Tempering of Steels

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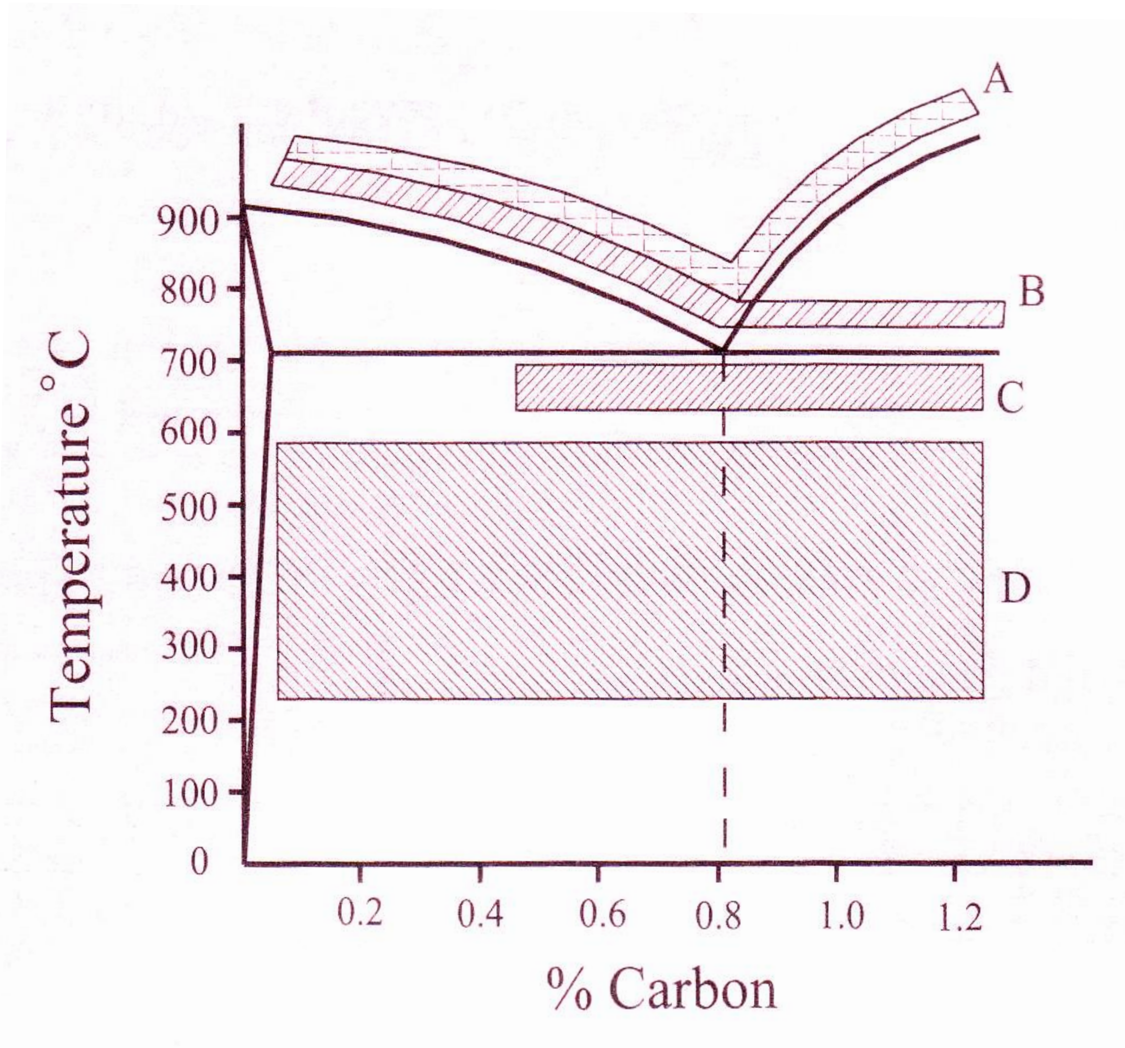
Lec-2

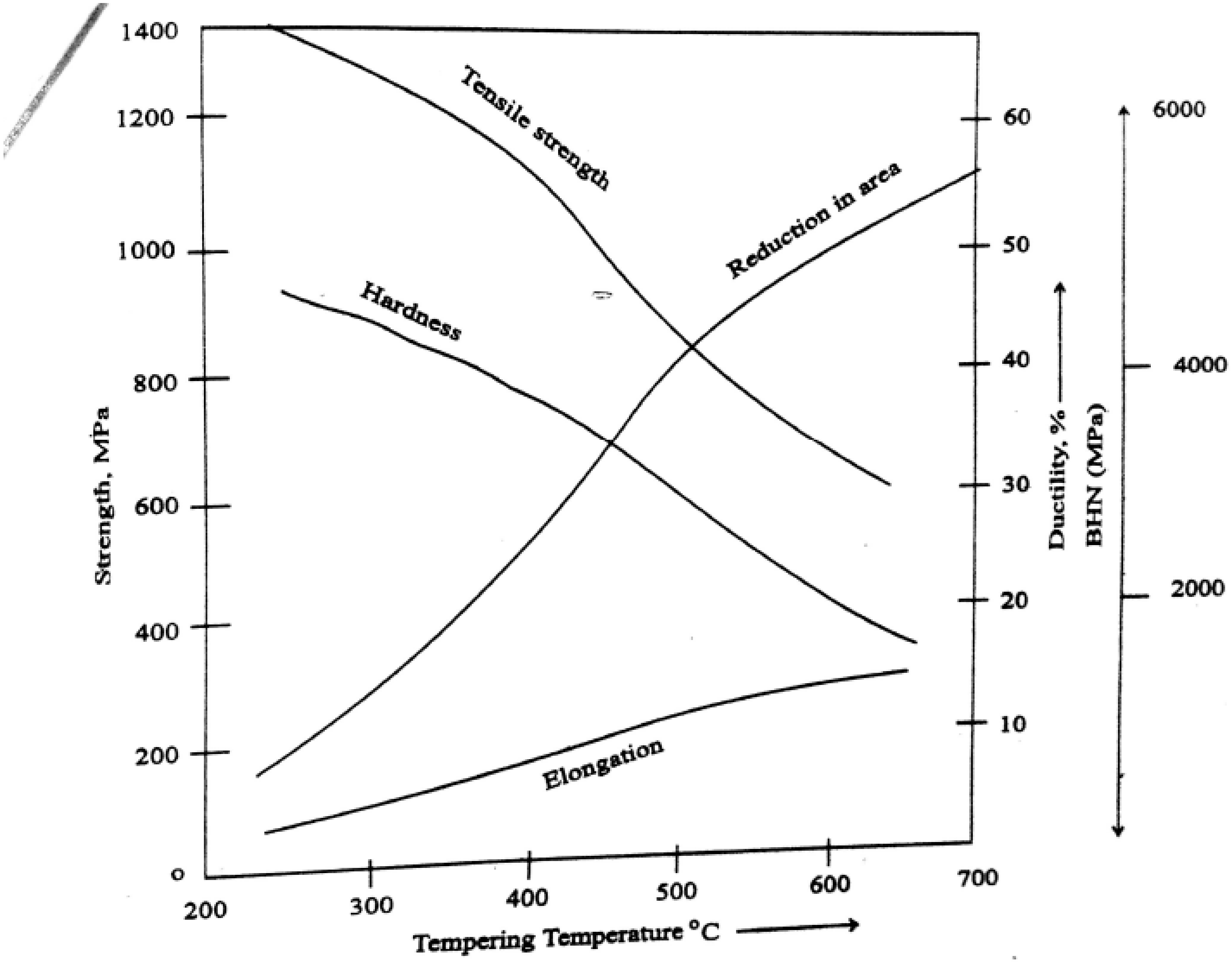
- A – Normalising
- B – Annealing or Hardening
- C – Spheroidising or Process Annealing
- D - Tempering



10.12. TEMPERING

As-quenched steels find very few engineering applications because martensite though strong but is very brittle. Quenching stresses may cause cracks even later on when in use. As martensite is a supersaturated solid solution of carbon in iron, it rejects on heating, carbon in the form of fine carbide, and thus, there takes place some decrease of hardness with progressive increase in ductility and impact strength, *i.e.* the properties of martensite can be modified. Thus, hardening, *i.e., formation of martensite provides a base to obtain a very wide range of combination of mechanical properties, if a* later treatment called *tempering* is done.

Tempering is the process of heating the hardened steel to a temperature maximum up to A_1 *temperature, soaking at this temperature, and then cooling normally very slowly.* Table 10.14 illustrates tempering temperatures used depending on the properties required by the carbon tools, whereas, Fig. 10.84 illustrates variation in properties with the tempering temperature for 0.45% carbon steel. As this steel provides a wide range of combination of properties, if the composition too is changed, than a still much wider range can be obtained.



1400
1200
1000
800
600
400
200
o
Strength, MPa
Tensile strength
Hardness
Reduction in area
Elongation
60
50
40
30
20
10
Ductility, %
BHN (MPa)
6000
4000
2000
200
300
400
500
600
700
Tempering Temperature °C

Table 10.14. Tempering Temperatures for Some Carbon Tools

Tools	*Tempering Temperature, °C*	*Hardness*
1. Cutting tools like milling cutter, screw taps	150° — 220°C	60 — 64 HRC
2. Dies and punches for swaging, cold forging	220° — 260°C	55 — 59 HRC
3. Tools subjected to shock as chisels etc.	280° — 300°C	53 — 56 HRC
4. Hammer dies	350° — 450°C	300 — 444 BHN

10.12.1. AIMS OF TEMPERING

Tempering of the steels is done with one or more of following aims:

1. To relieve quenching stresses developed during hardening.
2. To restore ductility and toughness with decrease in hardness and strength.
3. To improve dimensional stability by decomposing retained austenite.
4. To improve magnetic properties by transforming non-magnetic retained austenite.

10.12.2. STAGES OF TEMPERING (Plain Carbon Steels)

As the temperature is raised, tempering of carbon steels occurs in four distinct but overlapping stages:

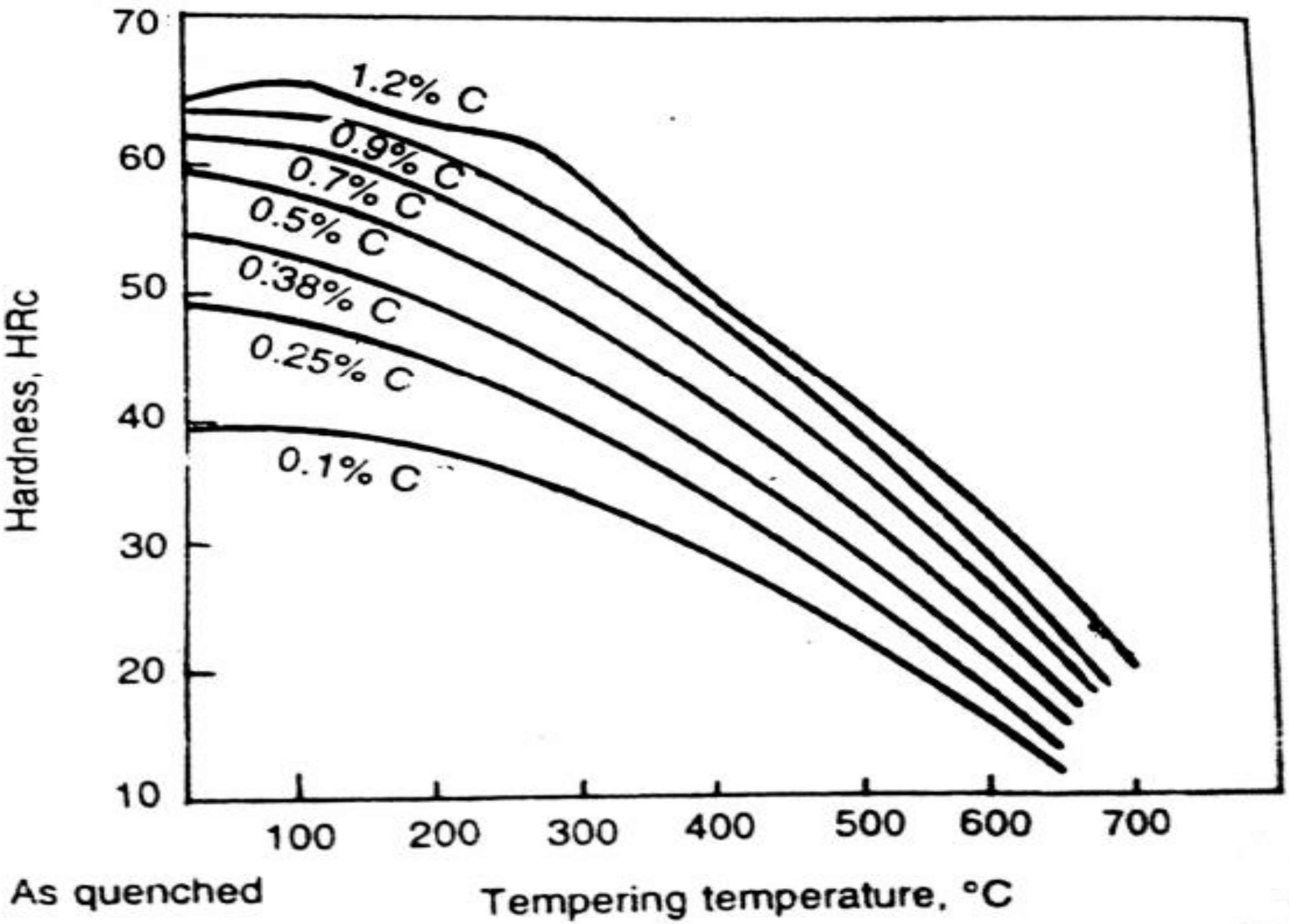
I. FIRST STAGE OF TEMPERING (up to 200°C)

Precipitation of epsilon (ε) carbide due to decrease of tetragonality of martensite. Steels having carbon up to 0.2% as a rule are not hardened and tempered. However, martensite in such steels has BCC structure, which does not show any change in the first stage of tempering except carbon atoms, if not already, segregate to dislocations.

Steels having more than 0.2% carbon are highly unstable due to super-saturation. In first stage of tempering, martensite decomposes into low tetragonality martensitte (≈ 0.2% carbon and c/a ≈ 1.014) and ε-carbide, $Fe_{2.4}C$. It is called tempered-martensite structure at this stage. Epsilon carbide nucleates and grows more rapidly than cementite. Contraction in volume occurs due to rejection of carbon. Decrease of tetragonality decreases the hardness, but precipitation of ε-carbide increases the hardness of the steel proportional to its amount formed. Thus, depending on the net result of these two effects, the hardness of the steel normally decreases continuously but only slightly. However in high carbon steels, for example 1.2% carbon steel, a slight increase in hardness is observed in this stage as relatively large volume of ε-carbide, not only compensates but gives a slight overall increase in hardness, Fig. 10.85 as illustrated by a slight hump in the curve.

II. SECOND STAGE OF TEMPERING (200°-300°C)

Decomposition of Retained Austenite: The amount of retained austenite in the as-quenched steel depends on the chemical composition of the steel, and the temperature to which the steel is quenched. In second stage of tempering, retained austenite transforms to lower bainite. There takes place slight increase in volume of the steel. When the carbon content of the steel is high, the amount of retained austenite being large transforms to more hard lower bainite in large proportions. It produces a hump in the hardness-tempering temperature curve, Fig. 10.85.



70
60
50
40
30
20
10
Hardness, HRc
1.2% C
0.9% C
0.7% C
0.5% C
0.38% C
0.25% C
0.1% C
100
200
300
400
500
600
700
As quenched
Tempering temperature, °C

III. THIRD STAGE OF TEMPERING (200-350°C)

Formation of rods of cementite, complete loss of tetragonality of martensite and dissolution of ε- carbide occur. Hardness decreases continuously and sharply. Structure is ferrite and small particles of cementite. Contraction occurs in volume in this stage.

IV. FOURTH STAGE OF TEMPERING (350°-700°C)

Coarsening and spheroidisation of cementite alongwith recovery and recrystallisation of ferrite occur. The growth of cementite starts at around 300°C, but spheroidisation occurs (to reduce surface energy) above 400°C. Above 600°C, equiaxed grains of ferrite (by recrystallisation) form having coarse globules of cementite. It is spheroidised or globular pearlite which is softest with highest ductility and best machinability.