4. HEAT TREATMENT

HEAT TREATMENT: It's a secondary process after production of steel to improve mechanical properties without changing chemical composition, but only changing grain structure of material by heating and cooling.

STEPS IN HEAT TREATMENT PROCESS			
HEATING (Grain Growth)	**HOLDING/ SOAKING**	**COOLING**	
a. Residual Stresses are relieved due to atomic vibration at boundary. b. Enlargement of grains	To get uniform grain formation And Holding time depends on thickness of the material	Slow Cooling	Fast Cooling
		Coarse Grains Obtained	Fine Grains Obtained.

COARSE GRAINS/ SLOW COOLING	FINE GRAINS/ FAST COOLING
Grain Boundary are low so low restriction of movement of dislocation.	Grain Boundary are high so high restriction of movement of dislocation.
1. Low Strength and hardness 2. High Ductility and Machinability 3. Low Residual Stress	1. High Strength and hardness 2. Low Ductility and Machinability 3. High Residual Stress

HARDENING PROCESS: It's Applied for steel to improve **hardness** and **wear resistance** of material.
Applicable: L-CS, M-CS, H-CS.

- Transformation of phase starts at Lower Critical Temp. and ends at Upper Critical Temp.
- $\alpha - Fe$ is not harden able due to low C%. Hence, we are heating **hypoeutectoid** steel 50 °C above upper Critical Temp. And **hypereutectoid** steel 50 °C above lower Critical Temp. (Fig. 4.1)

HARDENING STRAINS: It's Residual stresses generated in the material without applied forces.

- In hardening process, due to **RAPID COOLING**, the outer layer transforms into **Martensite** from austenite but inner core is in retained austenite form due to lack of sufficient time. (**Martensite is Body Centred Tetragonal)**
- The inner core ($\gamma - Fe$) is in expansion state and outer layer is in contraction state and due to expansion and contraction hardening strain are generated (Fig. 4.2). To relieve Strain Hardening Tempering process are performed.

HARDENABILITY: It's the depth from the surface of the specimen up to which Martensite is present (Fig. 4.3).

- **Jhomny End Quench Test method** is used to measure the hardenability of steel.

Factors Affecting Hardenability:
1) Composition of material: By adding allowing elements hardenability increases E.g. TTT diagram shifts tight side,
2) Type of Cooling: Quenching Medium effects on time E.g. $(D_h)_{Brine} > (D_h)_{Water} > (D_h)_{Oil}$,
3) Shape of the component: $(D_h)_{Thin\ Element} > (D_h)_{Thick\ Element}$.

FULL ANNEALING: This process is applicable for all types of steels to increase ductility and to get uniform grain formation of material.
Applicable: L-CS, M-CS, H-CS.
we are heating **hypoeutectoid** steel 50 °C above upper Critical Temp. And **hypereutectoid** steel 50 °C above lower Critical Temp. (Fig. 4.1) After that we are **cooling in the furnace** with slow cooling so that grain boundaries more.
Properties: 1) Good Ductility, 2) Good Machinability, 3) Low Strength and hardness, 4) Low Residual Stresses.

PROCESS ANNEALING:
To increase processability of a cold worked (Rolling, Forging, Drawing…etc.) and welded components.
we are heating steel 50 °C below Lower Critical Temp. And **Cooling in Furnace** so it's slow cooling.
Applicable: L-CS, M-CS. Because H-CS is generally not used for cold working.
NOTE: In Cold Working Process Large Internal Stress are generated due to accumulation of dislocations at grain boundary. And due to that next machining process is difficult, so to solve the problem process annealing is applied.

	Hardening	Full Annealing	Process Annealing
Grain Size	**Small**	**Large**	**Medium Because Less heating temp.**
Strength ($\propto$ (Grain Size)$^{-1}$)	More	Less	Medium
Ductility	Less	More	Medium
Residual Stress	More	Less	Medium

SPHEROIDISE ANNEALING: This process is applicable for M-CS, H-CS to increase machinability of a material.
NOTE: The machinability if H-CS is low due to more harder phase Fe_3C present in it.
Machinability increased by 1) sulphur and Selenium at the time of production of steel, 2) Spheroidise annealing at after production of steel.

DIFFUSION ANNEALING: This process is applied for M-CS, H-CS to get uniform chemical composition and uniform properties of a casted of solidified component.
Heating up to elevated temperature & Holing at that temperature to get uniform diffusion and cooling in the furnace.
Applicable: L-CS, M-CS, H-CS. **Cast ability:** L-CS < M-CS < H-CS.
NOTE: Diffusion is a transfer of mass from high concentration level to low concentration level.
NORMALIZING PROCESS: This process is applied for all types of steels to get normal fined **perlite structure**.
Heating up to Below mentioned temperature & Holing at that temperature to get perlite structured **cooling in Air.**
we are heating **hypoeutectoid** steel 50 °C above upper Critical Temp. (AC3) And **hypereutectoid** steel 50 °C above upper Critical Temp. (ACm) (Fig. 4.5)
APPLICABLE: L-CS, M-CS, H-CS
Advantages: 1) Uniformed Grain Structure, 2) Residual stress relieved, 3) Machinability increased, 4) Strength and hardness increased (Compared with full annealing)

Increasing order for each property	Hardening	Normalising	Process Annealing	Full Annealing
Grain Size	1	2	3	4
Strength/ hardness	4	3	2	1
Ductility	1	2	3	4
Residual Stress	4	3	2	1

TEMERING PROCESS: This process is a secondary process applied to the steel after hardening to relieve residual stress (Hardening Strains) and to increase toughness of the material.

<table>
<tr><td rowspan="6">TEMERING PROCESS</td><td colspan="3">Low Temperature Tempering (LTT)</td></tr>
<tr><td>Heating (150-250 $°C$)</td><td>Holding/ Soaking</td><td>Cooling</td></tr>
<tr><td>Hardened Component (Body cantered tetragonal)</td><td>Fined grained Cementite and soft ferrite phase</td><td>Air Cooling, we get Troosite. (BCC at room temp) (LTTT)</td></tr>
<tr><td colspan="3">High Temperature Tempering (HTT)</td></tr>
<tr><td>Heating (650 $°C$)</td><td>Holding/ Soaking</td><td>Cooling</td></tr>
<tr><td>Hardened Component (Body cantered tetragonal)</td><td>Relatively large grained.</td><td>Air Cooling, we get Sorbite. (BCC at room temp) (HTTS)</td></tr>
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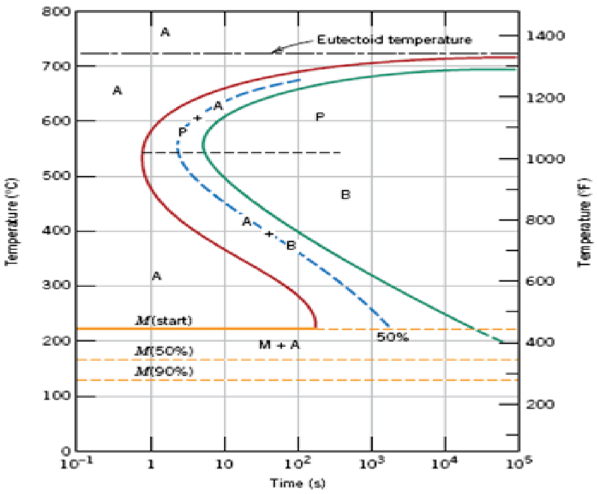
	Low Temperature Tempering (LTT)	**High Temperature Tempering (HTT)**
Grain Size	Low	High
Strength/ hardness	High	Low
Ductility	Low	High
Residual Stress	High	Low
Toughness	Low	High
Eg.	Cutting tool	Shafts, Gears

TIME TEMPERATURE TRANSFORMATION DIAGRAM(TTT):

Fe-Fe_3C Phase Diagram	**Time Temperature Transformation Diagram**
It's phase diagram. And it gives information about phases of an Fe-C Alloy.	It's not phase diagram. It gives information about different forms of steel.
Temperature Vs. Chemical Composition diagram at constant cooling rate (Quasistatically).	Temperature Vs. Cooling rate at constant chemical composition.
It's Equilibrium diagram.	It's non equilibrium diagram.
Useful in Research Application.	Useful in industrial application.
No Martensite	Martensite is present.

CRITICAL COOLING TIME: It's The maximum cooling time for austenite material to transform into martensite.
Bain has done experiment with 3 specimens:
1. Rapid cooling: Martensite
2. Air Cooling: Perlite
3. Rapid Cooling + Isothermal Cooling: Bainite.

Process of making bainite is called **Austempering**.

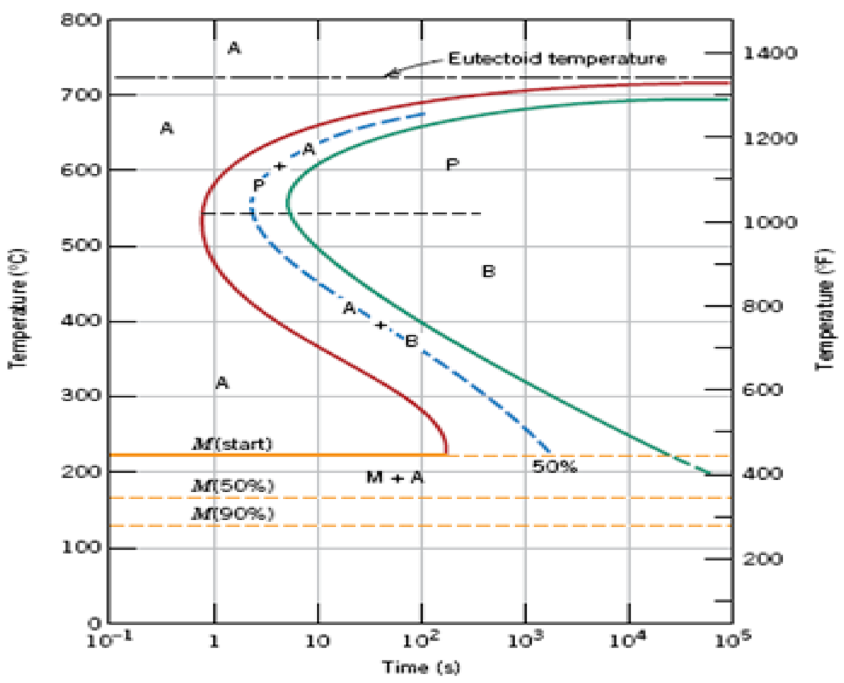


Properties	Martensite	Perlite	Bainite
Type of cooling	Rapid Cooling (Water Cooling)	Air Cooling	Interrupted Cooling (Rapid + Isothermal Cooling)
Process of Formation	Diffusion Less Process	Diffusion Process	Both
Grain Size	Fine	Coarse	M < B < P
Strength/ Hardness	High	Low	M > B > P
Ductility	Low	High	M < B < P
Residual Stresses	High	Low	M > B > P

CONTINUOUS COOLING TRANSFORMATION DIAGRAM (CCT DIAGRAM):

- In CCT Curve, No bainite formation.
- In CCT Curve, Continuous cooling is present/ No Isothermal Cooling.

Material (0.8% C)	Hardness (BHN)	Strength (MPa)
Coarse Perlite	16	700
Fine Perlite	30	1000
Perlite + Martensite	45	1500
Martensite	60	2000



FACTORS AFFECTING TTT OR CCT DIAGRAM		
Grain Size	**Carbon Content**	**Alloying Elements**
Coarse Grain: Curve moves Right and Critical cooling rate increases. **Coarse Grain:** Curve moves Left and Critical cooling rate decreases.	Increasing C%: More Martensite Forms. hence, Curve moves Right and Critical cooling rate increases. And Hardenability increases.	Increasing Elements: Curve moves Right and Critical cooling rate increases and Critical cooling rate increases.

SURFACE HARDENING PROCESS: This process is applied to the steel, to get hard and wear resistance surfaces with tough core of a material.

Eg. Gear Teeth, Cam Shaft, Crack Pin, Tools & dies.

SURFACE HARDENING PROCESS	
Hardening & Tempering Process	Chemical Heat Treatment/ Case Hardening Process
1. Flame Hardening 2. Induction Hardening	1. Carburizing 2. Nitriding 3. Cyaniding

PRECIPITATION PROCESS: This is applied for non-ferrous alloys to increase strength and hardness of a material. (Due to strain hardening, Strength & hardness of the component is increased.)

Eg. Al-Cu Alloy (Eutectic Alloy)

1) Solution Treatment: The specimen is heated up to above solvus (Eutectic Line) and hold for some time to form complete solid solution α −phase.
2) Quenching: After heating & Holding quench the specimen to form super saturated solid solution α −phase.
3) Precipitation Treatment (Aging): again, the specimen is heated below the solves line to form precipitates of β −phase. And then cooled to the room temperature.