TTT diagrams

TTT diagram stands for “time-temperature-transformation” diagram. It is also called isothermal transformation diagram

Definition: TTT diagrams give the kinetics of isothermal transformations

Determination of TTT diagram for eutectoid steel

Davenport and Bain were the first to develop the TTT diagram of eutectoid steel. They determined pearlite and bainite portions whereas Cohen later modified and included MS and MF temperatures for martensite. There are number of methods used to determine TTT diagrams. These are salt bath (Figs. 1- 2) techniques combined with metallography and hardness measurement, dilatometry , electrical resistivity method, magnetic permeability, in situ diffraction techniques (X-ray, neutron), acoustic emission, thermal measurement techniques, density measurement techniques and thermodynamic predictions. Salt bath technique combined with metallography and hardness measurements is the most popular and accurate method to determine TTT diagram

Fig 1 Salt bath I –austenitisation heat treatment.

Fig 2 Bath II low-temperature salt-bath for isothermal treatment.

In molten salt bath technique two salt baths and one water bath are used. Salt bath I (Fig. 1) is maintained at austenetising temperature (780˚C for eutectoid steel). Salt bath II (Fig. 2) is maintained at specified temperature at which transformation is to be determined (below Ae1), typically 700-250°C for eutectoid steel. Bath III which is a cold water bath is maintained at room temperature. In bath I number of samples are austenitised at AC1+20-40 C for eutectoid and hypereutectoid steel, AC3+20-40 C for hypoeutectoid steels for about an hour. Then samples are removed from bath I and put in bath II and each one is kept for different specified period

Fig:3 Sample and fixtures for dilatometric measurements of time say t1 , t2 , t3 , t4 , tn etc. After specified times, the samples are removed and quenched in water. The microstructure of each sample is studied using metallographic techniques. The type, as well as quantity of phases, is determined on each sample. 6 The time taken to 1% transformation to, say pearlite or bainite is considered as transformation start time and for 99% transformation represents transformation finish. On quenching in water austenite transforms to martensite. But below 230 C it appears that transformation is time independent, only function of temperature. Therefore after keeping in bath II for a few seconds it is heated to above 230 C a few degrees so that initially transformed martensite gets tempered and gives some dark appearance in an optical microscope when etched with nital to distinguish from freshly formed martensite (white appearance in optical microscope). Followed by heating above 230 C samples are water quenched. So initially transformed martensite becomes dark in microstructure and remaining austenite transform to fresh martensite (white). 7 Quantity of both dark and bright etching martensites are determined. Here again the temperature of bath II at which 1% dark martensite is formed upon heating a few degrees above that temperature (230 C for plain carbon eutectoid steel) is considered as the martensite start temperature (designated MS). The temperature of bath II at which 99 % martensite is formed is called martensite finish temperature (MF). Transformation of austenite is plotted against temperature vs time on a logarithm scale to obtain the TTT diagram. The shape of diagram looks like either S or like C.

TTT diagram gives

Nature of transformation-isothermal or athermal (time independent) or mixed Type of transformation-reconstructive, or displacive Rate of transformation Stability of phases under isothermal transformation conditions Temperature or time required to start or finish transformation Qualitative information about size scale of product Hardness of transformed products

Factors affecting TTT diagram

1)Composition of steel-

(a) carbon wt%,

(b) alloying element wt%

2)Grain size of austenite

3) Heterogeneity of austenite

Carbon wt%- As the carbon percentage increases A3 decreases, similar is the case for Ar3 , i.e. austenite stabilises. So the incubation period for the austenite to pearlite increases i.e. the C curve moves to right. However after 0.77 wt%C any increase in C, Acm line goes up, i.e. austenite become less stable with respect to cementite precipitation. So transformation to pearlite becomes faster. Therefore C curve moves towards left after 0.77%C. The critical cooling rate required to prevent diffusional transformation increases with increasing or decreasing carbon percentage from 0.77%C and e for eutectoid steel is minimum. Similar is the behaviour for transformation finish time. Pearlite formation is preceeded by ferrite in case of hypoeutectoid steel and by cementite in hypereutectoid steel. Schematic TTT diagrams for eutectoid, hypoeutectoid and hyper eutectoid steel are shown Figs. 5(a)-(b) and all of them together along with schematic Fe-Fe3C metastable equilibrium are shown in Fig. 6.

γ=austenite CP=coarse pearlite P=pearlite FP=fine pearlite UB=upper Bainite LB=lower Bainite M=martensite MS=Martensite start temperature M50=temperature for 50% martensite formation

Fig 5(a) : Schematic TTT diagram for plain carbon hypoeutectoid steel

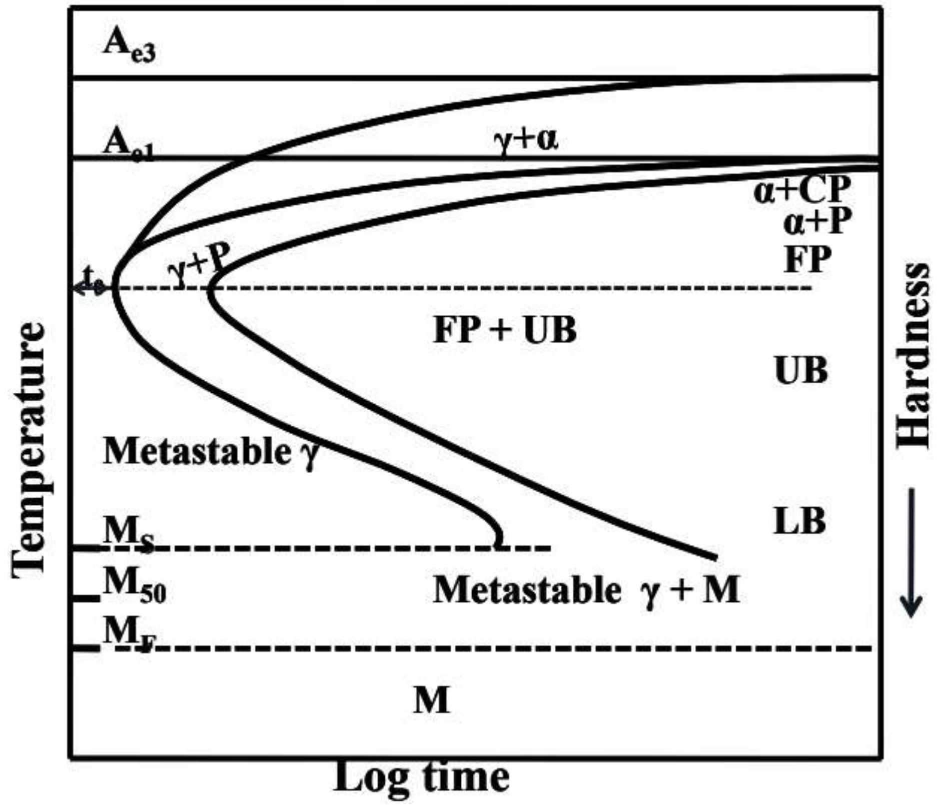


Fig 5(b): Schematic TTT diagram for plain carbon hypereutectoid steel

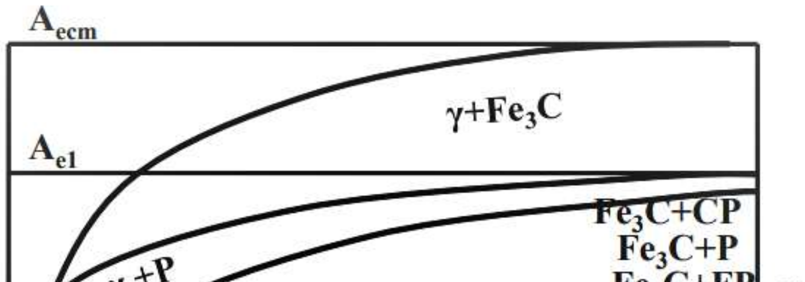
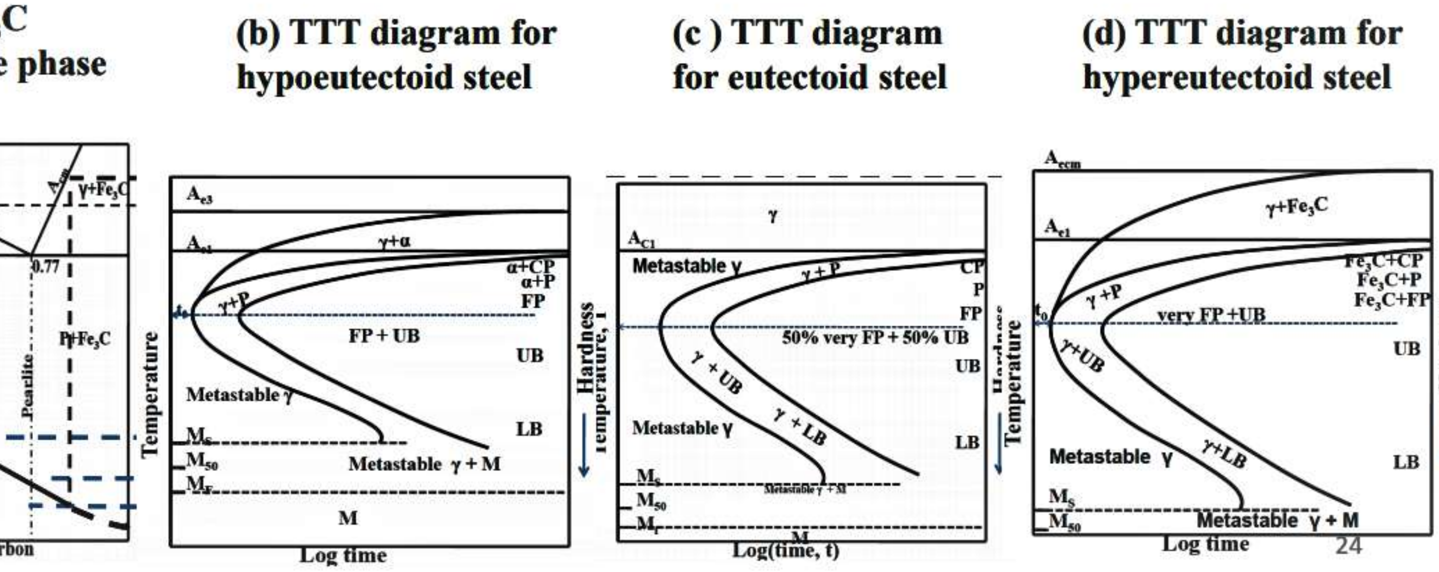


Fig. 6: Schematic Fe-Fe3C metastable equilibrium diagram and TTT diagrams for plain carbon hypoeutectoid, eutectoid and hypereutectoid steels

γ=austenite α=ferrite CP=coarse pearlite M=martensite MS=Martensite start temperature M50=temperature for 50% martensite formation MF= martensite finish temperature P=pearlite FP=fine pearlite UB=upper bainite LB=lower bainite



Alloying elements: Almost all alloying elements (except, Al, Co, Si) increases the stability of supercooled austenite and retard both proeutectoid and the pearlitic reaction and then shift TTT curves of start to finish to right or higher timing. This is due to i) low rate of diffusion of alloying elements in austenite as they are substitutional elements, ii) reduced rate of diffusion of carbon as carbide forming elements strongly hold them. iii) Alloyed solute reduce the rate of allotropic change, i.e. $\gamma \rightarrow \alpha$, by solute drag effect on $\gamma \rightarrow \alpha$ interface boundary. Additionally those elements (Ni, Mn, Ru, Rh, Pd, Os, Ir, Pt, Cu, Zn, Au) that expand or stabilise austenite, depress the position of TTT curves to lower temperature. In contrast elements (Be, P, Ti, V, Mo, Cr, B, Ta, Nb, Zr) that favour the ferrite phase can raise the eutectoid temperature and TTT curves move upward to higher temperature. However Al, Co, and Si increase rate of nucleation and growth of both ferrite or pearlite and therefore shift TTT diagram to left. In addition under the complex diffusional effect of various alloying element the simple C shape behaviour of TTT diagram get modified and various regions of transformation get clearly separated. There are separate pearlitic C curves, ferritic and bainitic C curves and shape of each of them are distinct and different.

Effect of grain size of austenite: Fine grain size shifts S curve towards left side because it helps for nucleation of ferrite, cementite and bainite. However Yang and Bhadeshia et al. have shown that martensite start temperature (MS) is lowered by reduction in austenite grain .

Heterogeinity of austenite: Heterogenous austenite increases transformation time range, start to finish of ferritic, pearlitic and bainitic range as well as increases the transformation temperature range in case of martensitic transformation and bainitic transformation. Undissolved cementite, carbides act as powerful inocculant for pearlite transformation. Therefeore heterogeneity in austenite increases the transformation time range in diffussional transformation and temperature range of shear transformation products in TTT diagram.

Applications of TTT diagrams

- Martempering: Martempering is also known as **stepped quenching** or **interrupted quenching**. In this process, steel is heated above the upper critical point (above the transformation range) and then quenched in a salt, oil, or lead bath kept at a temperature of 150-300 °C. The workpiece is held at this temperature above martensite start (Ms) point until the temperature becomes uniform throughout the cross-section of workpiece. After that it is cooled in air or oil to room temperature. The steel is then tempered. In this process, Austenite is transformed to martensite by step quenching, at a rate fast enough to avoid the formation of ferrite, pearlite or bainite.

- Austempering : **Austempering** is heat treatment that is applied to ferrous metals, most notably steel and ductile iron. In steel it produces a bainite microstructure whereas in cast irons it produces a structure of acicular ferrite and high carbon, stabilized austenite known as *ausferrite*.

- Isothermal Annealing: Isothermal annealing or process annealing, is slightly different from a full anneal, but produces a similar microstructure. In this process, the part is heated to above the upper critical temperature, and then is cooled quickly to approximately 650°C (1,200°F), and is held isothermally for a period of time.

- **Patenting:** Patenting heat treatment is the isothermal annealing at the nose temperature of TTT diagram . Followed by this the products are air cooled. This treatment is to produce fine pearlitic and upper bainitic structure for strong rope, spring products containing carbon percentage 0.45 %C to 1.0%C. The coiled ropes move through an austenitising furnace and enters the salt bath maintained at 550°C(nose temperature) at end of salt bath it get recoiled again. The speed of wire and length of furnace and salt bath such that the austenitisation get over when the wire reaches to the end of the furnace and the residency period in the bath is the time span at the nose of the TTT diagram. At the end of salt bath wire is cleaned by water jet and coiled.

HEAT TREATMENT OF STEEL

- troduction
- on phases depending on temperature,solubilities and commercial production
- ages of heat treatment
- pes of heat treatment

urpose of heating ses

HEAT TREATMENT

- Heat treatment is the controlled heating and cooling of metals to observe their physical and mechanical properties without changing the product shape
- teels are particularly suitable for heat treatment since they respond feasibly to heat treatment and the commercial use of steel is larger than any other material
- Generally heat treatment uses phase transformation during heating and cooling to change microstructure in solid shape.

In heat treatment ,the processing is most often entirely thermal and modifies only structure.

Thermo mechanical treatments which modify component shape and structure and thermochemical treatments which modify surface chemistry and structure,are also important processing approaches which fall into the domain of heat treatment

Different phases of Iron based on temperatures

on at room temperature is Alpha called Ferrite(BCC)

912°C ferrite transforms to gamma phase called Austenite (FCC)

is transforms at 1394°C to delta form(BCC)

ure iron melts at 1539°C

- Iron as a commercial product

ectrolytic Iron- It is the most pure form of iron about 99.99% of purity which is generally used for reasearch areas

got Iron- This form is about 99.9% pure and used in applications where high ductility or corrosion resistances are needed.

rought Iron- It contains about 3% slag but very little carbon impurities

Solubility limits of carbon in Iron

- **Ferrite** phase can dissolve about 0.022% carbon at 723°C

- **Austenite** can dissolve upto 2.1% carbon at 1130°C
- The differences in the solubility between alpha and gamma provides opportunities for strengthening by heat treatment

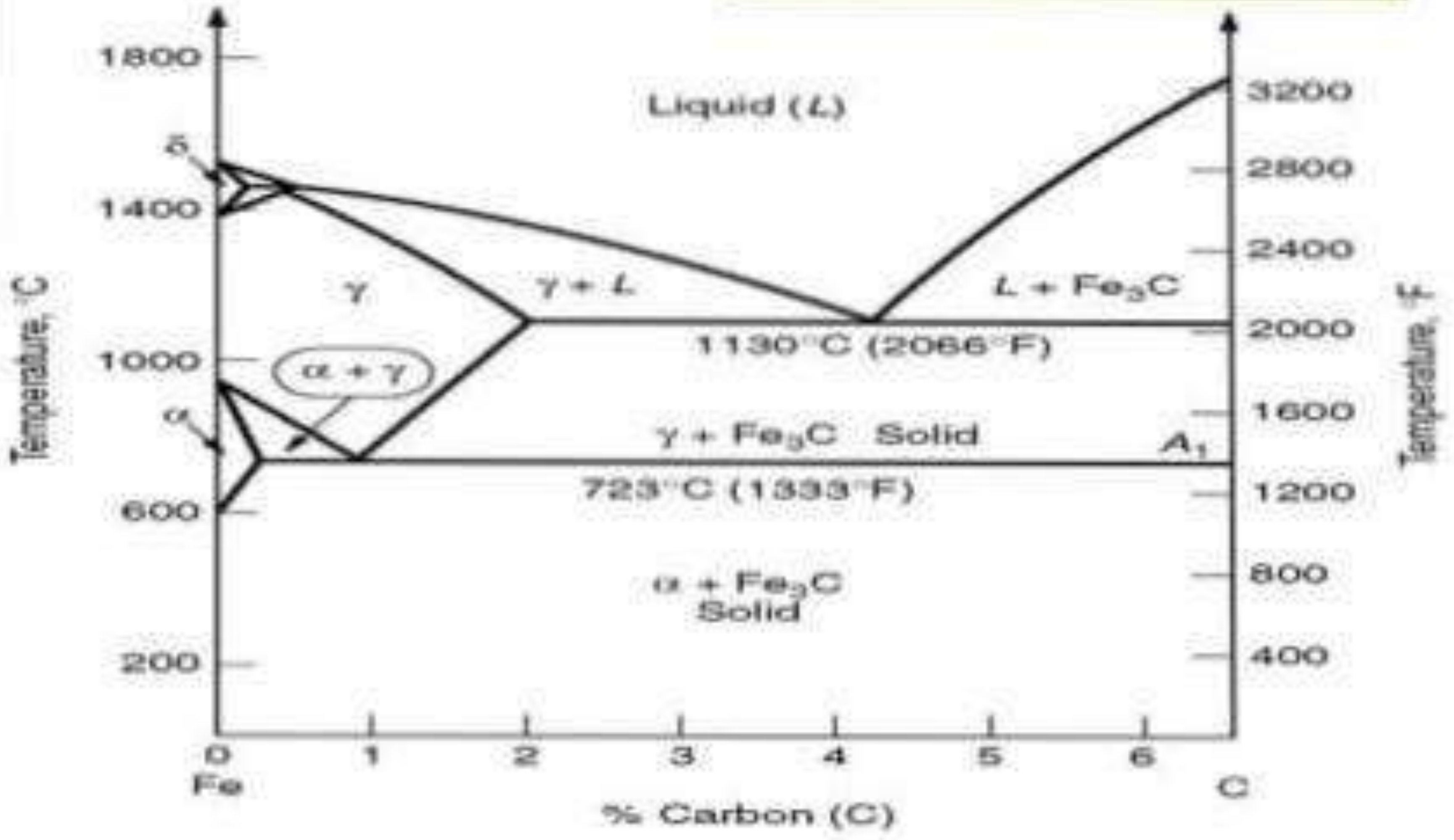


Figure - Phase diagramam for iron-carbon system, up to about 6% carbon ages during heat treatment

Stage 1-Heating the metal slowly to ensure a uniform emperature

Stage 2- Soaking the metal at a given temperature for a given period of time

Stage 3- Cooling metal to room temperature

Soaking

ernal structural changes takes place in this process.

aking period depends on the chemical analysis of the metal and mass of the part

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- COOLING STAGE

  - To cool the metal you can place it direct contact a composition of gas, liquid or solid and even combination of these in some cases.

Stages of Heat Treatment

- **Soaking Period**

Table 1: Soaking period for Hardening, Annealing and Normalizing Steel.

Thickness of Metal (inches)	Time of heating to Required Temperature (hr)	Soaking Time (hr)
Up to 1	3/4	1/2
1 to 2	1 1/4	1/2
2 to 3	1 3/4	3/4
3 to 4	2 1/4	1
4 to 5	2 3/4	1
5 to 8	3 1/2	1 1/2

TRANSFORMATION DURING HEATING AND COOLING OF STEEL

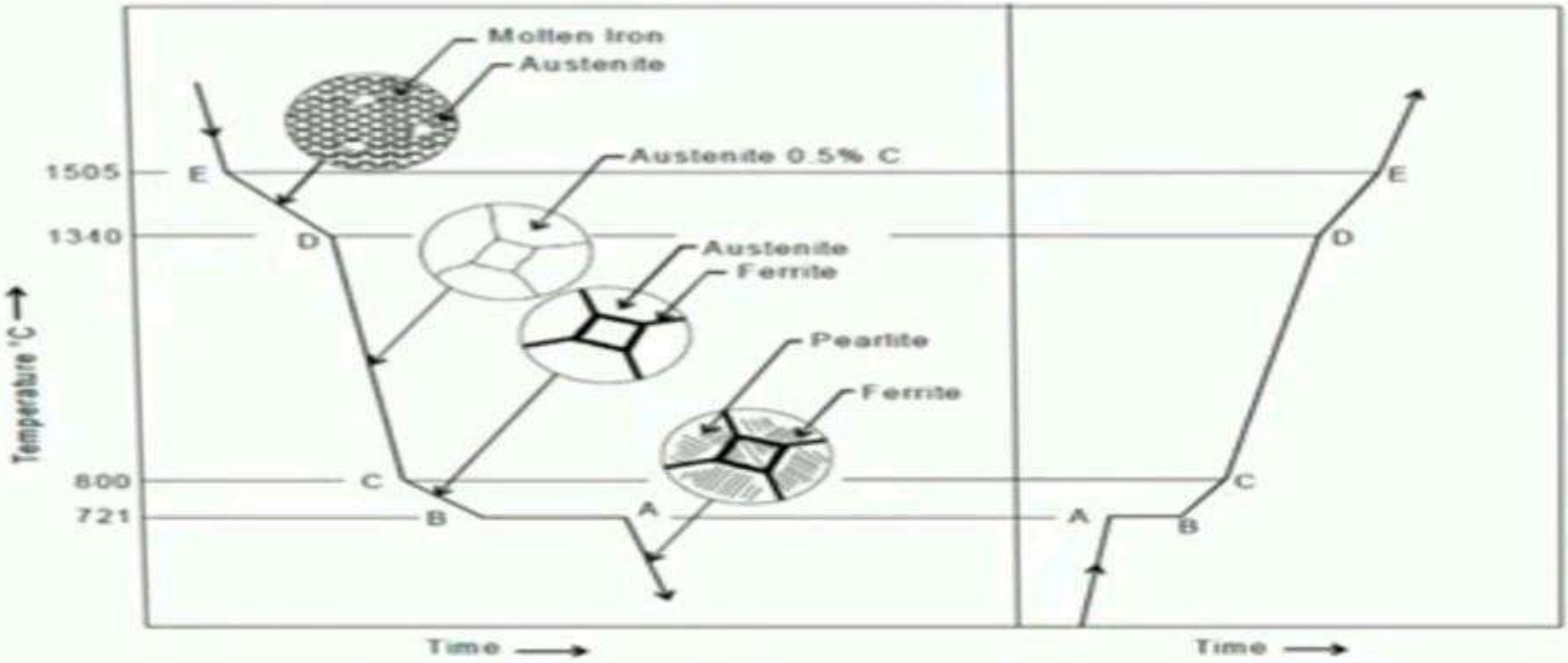

Fig. 8.5 Heating and cooling curve of steel

Types of heat treatment of Iron.

- Annealing or Normalising
- Case Hardening
- Precipitation Hardening
- Tempering and Quenching

Decarburisation during heat treatment and its effects.

- Decrease in the content of carbon in the metals is called   Decarburisation.

- The strength of the steel depends upon the amount of carbide present in its structure.

Purpose of heat treatment

- To improve internal stress
- To improve machinability

o refine the grain size

o soften the metal

o improve the mechanical properties

o Increase resistance against wear,heat and corrosi

o Improve ductility and toughness

o Change chemical composition

Who uses Heat Treati

- Aircraft Industry
- Automobile Manufacturing
- Defense Sector
- Forging
- Foundry
- Heavy Machinery Manufacturing
- Powder Metal Industries