CHPTER 4
Heat treatment of carbon steel

Introduction :

Steels can be heat treated because of the structural changes that can take place within solid iron-carbon alloys. The various heat-treatment processes appropriate to plain carbon steels are:

- Annealing.
- Normalising.
- Hardening.
- Tempering.

In all the above processes the steel is heated slowly to the appropriate temperature for its carbon content and then cooled. It is the rate of cooling which determines the ultimate structure and properties that the steel will have. Figure 1 shows the types of the ranges of carbon steels.

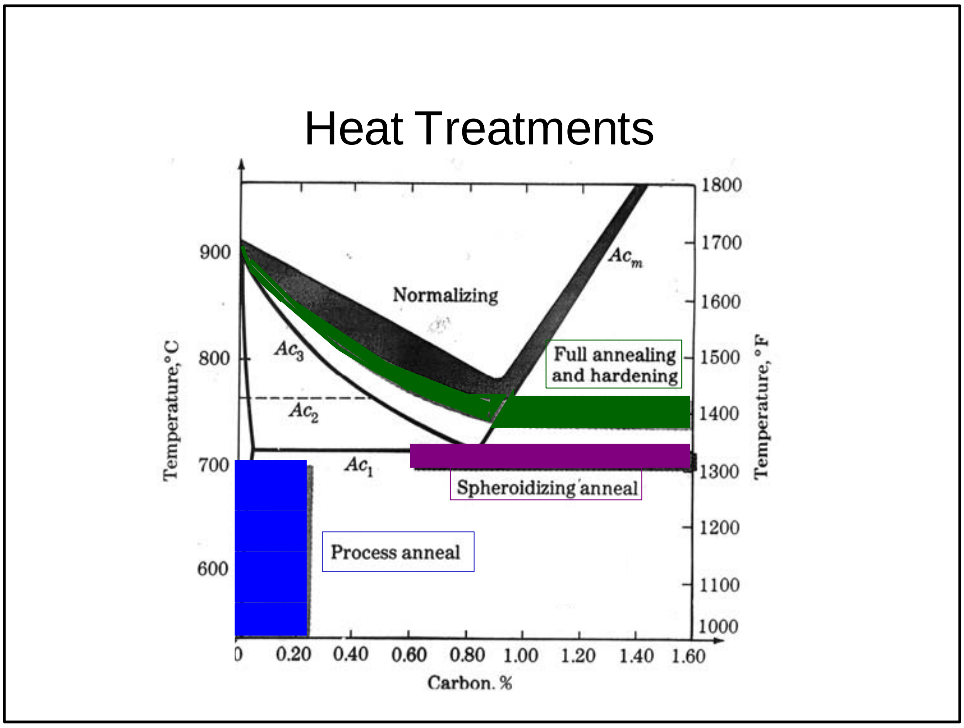


Figure 1. Heat-treatment temperature Ranges of Classes of Carbon Steels.

1. Annealing

All annealing processes are concerned with rendering steel soft and ductile. There are three basic annealing processes, as shown in figure 2, and these are:

- *Stress-relief annealing.*
- *Spheroidised annealing.*
- *Full annealing* for forgings and castings.

The process chosen depends upon the carbon content of the steel.

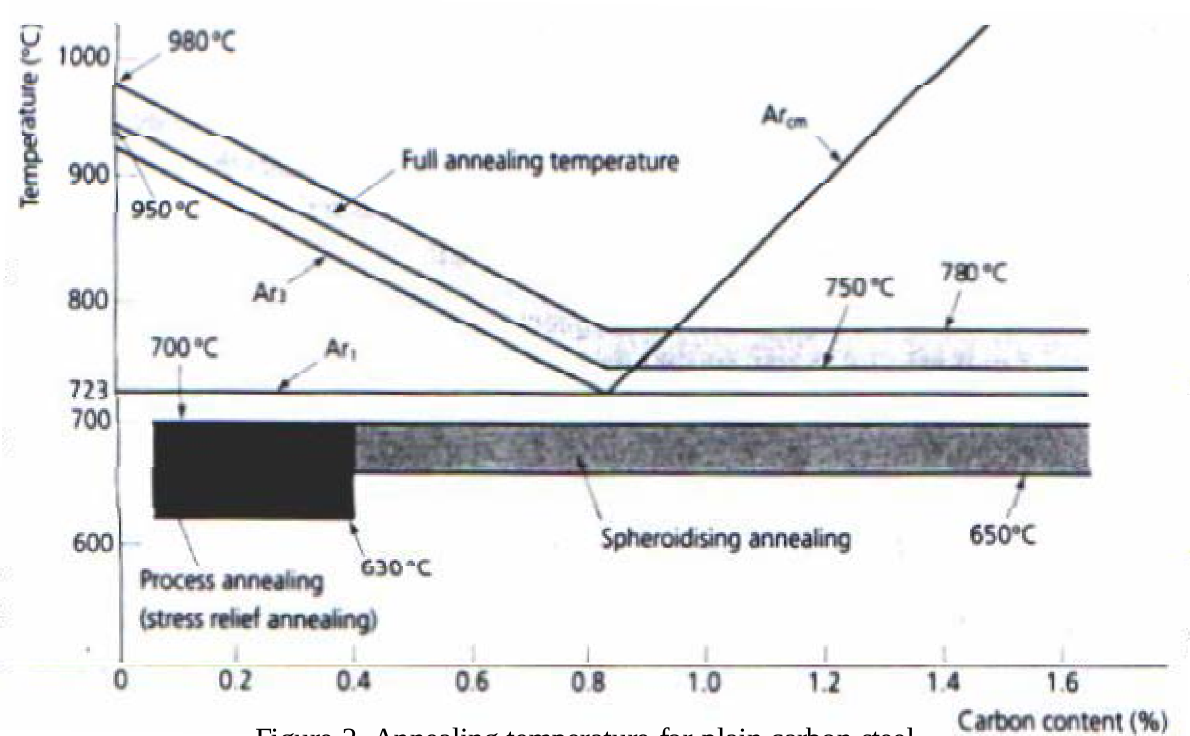


Figure 2. Annealing temperature for plain carbon steel .

a) Stress-relief annealing

It is also called 'process annealing' , sub- critical annealing, it is often used for softening cold worked low carbon(0.4 % carbon content) steel or mild steel . To fully anneal such a steel would involve heating to a temperature between(550-650˚C) for one hour, Process annealing is generally carried out in furnaces.

-Softening of cold- worked mild steel (times 1 hrs.

- Done to relieve residual stresses.

-Less chance of fatigue, stress corrosion etc.

b) Spheroidised annealing

The Spheroidised condition is produced by annealing the steel at a temperature between (650 and 700), just below the lower critical temperature. During this treatment cementite forms as spheroidal particles in a ferrite matrix, putting the steel into a soft, but very tough, condition.

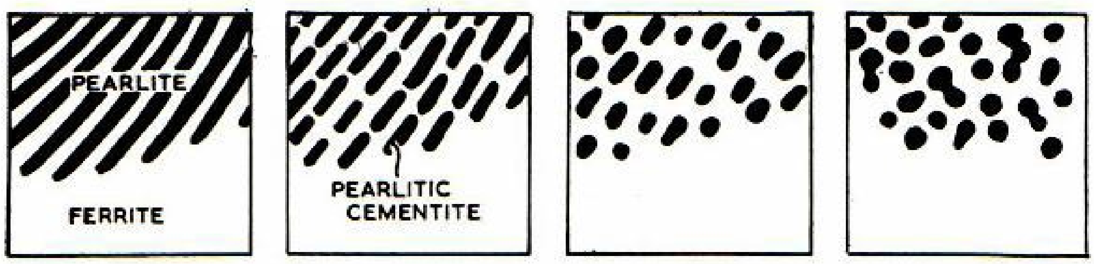


Figure 3. The Spheroidisation.

-24 hrs @ temp. just under A1 for high carbon steel (0.6-1.2 C).
–softens and puts steel in free machining condition.
–carbides will spherodize if held for longtime < 723°C.

c) Full annealing

It is the treatment given to produce the softest possible condition in a hypoeutectoid and hypereutectoid steel. It involves heating the steel to a temperature within the range (30 –50C) just above the upper and lower critical temperatures (A3 and A1) respectively and then allowing the steel to cool slowly within the furnace. This produces a structure containing coarse pearlite.

-Softens and refines a structure.

- complete removal of all casting stresses.
- UTS not greatly improved.
- both toughness and ductility are increased.
- improved mechanical shock resistance.

Ferrite, deposits first at the grain boundaries of the austenite. The remainder of the ferrite is then precipitated along certain planes within the lattice of the austenite. As shown in figure 4. representing typically what is known as a Widmanstatten structure. The main characteristics of such a structure are, weakness and brittleness, and steps must be taken to remove it either by heat-treatment . This operation need a very specific controlling on the heat temperature of annealing because if any fault is occurs, it will make some undesired phases in the steel such as :-

1-Over heating.
2-Burning (Excessive over heating).
3-Under-annealing.

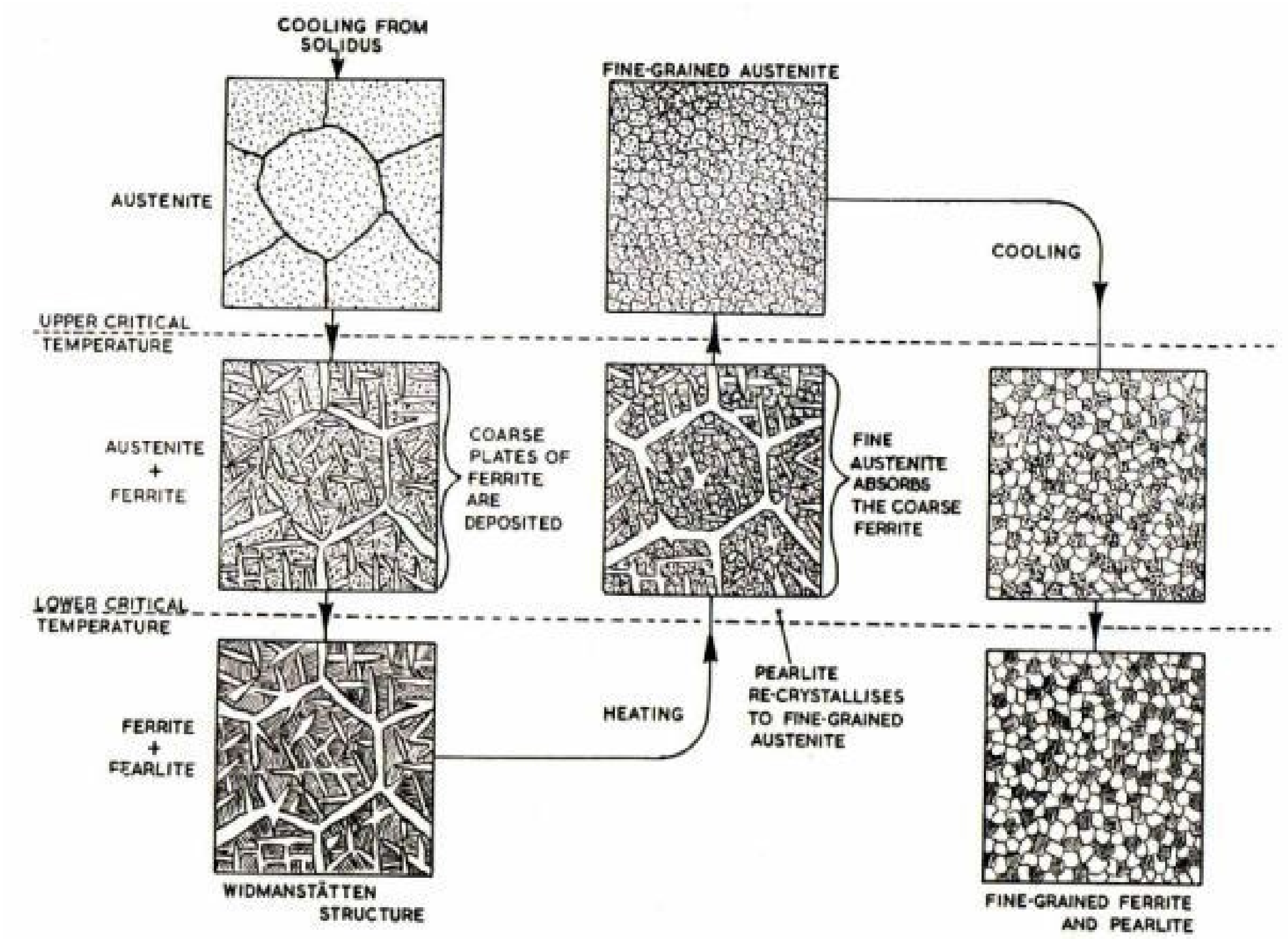


Figure 4. The structural effects of heating a steel casting to a temperature just above its upper critical , followed by cooling to room temperature.

2. Normalising

The process resembles full annealing except that, whilst in annealing the cooling rate is deliberately retarded, in normalising the cooling rate is accelerated by taking the work from the furnace and allowing it to cool in free air.

In the normalising process, as applied to hypoeutectoid and hypereutectoid steels, it can be seen that the steel is heated to approximately 50 C above the upper critical temperature line(A3). The fine grain ferrite and pearlite structure resulting gives improved strength and toughness to the steel but reduces its ductility and malleability. The increased hardness and reduced ductility allows a better surface finish to be achieved when machining and free any locked - stresses.

3. Hardening

When a piece of steel, is cooled rapidly from above its upper critical temperature it becomes considerably harder than it would be if allowed to cool slowly.

This involves rapidly quenching the steel, from a high temperature into oil or water. Hypereutectoid steels are heated to (30- 50C) above the upper critical temperature prior to quenching. It is possible that some cementite grain boundaries.

Consequently, hypereutectoid steels are hardened by quenching from (30- 50C) above the lower critical temperature.

Critical Cooling Rate (C.C.R)

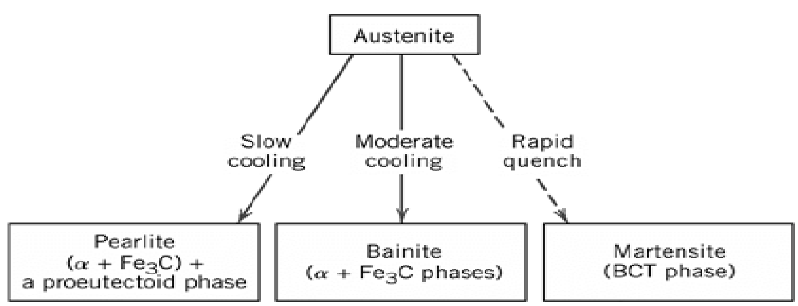
Is the minimum or slowest cooling of austenite, that will transform austenite into 100% martesite.

The affecting factors of (C.C.R) are dependent upon such factors as the properties and temperature of the initial and final of the quenching medium, the shape , size, and the composition of the steel, and amount of agitation.

To harden apiece of steel, it must be heated then quenched in some media which will produce in it the desired rate of cooling . **the medium quenching used will depend upon the composition of the steel ,the ultimate properties required and the size of component**.

The following list of media is arranged in order of quenching speeds: Brine, cold or warm water, mineral oil.

Effect of cooling rate



4.Tempering

A quench-hardened plain carbon steel is hard, brittle and hardening stresses are present. In such a condition it is of little practical use and it has to be reheated, or *tempered*, to relieve the stresses and reduce the brittleness.

This temperature will remove internal stress setup during quenching, remove some, or all, of the hardness, and increase the toughness of the material.

Tempering causes the transformation of martensite into less brittle structures. Unfortunately, any increase in toughness is accompanied by some decrease in hardness. Tempering always tends to transform the unstable martensite back into the stable pearlite of the equilibrium transformations.

Tempering temperatures below (200 °C) only relieve the hardening stresses, but above(220C) the hard, brittle martensite starts to transform into a fine pearlitic structure called ***troostite***. Troostite is much tougher although somewhat less hard than martensite and is the structure to be found in most carbon-steel cutting tools.

Tempering above (400C) causes any cementite particles present to "ball-up" giving a structure called ***sorbite.*** This is tougher and more ductile than troostite.
For most steels, cooling form the tempering temperature may be either cooling in air, or quenching in oil or water.

Martensite in Steel

When austenite is cooled sufficiently rapidly, it transforms into martensite without any change in chemical composition (no diffusion). The transformation begins at a well–defined temperature called the martensite–start temperature or M_S. The fraction of martensite increases with the undercooling below M_S.

Tempering of Martensite

Martensite containing carbon is very strong; this also makes it very hard and brittle. To achieve a compromise between strength and toughness, the martensite is tempered, i.e. heat treated at temperatures below that at which austenite can form. The heat treatment causes:

1. 200–400 °C. The precipitation of excess carbon at first as a transition carbide $Fe_{2.4}C$, which then converts to cementite (Fe_3C). This is accompanied by a significant loss of strength but an improvement in toughness (Fig. 3).
2. 400–500 °C. Recovery with a reduction in dislocation density. Cementite begins to coarsen with further loss in strength.
3. >500°C. Recrystallisation of plates into equiaxed grains of ferrite.

Time–Temperature–Transformation(TTT)Diagrams

Curves are govern the relationship between the rate of cooling of steel and its final microstructure and properties. This can be represented on the $(T-t)$ plot as a C curve (Fig. 4).

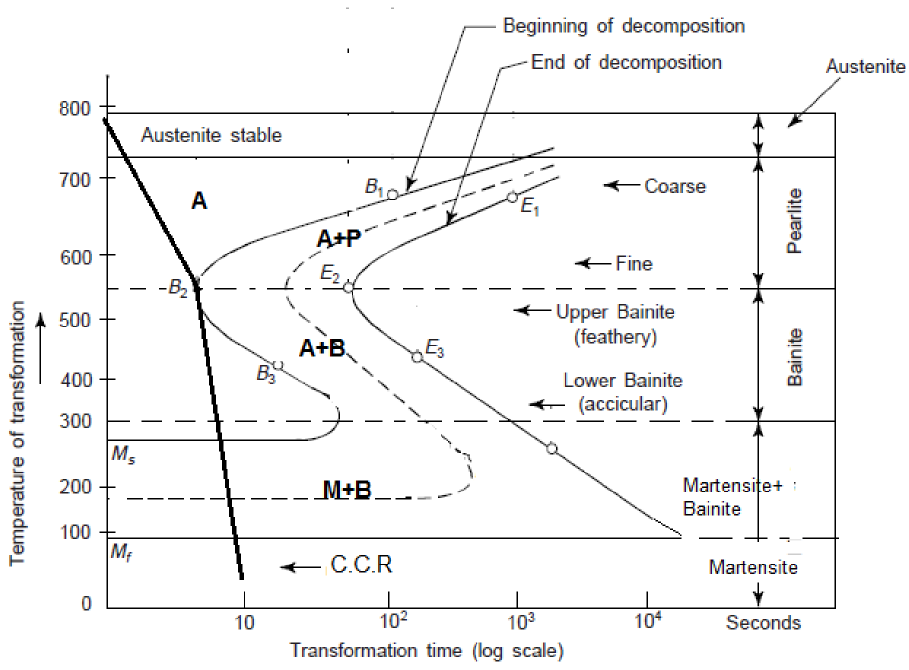


Fig. 4: TTT diagram for eutectoid steel

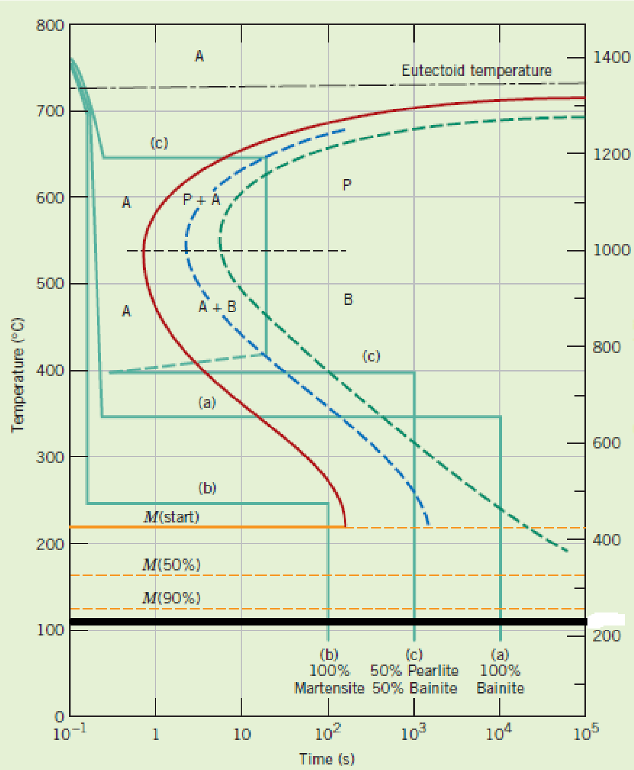


Figure 10.24 Isothermal transformation diagram for an iron–carbon alloy of eutectoid composition and the isothermal heat treatments (a), (b), and (c)

[Heat treatment of steel](Part 2)

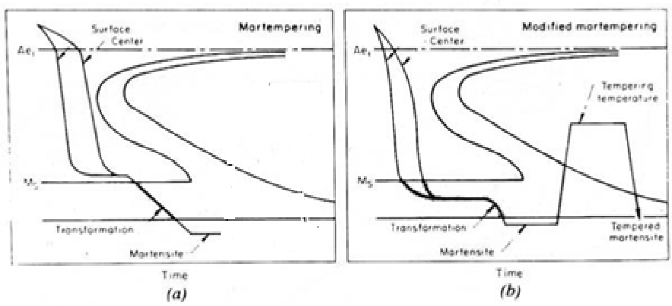
Martempering

-Quench it in a bath oil/ or molten salt to a temperature slightly above/ or below M_s.

-Hold it in the bath until temperature uniform throughout the steel.

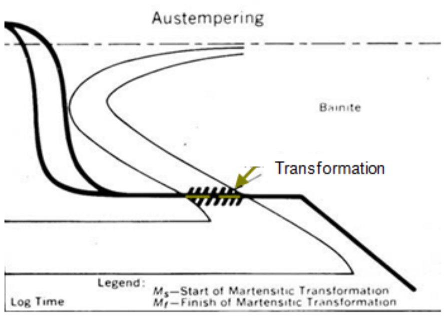
-Removed from the bath and cooling in **warm air**.

-Produced hard martensite structure without cracks and distortion.



Austempering

- Produces: **bainitic structure** like tempered martensite (toorsite).
- Quench into a bath @ a temperature slightly above M_S held isothermally.
- Cooled (is not important) to room temperature **in air**.
- Improved ductility and impact strength for a given hardness.
- Decrease cracking and distortion quenching



JOMINY HARDENABILITY TEST

The hardenability of a steel is defined as that property which determines the depth and distribution of hardness induced by quenching from the austenitic condition.

A part may be hardened by quenching into water, oil, or other suitable medium. The surface of the part is cooled rapidly, resulting in high hardness, whereas the interior cools more slowly and is not hardened. The hardness does not vary linearly from the outside to the center. Hardenability refers to capacity of hardening (depth).

The hardenability of a steel depends on:

(1) the composition of the steel,
(2) medium quenching,
(3) the quenching technique , and
(4) the mass effect(cross section area).

Plot a hardenability curve of Rockwell hardness vs. distance from the quenched end. (Fig. 3)

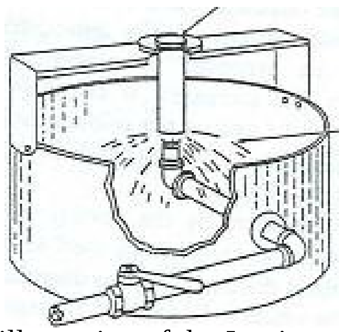


Fig.1 Schematic illustration of the Jominy end-quench test

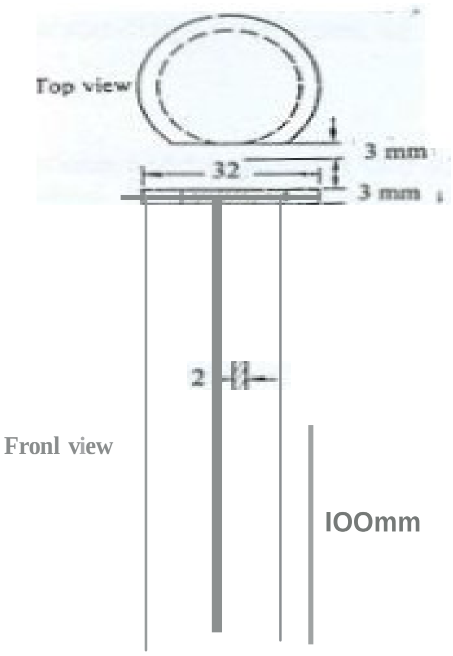


Fig.2 Standard-size sample.

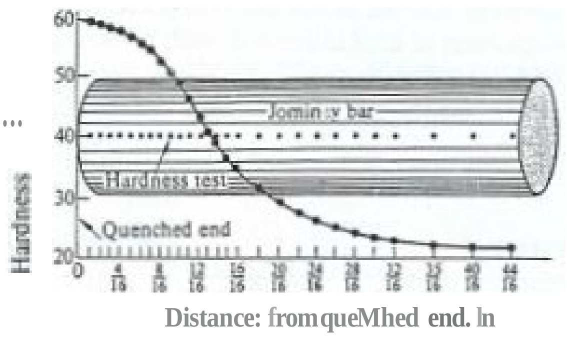


Fig.3 Position of hardness test points along the bar.