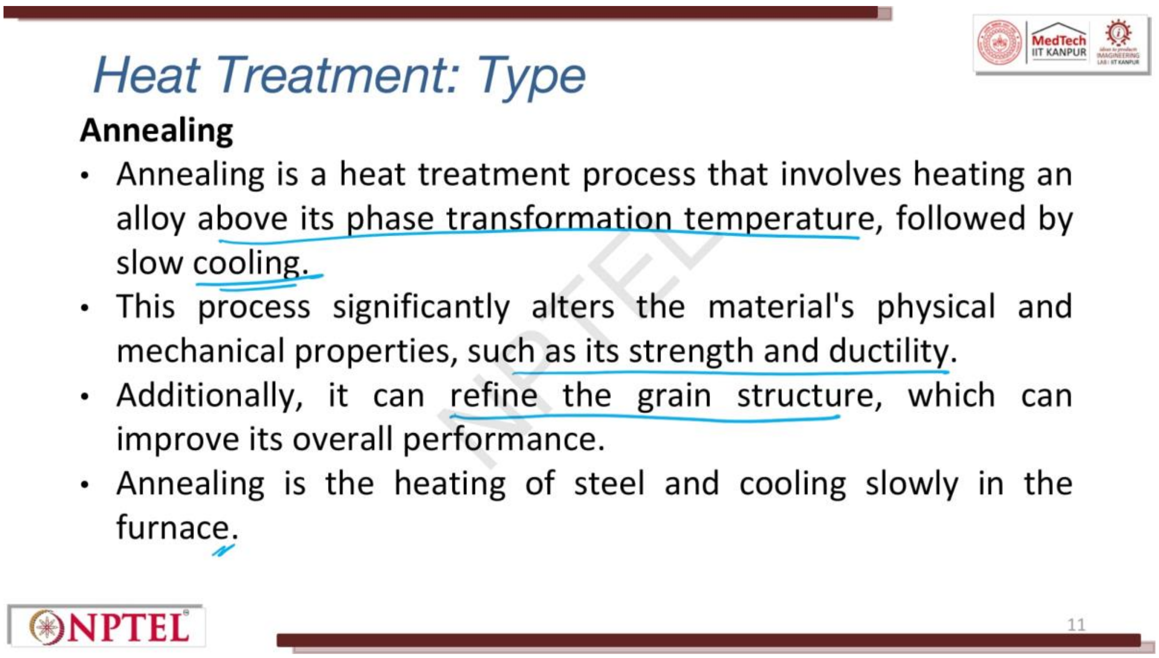
Cooling stage. The cooling technique employed can differ depending on the specific type of metal and may utilize cooling mediums such as liquid, gas, or a combination. For example, many times what we do is, we try to take a bath.

Inside a bath, we fill it up with liquid. This can be water or oil. So we quench the material. When we quench the material, it can be a sudden cooling. If you have oil, the cooling rate will be much lower.

So you can also blow air and then cool it. So you can think of liquid, you can think of gas, or you can think of something like steam also, depending upon your application. The rate at which the cooling occurs is affected by both the metal itself and the selected medium. So liquid medium, solid medium, or a gas medium, you can choose. Solid medium is you can also try to have some salts and then you can quench it in that salt.

So then there is a diffusion of the salt that also happens on the surface. If you see a blacksmith, he always tries to fully cover the hot rod with coal, and then he heats it and hammers it. So when the coal is around, it burns the iron, and there is a possibility of carbon diffusing into the surface. And when it diffuses, it forms cementite, or the carbon surface is hardened. And once he gets the shape, he immediately quenches it to retain the shape.

A blacksmith does it. That is how they have been making a sword. That is how they have been making a lot of utensils and other things at home. So the rate at which cooling occurs is affected by both the metal itself and the selected medium, making this process vital for obtaining desired properties of metals.



Now, let us see Annealing. So now, we saw these are the stages of heat treatment. Now, we are trying to take each of these processes under bulk. Annealing, normalizing, hardening, and tempering. Annealing. Annealing is a heat treatment process that involves heating an alloy above its phase transformation temperature.

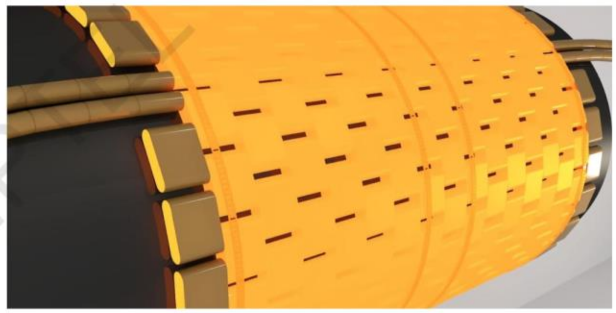
Phase transformation temperature, where there is a change of phases, right? Above its phase transformation temperature, followed by slow cooling. The process significantly alters the material's physical and mechanical properties, such as strength and ductility, of any given material, which is changed drastically. So, what do we do? We try to take a shaft. This shaft is heated to a phase transformation temperature and then allowed to cool slowly.

Slow cooling is when they put it inside a furnace and allow the furnace to slowly reduce the temperature and get cold. Additionally, it has refinement of grain structure, which can improve the overall performance. Annealing is the heating of steel and cooling it slowly in the furnace. So, annealing is heating, and furnace cooling is annealing.

Heat Treatment

Annealing

- The purpose of annealing is
- To reduce hardness
- To improve machinability
- To increase or restore ductility
- To relieve internal stresses
- To reduce or eliminate structural inhomogeneity.



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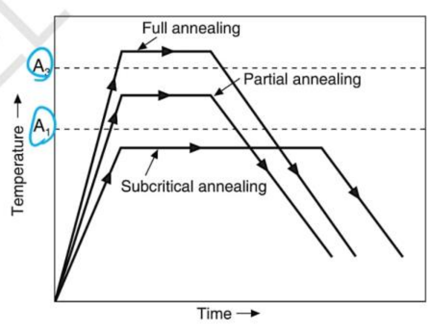
The purpose of annealing is to reduce the hardness, improve machinability, restore ductility, relieve all the internal stresses, and eliminate structural inhomogeneity. So, for doing all these things, we always anneal the given sample.

Annealing

Annealing	Diffusion Annealing	Full Annealing
	Spheroidize Annealing	Process Annealing

Diffusion Annealing

- Diffusion annealing, also known as homogenization within alloy steel ingots and castings.
- This process involves heating the material to a high temperature, typically between 1000°C and 1200°C.

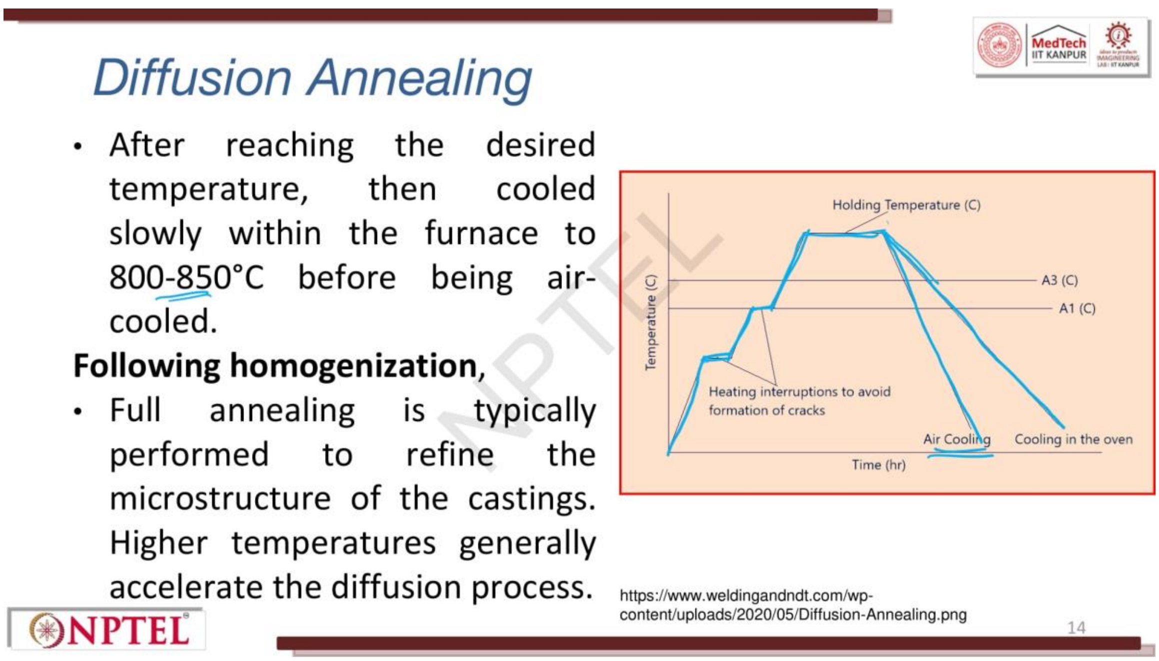


https://whatispiping.com/annealing/

So, in annealing, there can be four types of annealing. One is called diffusion annealing, then we have spheroidal annealing, full annealing, and process annealing. So, if you see, full annealing is A1 to A3. Where is this A1, A3 coming from?

If you go back to your iron-iron carbide diagram, I would have mentioned A1 and A3. So you do heating, then soaking, then cooling. Partial annealing means you do not go below A3, and then you do slow cooling. Subcritical cooling is when you do not even cross the A1 temperature, and then you soak it for a longer time, and then cool it. So diffusion annealing, also known as homogenization, is used within alloy steel, ingots, and castings.

The process involves heating the material to a high temperature, typically 1000 to 1200, and allowing it to undergo furnace cooling.

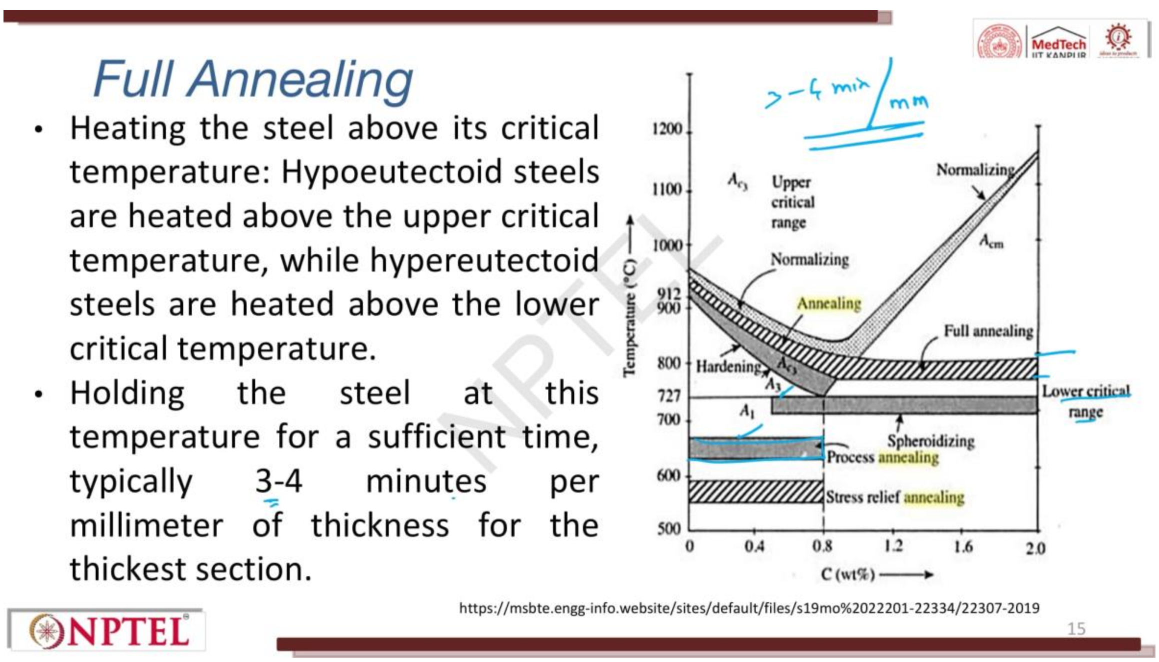


What is diffusion annealing? After reaching the desired temperature, it is then cooled slowly within the furnace to 800 to 850 degrees Celsius before being air-cooled. So here, what we do is try to take it to a temperature. And then, what we do is, after that, we hold it for some time.

Then, we do slow cooling, right? Slow cooling we do. So it follows like this. And, once it reaches a certain critical temperature, then what we do is we do a quick air cooling. So following homogenization, full annealing is typically performed to refine the microstructures of castings.

Higher temperatures gradually accelerate the diffusion process. So we saw diffusion annealing. So in diffusion annealing, we try to take it to a temperature of 800 to 850, and then do air cooling. So if you see this diagram, it is pretty interesting. So you initially heat, then you soak it for some time.

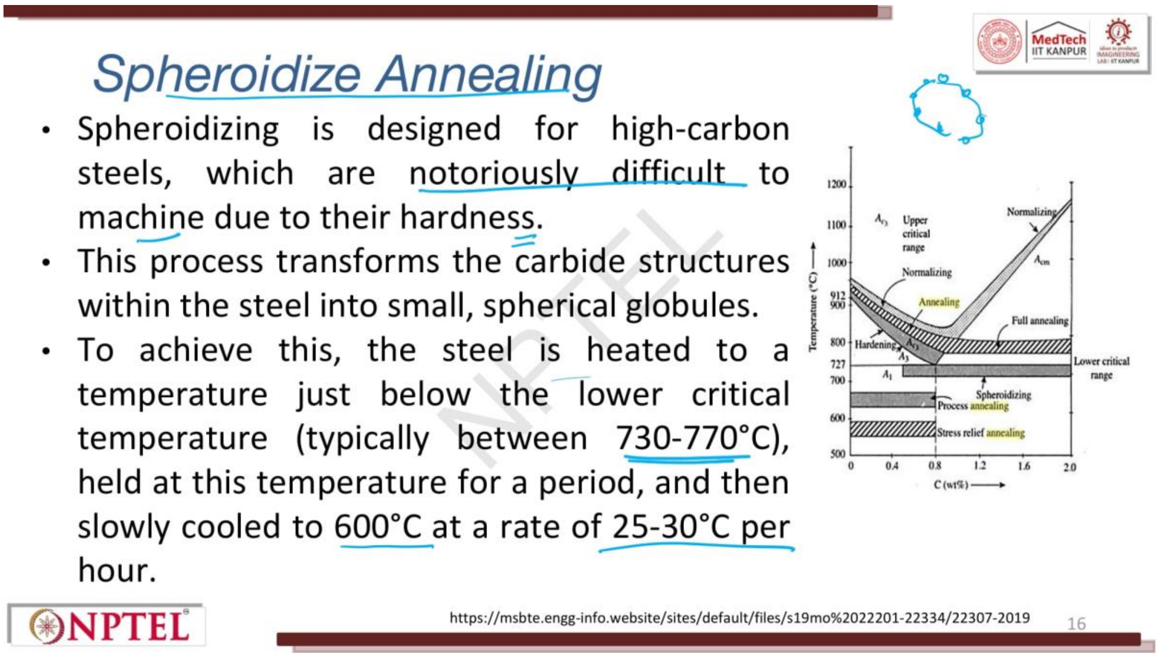
So then, you try to slowly heat, then you try to soak, then you heat, then you soak, and then you allow them to have air cooling. Then, air cooling means you take it from the furnace, put it outside in the free atmosphere, or you force air, or you try to do slow cooling, keeping it inside an oven so that the temperature slowly decreases in the oven. So the heating interruption is to avoid the formation of any cracks because the moment you keep on increasing, there is a thermal shock. The thermal shock tries to break or crack. So what we do is heat it, soak it, heat it, soak it, heat it, soak it. They do it step by step such that you get it.



Full annealing. Full annealing involves heating the steel above its critical temperature. Hypo-eutectoid steels are heated above the upper critical temperature, while hyper-eutectoid steels are heated above the lower critical temperature. So this is the lower critical range, and then this is the higher critical range.

This is the higher critical range, right? So, you see full annealing happening here. So, lower critical range. Holding the steel at this temperature for a sufficient time, typically 3 to 4 minutes per millimeter of thickness for a thick section, you hold it for this. So, 3 to 4 minutes if I say, then you will not, even for a flat surface, can we do that.

So, it is 3 to 4 minutes per millimeter. This is very important, right? So that you can try to calculate the thickness, and then you will see what is the sufficient time of holding. So again, A1, A3 are there. So here, you can see spheroidizing, process annealing, and stress relieving.



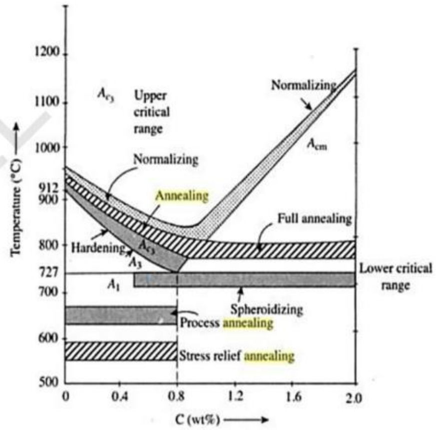
Spheroidized annealing. Spheroidized annealing is designed for high carbon steels, which are notoriously difficult to machine due to their hardness. So, spheroidized annealing is hard to machine because of its hardness. This process transforms the carbide structure within the steel into small spherical globules. So, the grains are there.

So, globules will be formed. These globules are hard while machining. To achieve this, the steel is heated to a temperature just below the lower critical temperature. It is held at that temperature for a period and then slowly cooled to 600 degrees Celsius at a rate of 25 to 30 degrees Celsius per hour. So this is spheroidized.

So you try to take it to 730 to 770, and then you try to bring it down 25 to 30 degrees per hour, slowly cooling it.

Process Annealing

- Process annealing is primarily used on low-carbon steels to reverse the effects of cold working.
- By heating the steel below the lower critical temperature, deformed grains recrystallize, leading to increased ductility and stress relief.
- The annealing temperature varies depending on factors like the degree of cold work, initial grain size, and the holding time.

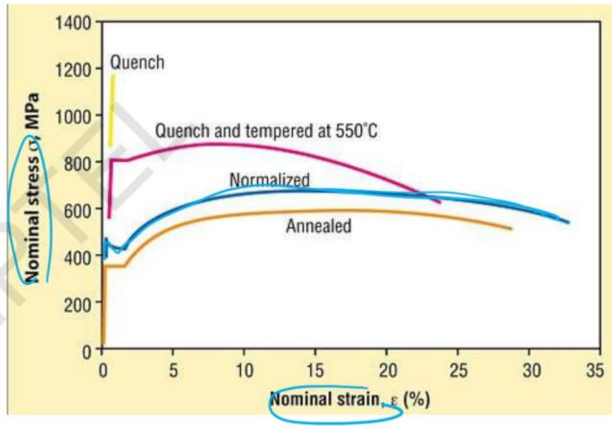


Process annealing. If you go back, there are four annealing processes: diffusion annealing, spheroidized annealing, full annealing, and process annealing. So if you look at it, process annealing happens at this temperature. Process annealing is primarily used for low carbon steel, right?

By heating the steel below the lower critical temperature A1, deformed grains recrystallize, leading to increased ductility and stress relief; this is process annealing. Below this temperature, we try to do that. The annealing temperature varies depending upon factors like the degree of cold working, initial grain size, and holding time. So the process annealing temperature changes.

Normalizing

- Normalizing is a final heat treatment process for components experiencing significant stress.
- It involves heating steel slightly above the austenite stability temperature, holding it briefly, and then air-cooling.



https://www.thermexmetal.com/what-is-normalizing

Next is normalizing. Normalizing is a final heat treatment process for components experiencing stress relief. So this is normalizing; you can see here. So strain and nominal stress. So when we try to do a normalized sample, you get the response. When you see an annealed sample, you get a response like this.

In a normalized sample, you see a huge strain we get. So normalizing is the final heat treatment process for components experiencing significant stresses. It involves heating steel slightly above the austenite stability temperature, holding it briefly, and then air cooling it. Holding it briefly in annealing, it was furnace cooling. Here in normalizing, it will be air cooling. So you see the ductility, the strain, whatever you get is very high.

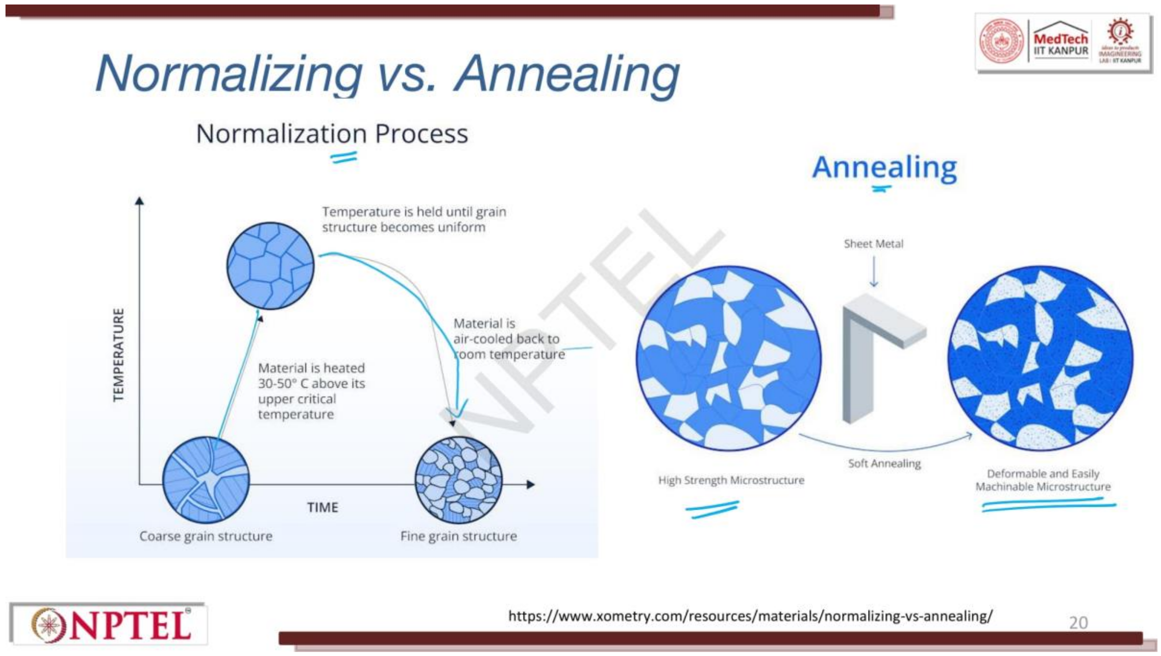
Normalizing

- This results in a microstructure of ferrite and pearlite in hypo eutectoid steels and pearlite and cementite in hypereutectoid steels.
- Normalizing enhances yield strength, ultimate tensile strength, and impact strength.
- Normalized steels are harder and stronger than annealed steels of the same composition but exhibit lower ductility.

https://www.xometry.com/resources/materials/normalizing-vs-annealing/

This results in a microstructure of ferrite and pearlite in hypo-eutectoid steels and pearlite and cementite in hyper-eutectoid steels. Now, it is very clear how the microstructure is formed. Ferrite and pearlite are formed in hyper-eutectoid. All these things you should please refer to your iron-iron carbide diagram.

Normalizing enhances yield strength, ultimate tensile strength, and impact strength. Normalized steel is harder and stronger than annealed steel of the same composition but exhibits lower ductility. In annealing, what happens is you do furnace cooling. Here, you do air cooling.



So if you try to look at the normalization process and the annealing process, temperature versus time, you see a coarser grain.

The material is heated 30 to 50 degrees above the upper critical temperature. Now, you see what happens to the microstructure. The temperature is held until the grain structure becomes uniform. From here, suppose if there is carbon here, all these things will get diffused inside the grain, and then you get it. So on air cooling, the material is air cooled back to room temperature, and you see fine grain structures getting formed.

So you see at temperatures, and then while cooling, what happens? So this material is air cooled to get this structure. So coarse grains are converted into fine grains during the process of normalization. Again, this we are talking about with respect to steel, iron, but if you try to do copper and other things, you might have different microstructures. When we try to do annealing, we have a high-strength microstructure.

So when you do a soft annealing, you see here deformation and easily machinable microstructures are formed. High strength annealing, you get this in structure.

Hardening

- This process is conducted in three steps.
  - First, the object is heated to a temperature higher than the critical point.
  - Then, it is held at this elevated temperature for a specific period.
  - Finally, the object is rapidly cooled by immersing it in a quenching medium such as water, salt bath or oil.

https://flametreatingsystems.com/gear-flame-hardening-3/

NPTEL

Hardening and tempering, this is the next one. The process is conducted in three steps. First, the object is heated to a temperature higher than the critical point.

Then, it is held at the elevated temperature for a specific period. Finally, the object is rapidly cooled by immersing it in a quenching medium like water, salt bath, or oil. You can also have air cooling. Air means something like nitriding. So something like that.

You can have nitrogen passing through it. So you can also have water, salt, oil, or gases. So hardening is a process which is very important. Here, it is held at a certain temperature for a certain period of time and then rapidly cooled.

Quenching

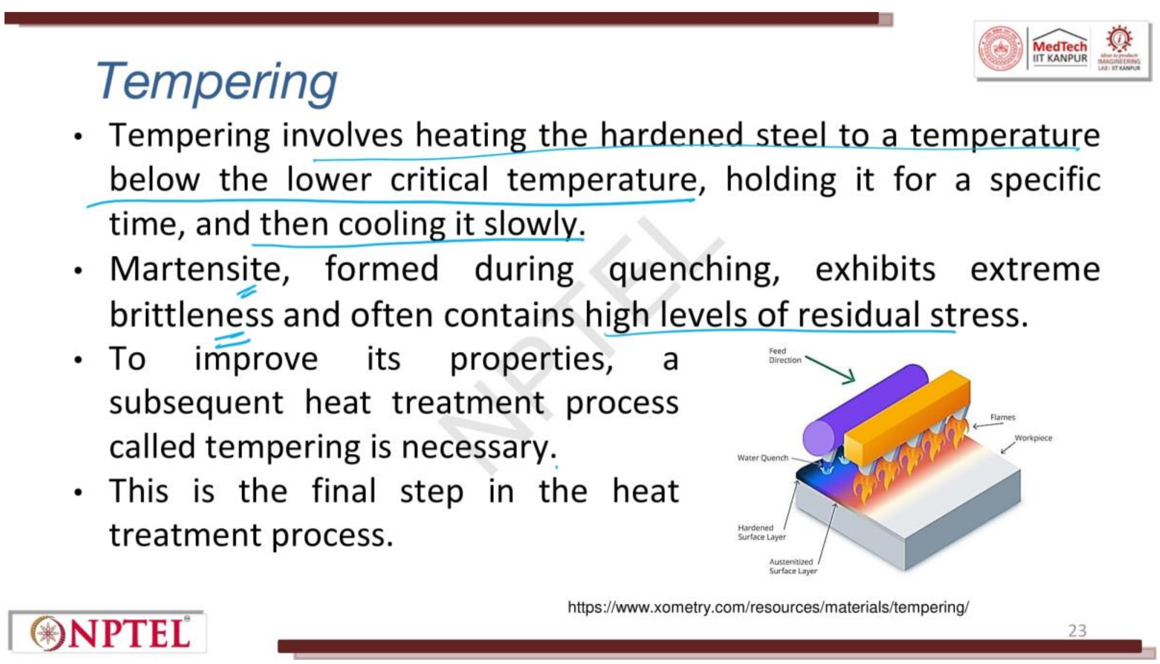
- Quenching is the process of rapidly cooling metal using various substances, including air, water, oil, or brine.
- While quenching is often linked to the hardening of metals, it does not always lead to hardening.
- Compared to water quenching, oil offers several advantages:
  - It provided range, minimizing the risk of quenching defects like distortion and cracking.
  - The cooling capacity of oil remains relatively stable over a wider temperature range,
  - Oil baths are widely used for quenching alloy steels due to their controlled cooling characteristics.

NPTEL

Quenching is a process of rapid cooling of metals using various substances, as we have discussed earlier. Brine solution, air, water, oil, etc., etc. While quenching, it is often linked to the hardening of the metal. It does not always lead to hardening. It can also help to reduce the hardening.

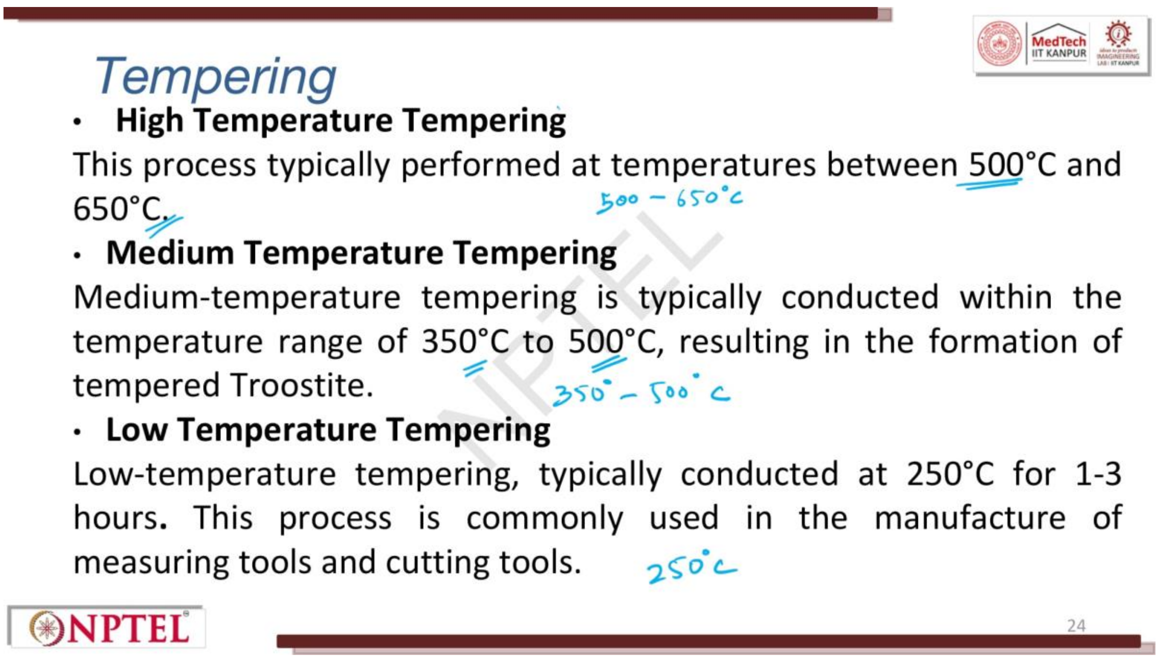
Compared to water quenching, oil offers several advantages. Because when you quench it in water, what happens is the heat gets transferred to the water. The water starts bubbling, and then it forms a jacket around it. So once it forms a jacket around it, the performance is different. So, oil quenching is always preferred.

It provides a range, minimizing the risk of quenching defects like distortion and cracking. In oil, it is reduced. The cooling capacity of oil remains relatively stable over a wide range. The oil baths are widely used for quenching alloy steel due to their controlled cooling characteristics.



Hardening and tempering. Tempering involves heating the hardened steel to a temperature below the lower critical temperature, holding it for a specific period of time, and then cooling it slowly. Tempering is heating the hardened steel to a temperature below the lower critical temperature. This is very important. Martensite formed during quenching exhibits extreme brittleness and often contains higher levels of residual stresses. To improve the properties, a subsequent heat treatment process called tempering is always done. Martensite is the hardest microstructure.

So when you do quenching, the martensite formed during quenching exhibits extreme brittleness, contains very high residual stress, and is very hard. This is the final step in the heat treatment process. You do tempering, and then you try to remove the brittleness and induce ductility.



High-temperature tempering, medium-temperature tempering, low-temperature tempering. These are the different types of tempering processes. This process typically performs tempering around 500 to 650 degrees Celsius.

Medium-temperature tempering is typically conducted within a range of 350 to 500 degrees Celsius. So, 500 to 650 is high, 350 to 500 is medium, and anything less than 250, typically 250 degrees Celsius and less for 1 to 3 hours. The process is commonly used in the manufacturing of measuring tools and cutting tools. We do low-temperature tempering. So what we do is, we get a sustained, stable microstructure.

Heat Treatment: Benefits

- Relieving residual stresses
- Enhancing ductility
- Increasing toughness
- The tempering temperature significantly influences the final properties.
- Higher tempering temperatures lead to lower residual stresses, reduced hardness, and increased toughness.
- After tempering, the steel is typically cooled slowly to minimize the development of new thermal stresses.

So the heat treatment benefits are: it relieves residual stress, it enhances ductility, and it increases toughness. The tempering temperature significantly influences the final properties. Higher tempering temperature leads to lower residual stress, reduced hardness, and increased toughness. After tempering, the steel is typically cooled slowly to minimize the development of new thermal stresses.

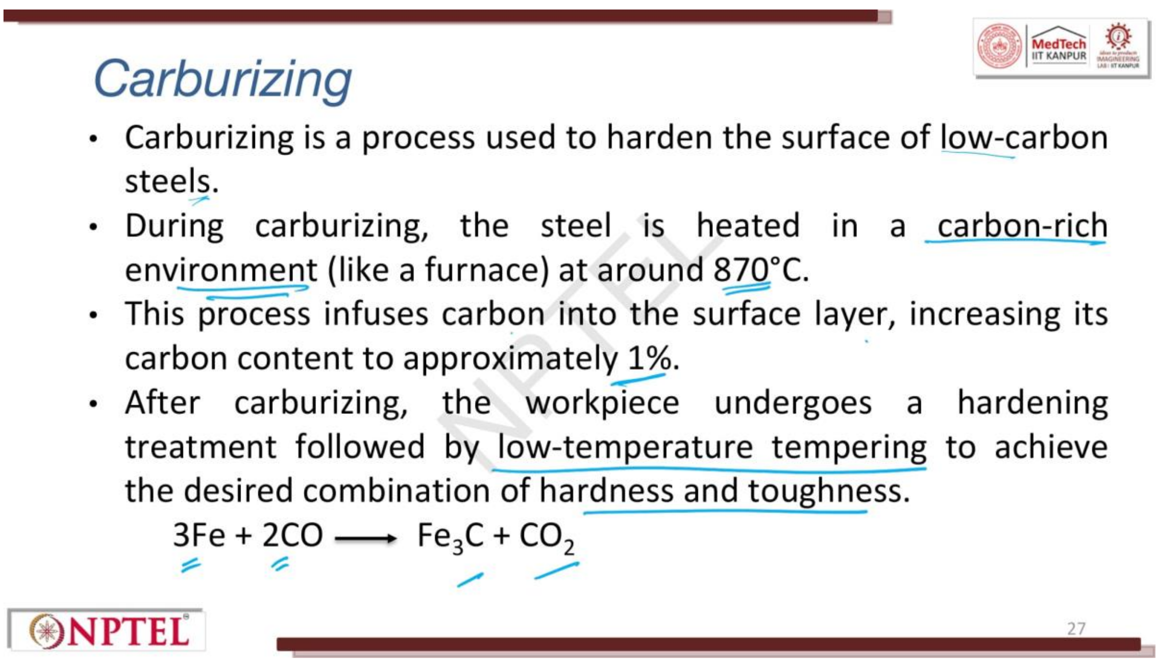
Case Hardening

- The hardened outer layer is referred to as the "case," while the softer, more ductile interior is known as the "core."
- Case hardening is a process that creates a hard, wear-resistant surface on a softer core material.
- This technique is particularly useful for components subjected to wear and impact, as it combines the benefits of a durable surface with the toughness of the underlying core.
- The case hardness typically follows this order:

  Nitriding > Cyaniding > Carburizing

Case hardening. So, till now, whatever we studied was part of annealing, normalizing, hardening, and tempering. We saw that. Now, what we are going to do is surface treatment. So that is case hardening. Let us see case hardening.

Case hardening: the hardened outer layer is referred to as a case, while the softer, more ductile inner part is called the core. Case hardening is a process that creates a hard, wear-resistant surface on a soft core material. This technique is particularly useful for components subjected to wear and impact, as it combines the benefits of a durable surface with the toughness of the underlying core. The case hardness typically follows the order: nitriding, then cyaniding, then carburizing. Case hardening is extensively used in the automobile industry, toy industry, and domestic industry. Many places use carburizing.



Carburizing is a process used to harden the surface of low-carbon steel. During carburizing, the steel is heated in a carbon-rich environment at around 870 degrees Celsius. Carburizing is nothing but what I told you about a blacksmith.

This process infuses carbon into the surface layer, increasing its carbon content to approximately 1%. After carburizing, the workpiece undergoes a hardening treatment followed by low-temperature tempering to achieve the desired combination of toughness and hardness. So, after you do case hardening, carburizing, you do low-temperature tempering also. 3Fe + 2CO → Fe3C + CO2.

Carburizing

- Fe_3C is austenite with dissolved carbon At 870°C the maximum amount of carbon can be dissolved in austenite.

Carburizing is performed in the following ways.

- **Pack carburizing**
- **Gas Carburizing**
- **Liquid Carburizing**

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Fe3C is austenite with dissolved carbon at 870 degrees Celsius. The maximum amount of carbon that can be dissolved in austenite. Carburizing is performed in various ways. It can be packed, gas, or liquid. So, you have a bath; the liquid can dissociate and then bring in carbon. The gas that you infuse can bring in carbon.

Carburizing

Pack Carburizing

- The parts are immersed in a carburizing mixture and then sealed within a steel box using clay to prevent any gas exchange.

Gas Carburizing

- The work is treated in a medium of gases containing CO and hydrocarbon gases such as CH_4, Propane butane etc.

Liquid Carburizing

- This process utilizes a molten bath containing 20% sodium cyanide (NaCN), which serves as a source of both carbon and nitrogen. The process is conducted at a temperature of 950°C.

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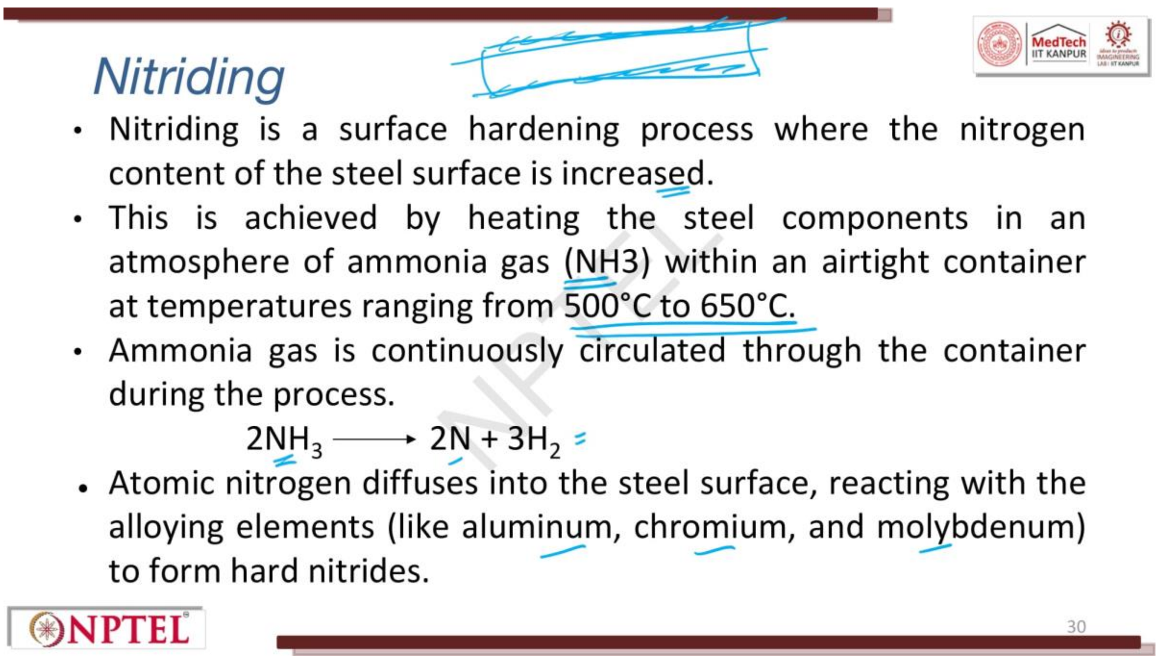
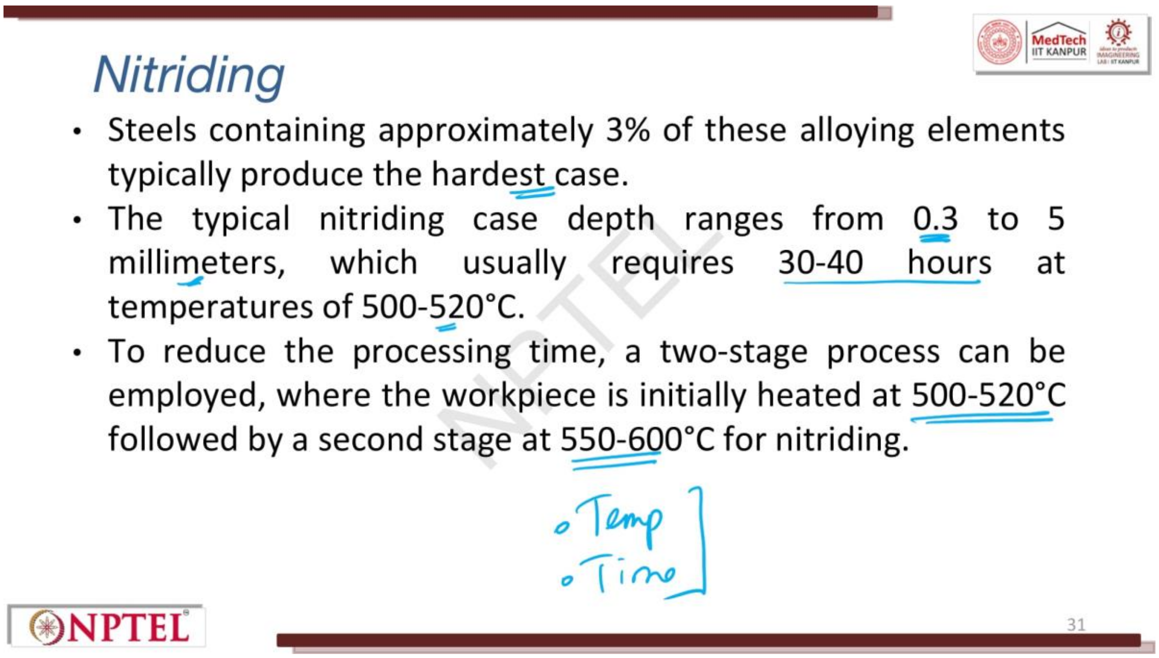
The pack, whatever you have, a coal that can also induce carbon. The parts are immersed in a carburizing mixture and then sealed within a steel box using clay to prevent any gas exchange; that is pack carburizing. Gas carburizing, this work is treated in a medium of gas containing CO and hydrocarbon gas such as methane, propane, butane, etc., to give gas carburizing. Liquid carburizing, this process uses a molten bath containing 20% sodium cyanide, which serves as a source of both carbon and nitrogen. The process heat treatment is done up to 950 degrees Celsius, and then you do carburizing.

So if you see here, gears are carburized. Any moving part, wheel axle, axle parts are carburized.



Nitriding is a surface hardening process wherein the nitrogen content of the steel surface is increased. So what we are talking about is, on the surface, this on top and bottom, carburizing and nitriding here.

This is achieved by heating the steel component in an atmosphere of ammonia NH3 within an airtight container at temperatures ranging from 500 degrees to 650 degrees. Every process you should try to remember the temperature, and this temperature you will get in mind when you try to memorize or keep in mind the iron-iron carbide diagram. The ammonia gas is continuously circulated through a container wherein 2NH3 is dissociated into 2N and 3H2. The atomic nitrogen diffuses into the steel surface, reacts with the alloying elements like aluminum, chromium, and molybdenum to form very hard nitrides. Aluminum nitride, chromium nitride, molybdenum nitride can be formed, and this is giving you a very, very hard surface.



The steel containing approximately 3% of these alloying steels typically produces the hardest case. So the typical nitride case depth can be 0.3 to 5 millimeters, which usually requires 30 to 40 hours where the temperature has to be maintained from 500 to 520 degrees Celsius. So if you see, temperature and time are very important. In heat treatment, temperature and time are very important. So to reduce the processing time, a two-stage process can be 30 to 40 hours.

To reduce it, a two-stage process can be employed where the workpiece is initially heated to 500 to 520 degrees, and then it follows a second stage of 550 to 600 degrees Celsius for nitriding.

Cyaniding

- Workpieces are immersed in a molten salt bath containing 20-30% sodium cyanide (NaCN), 25-50% sodium chloride (NaCl), and 25-50% sodium carbonate (Na_2CO_3) and heated to a temperature between 820°C and 860°C.
- This process introduces carbon and nitrogen into the steel surface.
- After a holding time of 30-90 minutes (depending on the case depth of 0.15-0.5 mm), the workpiece is immediately quenched in water.
- A subsequent low-temperature tempering at 200°C is typically performed.

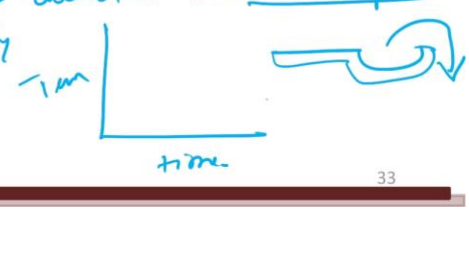
Cyaniding. The workpieces are immersed in a molten sand bath containing 20 to 30% of sodium cyanide, 25 to 50 percent of NaCl, 25 to 50 percent of sodium carbonate, and heated to a temperature between 820 degrees Celsius to 860 degrees Celsius. This process introduces carbon and nitrogen into the steel surface. After a holding time of 30 to 90 minutes, the workpiece is immediately quenched in water so that you get this cyaniding on top of the surface.

The subsequent low-temperature tempering at 200 degrees Celsius is typically performed to increase mechanical properties like ductility.

To Recapitulate

- What is the heat treatment process and purpose?
- Classification and stages during heat treatment.
- Different heat treatment processes like
  - Annealing
  - Tempering
  - Normalizing
  - Carburizing, etc.
- Benefits

- Candle → wax → heat → liquid →
  - oil — shape & size → wax
  - water —
  - Air —
- oil — heat → Quench a Air heated spoon.
- water - Quenching
- force Air



To recap in this lecture, what we went through was what the heat treatment process and purpose are. Different stages of heat treatment. What are the different heat treatment processes like annealing, tempering, normalizing, and carburizing? We also saw the benefits.

So now, let us do a small exercise as an assignment for our understanding and appreciation of heat treatment. So let us try to take some candle wax. You heat it. It turns into a liquid. Now, you pour the entire liquid into oil, water, and free air.

See what is happening during the process. What shape and size is it forming, right? So you try to do this with wax. Then, let us try to do one more exercise. In this exercise, what you do is try to take material available in the household. I am just trying to see.

So you can try to take oil, okay. Heat the oil and try to quench an air-heated spoon. That means to say, you take a steel spoon, heat it in the flame until it becomes a little red hot, then you try to oil quench it. You try to quench it with water. Then, you try to quench it with forced air.

That means to say, you have a fan, and then you hold it. Now, you see the temperature versus time plot you do, see what response you get. So that means to say, the red hotness has to come down to normal. So when you do this, after doing it, you have to see the shape and size of the wax you poured. Here, you will try to bend the spoon.

The spoon, whatever is there, you will try to bend the spoon. After doing all these things, oil heating, bring it to room temperature, and then bend it. Water quenching, bring it to room temperature, do it. Forced air cooling, bring it to room temperature, and then bend. Make sure you do not hurt yourself.

These two will clearly demonstrate what the influence of heat treatment is with respect to the output.

References

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These are the reference books which we have used for making the slides. And thank you very much.