Sheffield Hallam University

The technology of heat treatment

TITTAGALA, Sunil <http://orcid.org/0000-0003-0783-1088>

Available from Sheffield Hallam University Research Archive (SHURA) at:

https://shura.shu.ac.uk/29367/

This document is the Accepted Version [AM]

Citation:

TITTAGALA, Sunil (1990). The technology of heat treatment. In: Workshop on Heat Treatment of Steel for Small and Medium Industries, Colombo, Sri Lanka, 14 November 1990. Project SMED (Small and Medium Enterprise Development). (Unpublished) [Conference or Workshop Item]

Copyright and re-use policy

See http://shura.shu.ac.uk/information.html

Sheffield Hallam University Research Archive
http://shura.shu.ac.uk

P6

PROJECT SMED

WORKSHOP ON

"Heat Treatment of Steel"

for Small and Medium Industries

HEAT TREATMENT TECHNOLOGY

by

Dr Rohan Tittagala

Senior Lecturer

Dept. of Mechanical Engineering

University of Moratuwa

Project SMED

Workshop on
HEAT TREATMENT OF STEEL for Small & Medium Industries

Hotel Taj Samudra, 14th November 1990

HEAT TREATMENT TECHNOLOGY

Speaker : Rohan Tittagala
Department of Mechanical Engineering
University of Moratuwa.

What is Steel ?

Steel is an alloy (ie. a mixture) of iron (Fe) & carbon (C). Theoretically speaking, 'Plain-carbon Steels' have Fe & C only, but when produced commercially certain other elements such as manganese, phosphorous, sulfur and silicon are present in small quantities.

Note: Cast Iron also is basically a mixture of iron and carbon but the carbon content in Cast Iron is much more than in steel, generally 2.0 to 4.0% . In addition most commercial cast irons contain significant amounts of silicon (0.5 to 3.0 %).

Depending on the carbon %, Plain-carbon Steels can be catergorized as:

Low-carbon Steels	-	Up to about 0.25% C (Steels commonly known as "mild steels" may have about 0.15 to 0.20% C)
Medium-carbon Steels	-	0.25% to 0.5% C (say)
High-carbon Steels	-	0.5% to 2.0% C (say) (These are mainly used as die and tool steels with other appropriate alloying additions).

With increasing C%, steels become stronger but more likely to fracture (ie. Hardness is more but toughness is less)

In steels, the carbon is 'dissolved' to give a complex mixture and one must never imagine that Fe & C are separate. (In cast irons of course there can be free carbon, ie. graphite, which is not mixed with Fe).

Alloy Steels

When other elements are added to plain-carbon steels the resulting steels are 'alloy steels'. The most common alloy elements are choromium, nickel, molybdenum, vanadium, tungsten and cobalt. Even manganese and silicon (which are usually present in plain - Carbon steels) are considered as alloying additions when more than 1.5% Mn or 0.5% Si is present.

What is the purpose of alloying ?

Alloying elements are added in larger amounts (say, greater than 5%) to give special properties to steel. For example, in stainless steel there is high choromium (10 to 25%) which gives corrosion resistance. High nickel content gives high temperature resistant steels.

However, the main aim of adding alloy elements in small amounts (Low Alloy Steels) is to improve the strength of steel and, more significantly, to improve the flexibility in heat treatment of steel. The characteristic we are interested in is HARDENABILITY ie. the ability to harden on quenching or, in quantitative terms, the depth of hardening possible on quenching.

Thus,

> ONE MUST NEVER 'TREAT' ALL STEELS ALIKE OR ASSUME THAT THEY ARE MORE OR LESS THE SAME. IF YOU DO NOT APPRECIATE THIS BASIC FACT, THEN YOU ARE MOST LIKELY TO MAKE THE FUNDAMENTAL ,AND THE FATAL, MISTAKE IN HEAT TREATMENT.

However, steels can be grouped into several categories and normally steels of a particular category will have similar characteristics and can be 'treated' alike. This leads us to the steel classification systems.

The AISI Classification System

This system of grouping steels, started by the Society of Automotive Engineers (SAE) to provide standardization of steels used in automotive industry, was later adopted and expanded by the American Iron and Steel Institute (AISI) and is now universally used. The British EN classification system is somewhat out dated. Russians, Japanese and other major industrialised nations also have their own steel classification systems. Generally, an equivalent AISI grade can be found for all such steels.

In the AISI system, both plain-carbon and low-alloy steels are identified by a 4 - digit number. The first digit indicates the major alloying element (or elements) and the second digit indicates a sub-group of alloying elements. The last digit indicates the approximate carbon content.

Examples:

1045 - a plain-carbon steel with 0.45% carbon. (digit 1 indicates carbon)

4040 - a low-alloy molybdenum steel with 0.40% carbon. (digit 4 indicates molybdenum as the major alloying element)

4140 - a low-alloy molydbenum-chromium steel with 0.40% carbon

4340 - a low-alloy molybdenum-chromium-nickel steel with 0.40% carbon.

The AISI system also covers high-alloy steel types (for example, a 3-digit number identifies stainless steels).
Since many participants will be interested in heat treatment of tool steels, information on tool steels including their classification is provided on separate sheets.

What is Heat Treatment of Steel ?

It has been explained that every steel is not the same. What the user expects from a steel, ie. his final requirements, will vary from application to application. For example, a medium carbon steel is not a substitute for a tool steel. Again, the same tool steel will not satisfy the property requirements of a blanking die and at the same time those of a hot forging die.

Having selected the most suitable steel for an application, it must be properly heat treated to "bring the best out" of the steel. Here, the term heat treatment is used to mean the final time - temperature treatment that a finished (or close to finish form) component is subjected to before putting it into service. This is normally a Quench & Temper procedure. However, the general term heat treatment may mean many other time-temperature treatments which may be applied to a steel at different stages during its processing leading to a final component. These include many 'softening' type treatments that improve machinability, make possible further cold deformation (for example, between stages in wire drawing) or relieves internal stresses.

What Happens in Heat Treatment of Steel ?

It has been told that steel is a complex mixture of iron and carbon and also of any other alloying elements that may be present. Here we do not intend to go into too much detail about the metallurgy of steel, but one must appreciate the fact that steel consists of several 'phases' (ie. different types of mixtures of iron - carbon) and together these form the 'microstructure' of a particular steel. The relative amounts and the pattern of distribution of these phases can be changed by heat treatment which in turn will change the properties and behaviour of the steel. The microstructure is basically what one sees on the 'properly prepared surface' of a steel specimen under magnification when viewed through a microscope.

Some phases in the microstructure are soft and tough while other phares are hard and brittle (liable to fracture).

Equilibrium phases in steel:

At low temperature -

Ferrite - soft and ductile (makes cold forming of steel possible)

Cementite - hard and brittle

Note : 'Pearlite' is a mixture of ferrite-cementite and has intermediate properties

At high temperature -

Austenite - soft and ductile (makes hot- forming of steel possible)

The above are called 'equilibrium' phases of steel because they are formed in the steel when it is cooled gradually at a slow rate. Those who are familiar with the 'Phase Diagram' of the Fe-C system will identify these phases as the ones that are represented on it.

Softening - (the formation of Pearlite)

Now, most heat treatments for steels involve heating at a fairly high temperature and cooling either slowly (anneal,normalize) or rapidly (quench) from this temperature. To begin with, when the temperature is sufficiently high (actual values depend on the type of steel) the steel will be in the austenite condition. A steel billet which is to be hot-forged or hot-rolled is also in a structurally similar condition. When this steel is slowly cooled, generally it will transform to pearlite and the steel will be in a machinable condition.

What happens if steel is quenched from the high temperature austenite condition ?

Hardening - (the formation of Martensite)

When quenched, steel will not transform to pearlite but to an entirely different phase called martensite. You will know that the quenched steel is extremely hard but likely to crack if a sharp blow is imparted with a hammer. This is because martensite is very hard and brittle. We are talking about a Rockwell hardness

(HRc) of about 60-70. The higher the C% in the steel, higher will be the hardness of martensite.

Note : Because it lacks good toughness, martensite is not a useful engineering microstructure despite its great strength. Subsequent heating known as TEMPERING is required to restore some desired degree of toughness at the expense of a reduction in strength and hardness.

There are a few things you will need to know about the quenched steel if you are to understand the complexity and risks in the process of hardening.

When steel is quenched, the temperature has to drop below a certain value (M_s temperature) for martensite transformation (hardening) to start. For the martensite transformation (hardening) to complete, the temperature has to drop below a second value (M_f temperature). Now let us assume that the quench bath is at room temperature which is often the case. M_s temperature for any steel is well above room temperature but M_f temperature may not be. For plain-carbon steels containing more than about 0.9% C, the M_f temperature is below room temperature. With highly alloyed steels, for example tool steels, the M_f temperature is significantly below room temperature. (These steels require refrigeration or a quench in liquid nitrogen to obtain full hardness.)

What are the implications of the above ?

For most special steels full hardness may not be achieved during quenching. For example, for a certain steel only 80% of the austenite may transform to martensite and the balance will remain as 'retained-austenite' in the hardened steel. Not achieving full hardness before the tempering stage cannot be helped, but one must be careful about the 'retained-austenite' in steel. Retained austenite transforms with time and gives rise to dimensional changes and cracking tendencies under working conditions. For example, the clearance between a blanking punch and die can change with time if not properly heat treated. Proper heat treatment here means getting rid of any retained-austenite completely during the tempering stage.

Note : This problem of retained-austenite will not be encountered in the heat treatment of low, medium -carbon or low-alloy steels.

What is the significance of cooling rate ?

Hardenability & the 'Size-effect'

Does martensite transformation, ie. hardening of steel, occur only with high speed cooling ? No. You will know that there are steels which harden sufficiently on cooling in air. Only rule is that the cooling rate must be 'fast enough' to avoid transformation of austenite to equilibrium product pearlite. The necessary cooling rate is completely determined by the type of steel. (more exactly, by the Time-Temperature-Transformation Curve for the particular steel).

Plain-carbon steels must be very quickly cooled, if any transformation to softer pearlite is to be avoided and martensite transformation initiated. The lower carbon steels will definitely require water as the quenching medium. Further more, the 'thickness' of the component must be very limited if the required fast cooling rate is to be achieved in the centre sections. This imposes a limit to the 'section-size' that can be through hardened. With low-alloy steels, however, the situation is vastly improved. The depth of hardening possible is now much more. At the other end of the range of steels the 'deep hardening' types of steel, which are the highly-alloyed steels, can be seen. Satisfactory through hardening of relatively large section thicknesses of such steels, even with circulating air as the quenching medium, is possible.

Note : To fully appreciate the effect of cooling rate on hardening, a basic understanding of the TTT curve will be necessary. Steel suppliers' specifications often include this diagram.

Heating at High Temperature

In 'full annealing', normalising or hardening procedures the steel is first heated at a high temperature so that its structure becomes austenite completely. This temperature and the holding time ('soaking time') both are very important parameters in heat treatment. Overheating the steel at high temperature, particularly in hardening, must be avoided at all costs and this is why it is necessary to preheat the steel at a temperature of about 650^{0}C (generally for about 1/2 min/mm section thickness) before heating up to the high temperature. Overheating at high temperature not only causes oxidation of the suface (scale formation) and loss of surface hardness ('decarburization') but also, more seriously, weakens the steel ('grain growth').

Heating Media

To protect the steel from scale formation and any decarburization, particularly the special steels such as tool steels, adequate precautions must be observered depending on the type of furnace used.

Salt-bath furnaces : These provide very quick through heating, and the netural salts used ensure very good surface protection.

Some typical compositions and working temperatures of neutral salt baths are :

45% NaCl + 55% KCl	675 - 900^{0}C	(eg. AISI W,O,S grades)
20% NaCl + 80% $BaCl_2$	675 - 1060^{0}C	(eg. AISI A,D grades)
100% $BaCl_2$	1025 - 1325^{0}C	(eg. HSS, AISI H grades)

Salt baths must be maintained very 'clean' during service. Iron oxide formed in the bath has a decarburizing effect on steel and the bath must be 'regenerated'. For example, $BaCl_2$ baths can be regenerated with pieces of silica brick. This combines with iron to form a removable sludge. Presence of iron oxide in the bath can be checked by immersing a graphite rod; small bright specks of metallic iron will form on the rod. Whether salt baths have a caburizing or a decarburizing action can be checked by dipping standard steel foil into the bath, quenching and checking whether soft or brittle.

Muffle furnaces: These are gas- or oil-fired or electrically-heated. Furnace atmosphere control using protective gases is a universally practiced method in heat treatment, but is seldom used in local industry. Thus, protection must be provided for special steels by packing in 'annealing boxes' with some protective material which should be as neutral as possible. One purpose of the packing material is to prevent access of oxygen to the steel. Cast iron chips are very suitable for this as the air drawn into the box preferentially oxidizes the chips. The surface of the steel part can be protected against mechanical damage by wrapping in a thin layer of news paper before being packed with the chips. Cast iron chips should not be used at temperatures above 1050^{0}C as they begin to sinter.

Wood-charcoal or coke fines (but not the carburizing compounds) are also used as protective material but these can have a carburizing effect in the case of high-chrome (AISI D type) and hot-work (AISI H type) steels in view of the high hardening temperatures used. Under certain conditions, borax powder sprinkled over the surface may be used as a protective agent. Borax melts and forms a covering film. Protective pastes are also available commercially but seldom used in local industry. Also, heat-resisting steel foil in which the steel parts are wrapped can be used as a protective measure.

Cracking during Hardening

The tendency of the layman often is to associate quench cracking with the direct thermal stresses resulting from drastic cooling rates. This, however, is not the real reason for cracking in the majority of situations.

The hardening process, ie. the transformation of austenite to martensite, results in a significant volume expansion of steel since the density of the latter phase is lower. When a steel component is quenched, the outer layers will transform to martensite immediately. The inner material will begin to transform at a later instant in time and the associated volume expansion will be prevented by the already transformed outer layers. The outer layers will be subjected to tensile stresses which may ultimately give rise to cracking depending on the shape of the section and the temperature gradient occuring across it. Delayed cracking is often a possibility. Even if the component does not crack, it is likely that severe residual stresses can be present in a quenched component which could lead to problems in service if these stresses are not completely eliminated during subsequent tempering.

Quench Media

While cooling rate is the basic factor in selecting a quenchant, the ideal cooling medium should cool the steel quickly to M_s temperature and then slowly to bath temperature (usually the room temperature).

The cooling effectiveness is related to three stages of quenching:

Stage 1. When hot metal contacts liquid quenchant, the latter vaporizes forming a gas layer (vapour jacket) at the surface. Cooling is slow.

Stage 2. Bubbles form removing the gas layer and liquid contacts metal. Liquid vaporizes removing heat. Rapid cooling.

Stage 3. When metal cools below boiling point of quenchant, heat transfer is through conduction across solid-liquid interface. Moderate cooling rate.

Agitation or spraying of the quenchant increases the effectiveness of a given medium very much.

Water : Practically always the medium for plane carbon steels.
Brine (10% common salt in water) or 10% soda in water gives a more severe quench due to rapid formation of bubbles and gives good hardness in low-carbon steels. Pure water is rather unsuitable as a quenchant since its maximum cooling efficiency is at 300 C, ie. the temperature at which martensite starts to form (M_s) in many steels. This exposes the steel to higher risk of cracking due to combined effect of thermal and transformation stresses. In brine, the cooling efficiency is maximum at 500^0 C, ie. well above M_s. The danger of cracking in water quenching may be reduced if the steel is removed at $400-200^0$ C and rapidly tranferred to an oil bath.

Oil : Oil has a rather low capacity for heat extraction compared to water. The slower cooling through temperature range of martensite formation (M_s to M_f) gives less tendency to cracking. Although one may be reluctant to accept this, the cooling capacity of oil can be increased by raising the temperature to $50 - 80^0$ C.

In local industry many 'non-standard' quenching oil types are used. Ones own experience is the best indicator of the suitability of a particular oil for a particular class of steel. One rule to be observed is that the 'flash point' should be high enough to avoid a fire hazard.

Salt-baths : Molten salts are often suitable as a quench medium, particularly in special heat treatments. These are seldom used in local industry not because of additional costs but mainly due to lack of awareness of their necessity in heat treatment, for example, of complex tooling made of special steels. (see also 'martempering' later).

Salt baths have the property of going directly into the third stage of cooling. The most popular type is;

50% sodium nitrite + 50% potassium nitrate
with a cooling range of $160 - 500^0$ C.

Recommended holding time may be a 2-4 minutes per 10mm section thickness, the longer time applying to high hardening temperatures and heavy sections.

Air : High-alloy steels in heavy sections (and medium - alloy steels in light sections) can be through hardened by cooling in a forced air draught or even in still air. Air must have access to all parts of the surface; the part can be rotated in a steady current of air. High speed steels, hot-work steels (AISI H grades) and high-chrome steels (AISI A,D grades) have sufficiently high hardenability to enable hardening in air. For example, D6 can be hardened in quite heavy dimensions while H13 is the most popular air hardening steel. The latter can be hardened in still air up to 200mm diameter sections. Distortions are neglegible in air quenching, but one draw back is that the surface may be oxidized.

Prevention of Distortion and Cracking - ('Interrupted Quench')

MARTEMPER (more appropriately called MARQUENCH) is a modified quench procedure which minimizes risk of distortion and cracking and enables good dimensional control. It is possible, however, only for steel types with adequate hardenability.

From the normal hardening temperature, instead of quenching through the martensite formation range, the steel is rapidly quenched to a temperature just above M_s temperature usually in a salt bath. The component is held in the bath for a sufficient time for temperature equalisation through the section and is then cooled slowly (usually in air) across the martensite formation range. The component is then tempered in the same manner as after a conventional quench.

The idea is to avoid high temperature gradients during transformation and, more importantly, to form martensite uniformly throughout the section at more or less the same instant. This will avoid the build up of excessive residual stresses which leads to cracking.

In a slightly different martempering procedure, the steel is quenched to an intermediate temperature in the M_s-M_f range and cooled slowly after temperature stabilisation. This process is applicable even to steels with somewhat lower hardenability as the initial quench is faster due to the lower temperature. A more important advantage is that heated oil can be used as the quenchant instead of a salt bath. Existing oil baths can be converted at a low cost.

Note: If the steel is held in the salt bath for a long period (say 2-3 hours), austenite will transform to bainite. This is AUSTEMPERING. For a greater understanding of these special heat treatments, a basic knowledge of the TTT curve is essential.

Metallurgy of AISI Grades of Tool Steels

1. Water - hardening Carbon tool steels(W)

Least expensive type
Good machinability

Very low hardenability - (< 3/8" Dia.)
(water quench)

Thus only small parts can be full depth hardened. However in shock loading applications an advantage may be a highly wear resistant surface - tough core combination.

The low hardening temperature (770 - 800°C) is advantageous in practice.

Small (< 0.2%) Vanadium additions (eg. in W2) counters grain growth at hardening temperatures. Due to the refined grain size, shock resistance is improved.

Limitation : Prolonged exposure to temperatures over 150°C causes rapid softening.

2. Cold-work 'non-shrink' Steels (O,A,D)

'non-shrink' : Very little dimensional movement through the processes of hardening and tempering. Expensive grinding minimized or completely eliminated.

a. Oil hardening types (eg. O-1) - Improved hardenability results from manganese & chromium contents.

b. Air hardening types (eg. A2) - Further improvement in hardenability due to molybdenum contents (approx. 1%). Even less prone to dimensional change or distortion.

The high chromium (approx. 12%) types (eg. D2, D6) have very good wear resistance but are difficult to machine.

Note: In this series A2 has a good combination of properties, being wear resistant, relatively tough and dimensionally stable.

3. Shock-resisting Steels (S)

Primarily used when extreme wear resistance can be sacrificed but resistance to shock loading is of paramount importance. High toughness is associated with medium carbon content (approx. 0.5%). Satisfactory wear resistance, hardenability and moderate hot-work capability achieved through carbide-forming alloying elements.

4. High-speed steels (T,M)

Versatile in cutting tool applications due to hot hardness and strength (resulting from secondary hardening) coupled with an acceptable level of toughness. Find limited applications as cold-forming and hot-forming tools.

The heat treatment is relatively complicated requiring multi-tempering and the high hardening temperatures demand adequate precautions and control of variables during heat treatment.

5. Hot-work steels (H)

The 5% chromium type (eg. H13) is the most commonly used type. Hot-work tool steels are established in metal-forming as well as in pressure die-casting and plastic moulding applications.

The medium carbon content together with the carbide forming alloying elements provide a good combination of toughness and wear resistance. These steels also exhibit 'secondary hardening' which provides the necessary temper resistance enabling the dies to retain hardness at high operating temperatures. Additionally the hot-work steels are resistant to thermal fatigue.

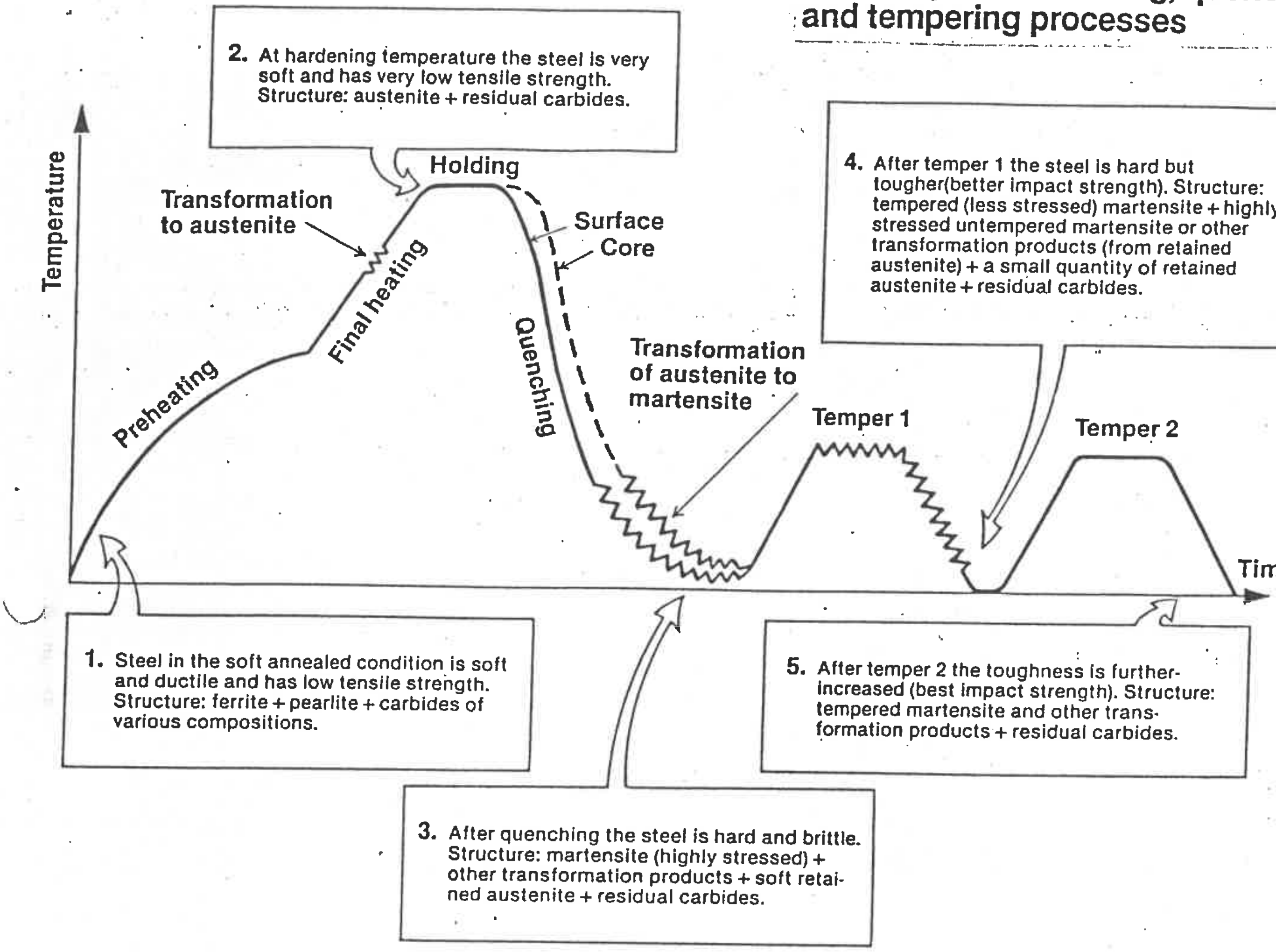
6. Plastic Mould steels (P)

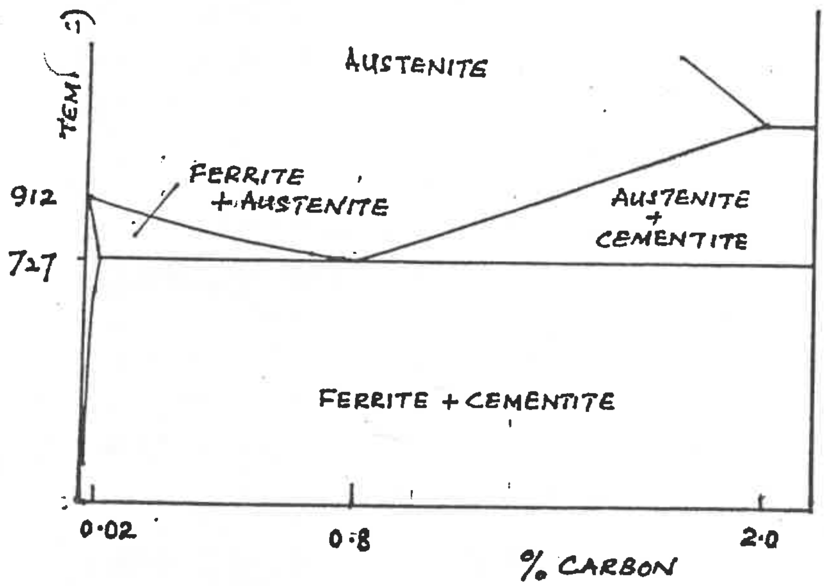
These are machinable steels with medium carbon content and satisfactory hardenability. Used also in die casting applications for lead, zinc and tin alloys.

Note: These steels are usually commercially available in a pre-hardened condition which may suffice for certain applications. Thus no heat treatment is required in such applications.

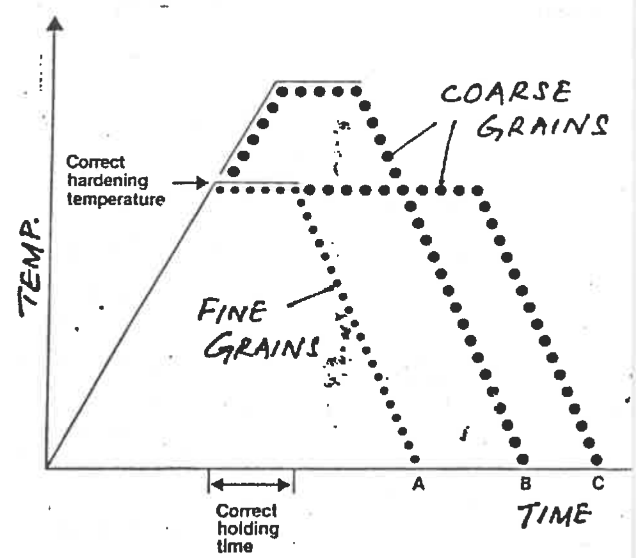
When extreme polishability is required or when the plastic materials being moulded have a corrosive effect on the dies (eg. in moulding of PVC), Martensitic stainless steel grades can be used for mould manufacture (eg. AISI 420 containing 13%Cr).

Summary of the heating, quenching and tempering processes



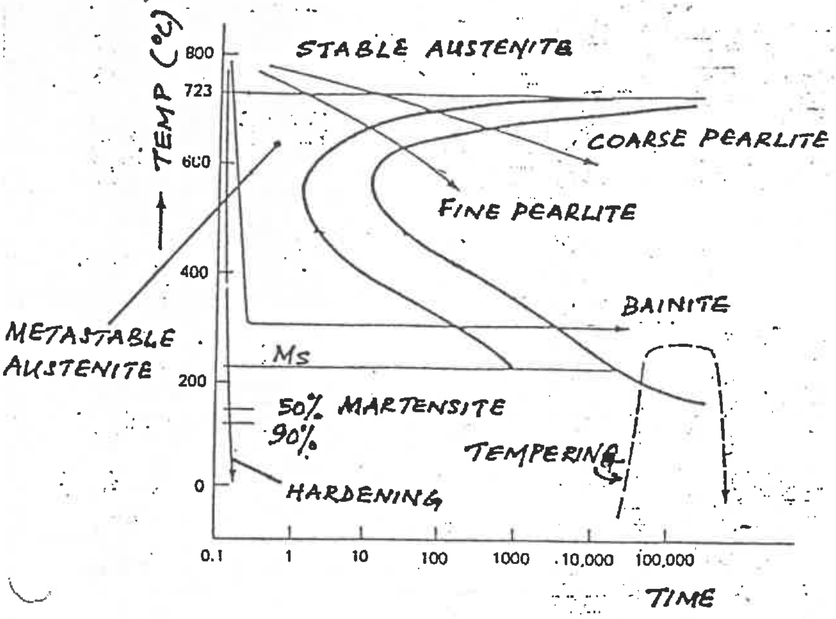


SIMPLIFIED IRON-CARBON DIAGRAM



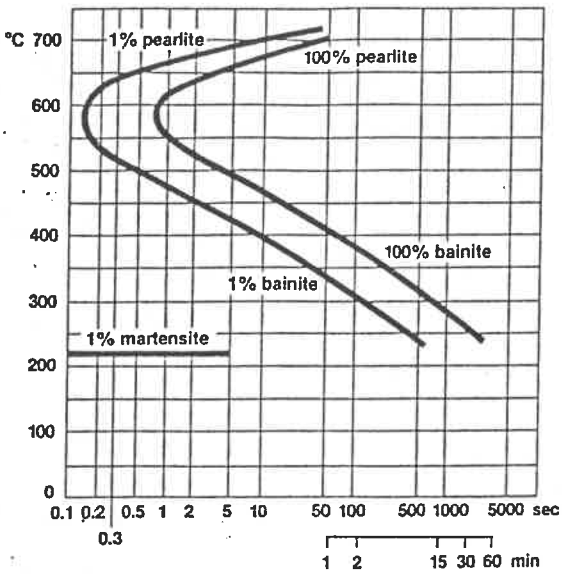
Effect of temperature and holding time on grain growth in plain carbon and low alloy steels.

TTT diagram



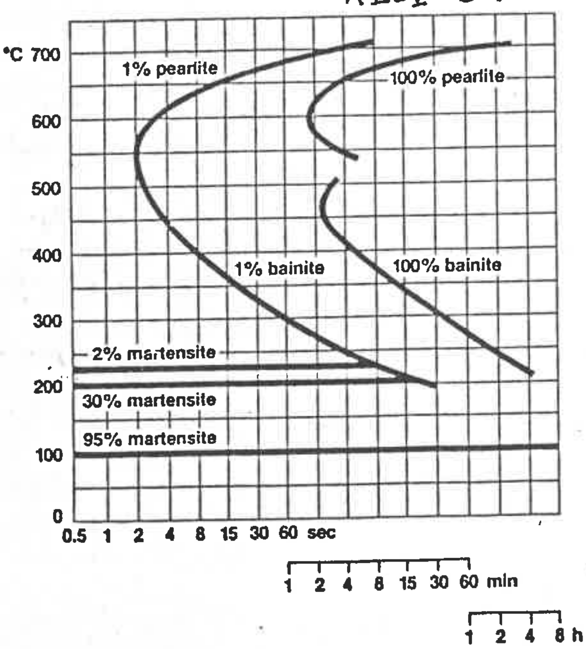
TTT CURVE FOR 0.8% CARBON STEEL

AISI W-1



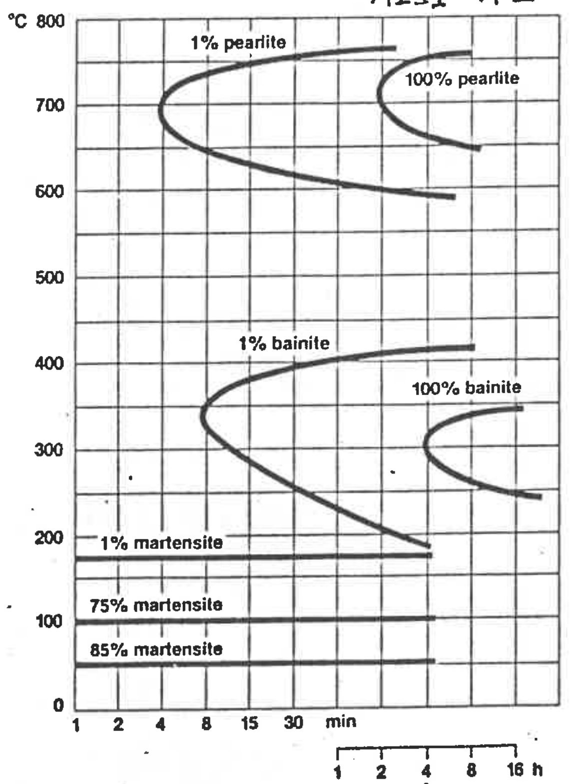
TTT diagram for – (AISI W1). Austenitizing (hardening) temperature 780°C.

AISI O-1

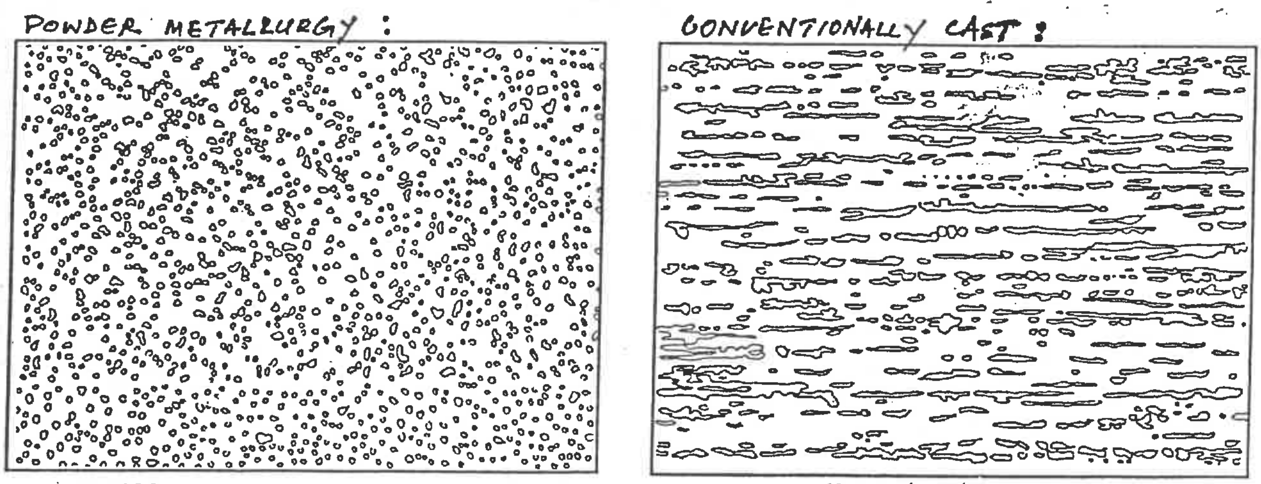


TTT diagram for – (AISI O1). Austenitizing (hardening) temperature 810°C.

AISI A-2

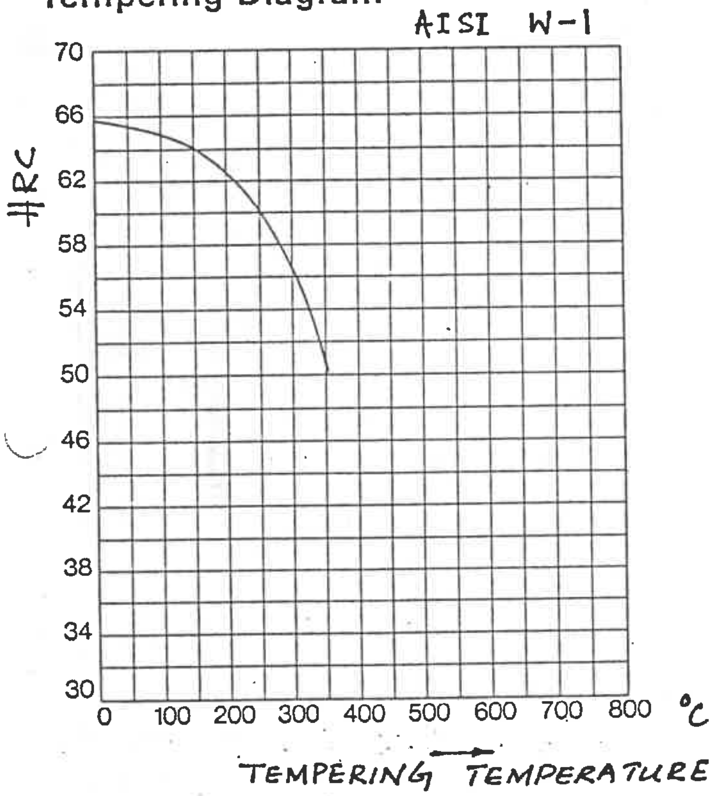


TTT diagram for – (AISI A2). Austenitizing (hardening) temperature 950°C.

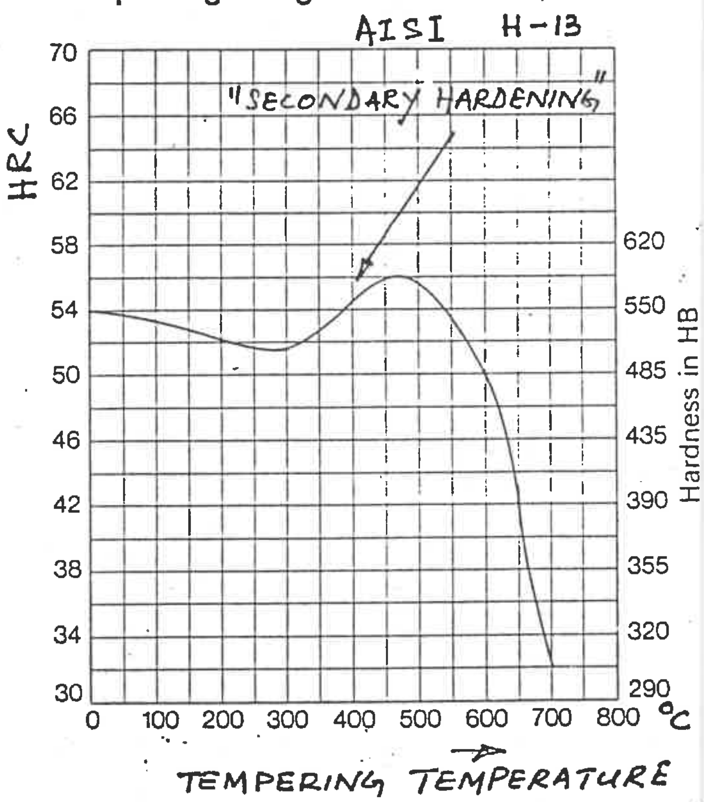


Carbide distribution IN HSS

Tempering Diagram

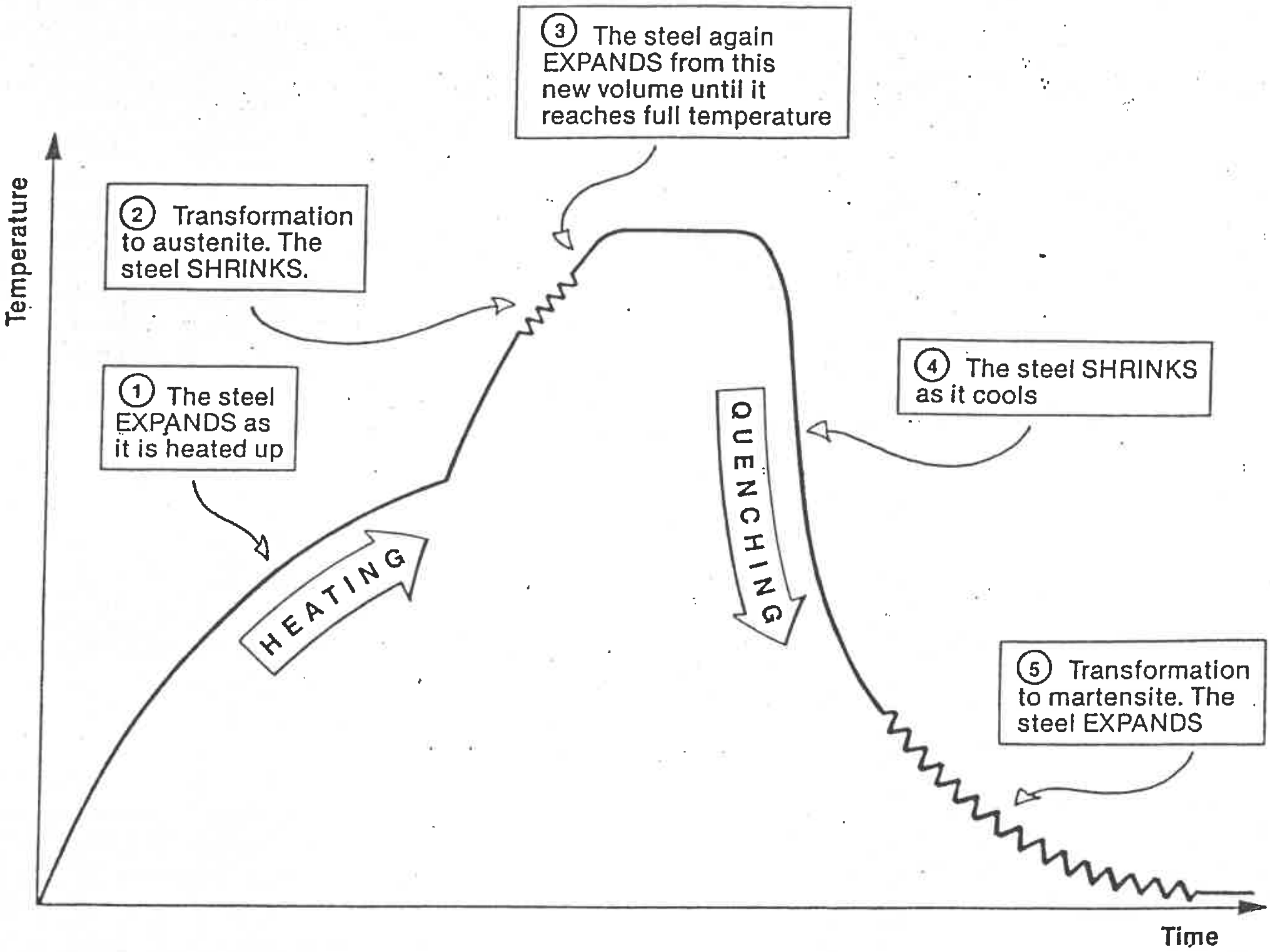


Tempering Diagram

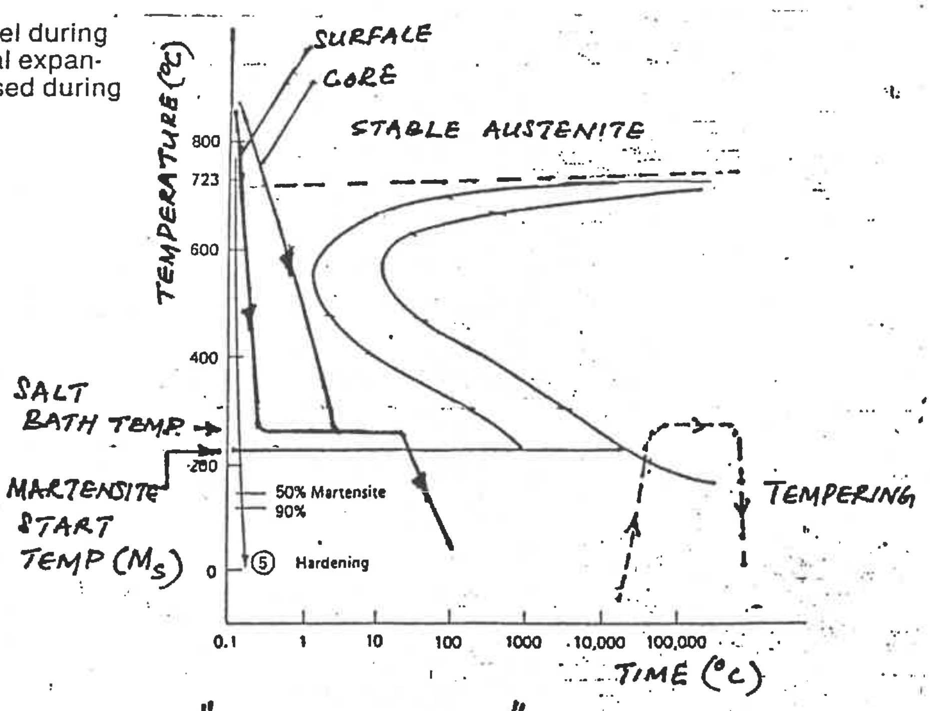


Expansion and shrinkage during HEAT TREATMENT

We all know that steel, like most other materials, expands when heated and shrinks when cooled. However, during hardening, transformations in the structure temporarily reverse this normal process. An understanding of these phenomena will help the heat treater to avoid undue distortion or cracking.



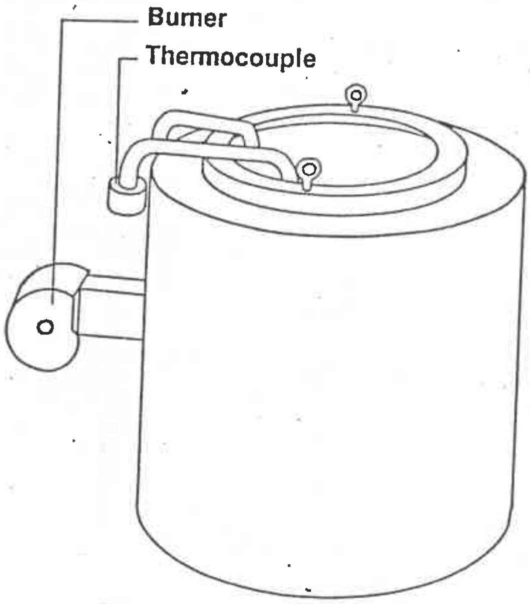
. Expansion and shrinkage in steel during hardening. Note that the normal thermal expansion and shrinking processes are reversed during transformation (phases 2 and 5).



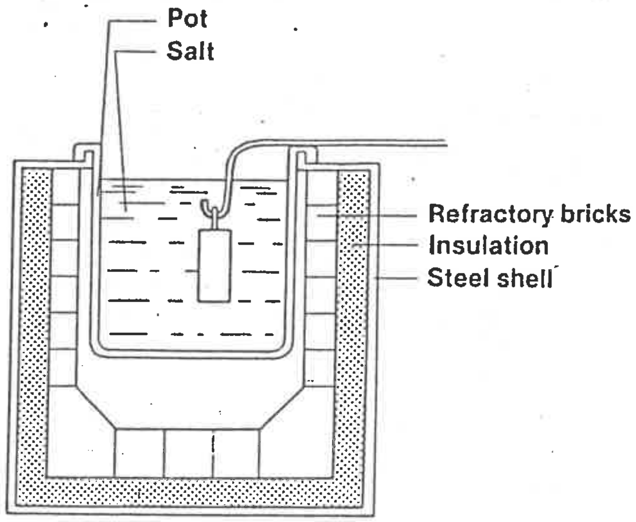
"MARTEMPERING" (INTERRUPTED QUENCH)

Salt baths for hardening

The salt bath consists of a pot filled with salt, which is melted by heating with electricity, oil or gas. Electrical heating can be by electrodes inside or by elements outside the pot. Salts of different composition are used for different temperature ranges.



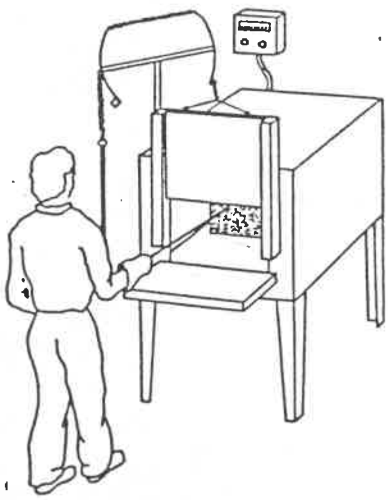
Typical oil-fired salt bath.



Cross-section of salt bath.

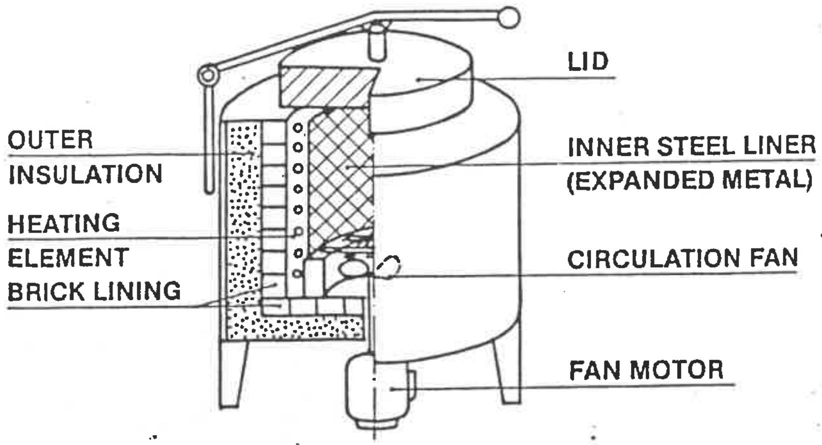
Heating in a muffle furnace

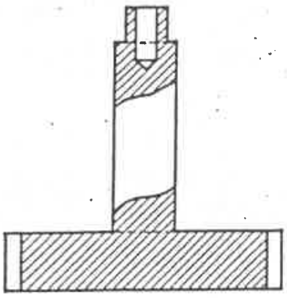
Muffle furnaces can be oil or gas fired or electrically heated. In either case, the tools will take a longer time to reach hardening temperature than in the case of a salt bath. The time will be considerably longer if the furnace is at room temperature or at an intermediate temperature when the tools are put in.



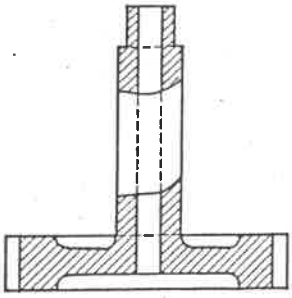
Heating in a muffle furnace.

SEALED CONVECTION FURNACE:
(FOR TEMPERING)

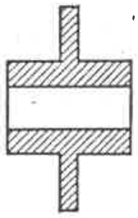




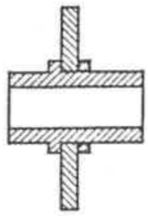
Wrong: sharp corners and big differences in section.



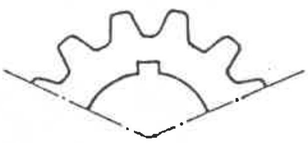
Right: radius in corners and more even section.



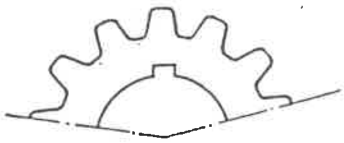
Wrong: big differences in section.



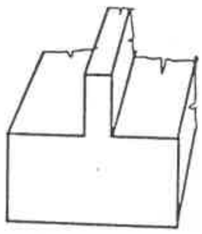
Right: tool made in two parts of more even section.



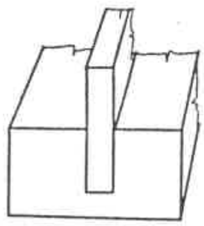
Wrong: keyslot opposite gap between teeth.



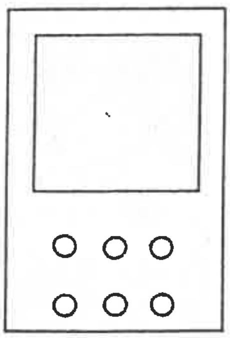
Right: Keyslot moved half a pitch.



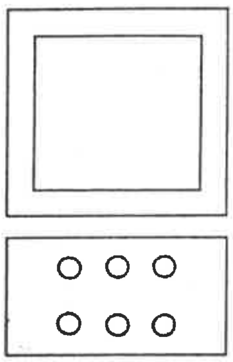
Wrong: big differences in section (in some cases unavoidable).



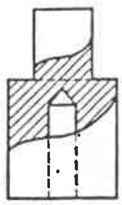
Right: tool made in two parts of more even section.



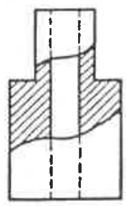
Wrong: big differences in section.



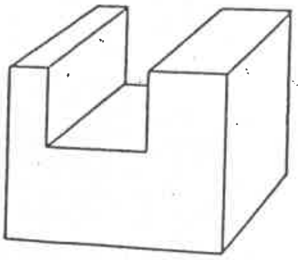
Right: progressive die plates can be divided into two.



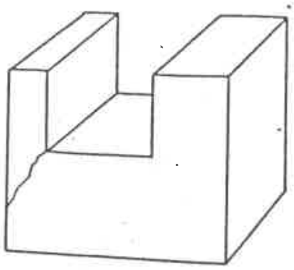
Wrong: deep blind hole hinders quenching.



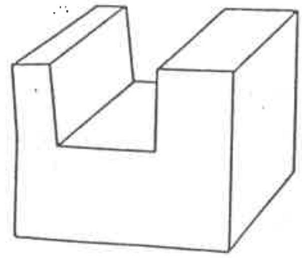
Right: hole continues right through.



The piece before hardening.



Cracking resulting from violent heating and quenching.



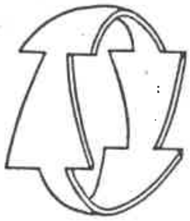
Deformation resulting from violen heating and quenching.

Designing for successful heat treatment

Many serious failures in hardened tools are caused by internal stresses. Much can be done to prevent cracking and distortion during heat treatment by bearing this heat treatment in mind when the tools are being designed.

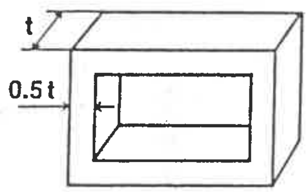
The ideal shape for heat treatment is one in which all points of any section or surface receive or give back the same amount of heat at the same rate. Such a shape does not of course exist in practise, but the designer's task is to remember it and try to come as close to it as possible. Some common rules are:

- Avoid sudden changes of section
- Keep the shape simple, uniform and symmetrical
- Avoid sharp internal corners—use adequate radii.

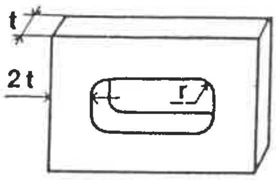


Wrong: uneven section if teeth are opposite.

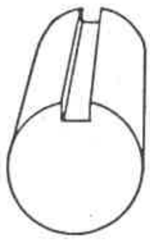
Better: Staggered teeth give more even section.



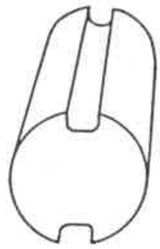
Wrong: wall section too thin and internal corners too sharp.



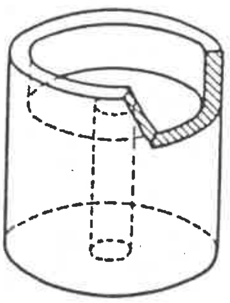
Right: thicker section and rounded corners.



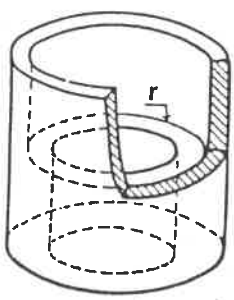
Wrong: groove on one side only, and with sharp corners.



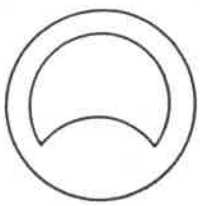
Better: grooves on either side, and with radius.



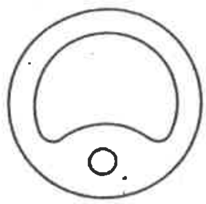
Wrong: big differences in section and no radius in fillet.



Right: more even section and radius in fillet.



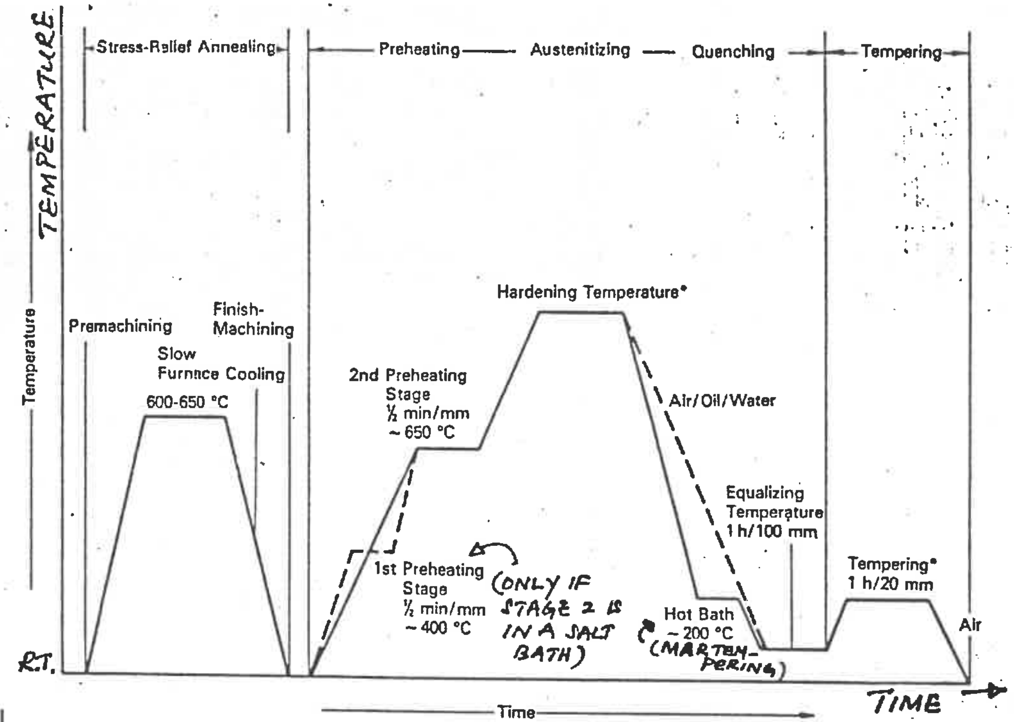
Wrong: sharp corners and big differences in section.



Right: radius in corners and more even section.

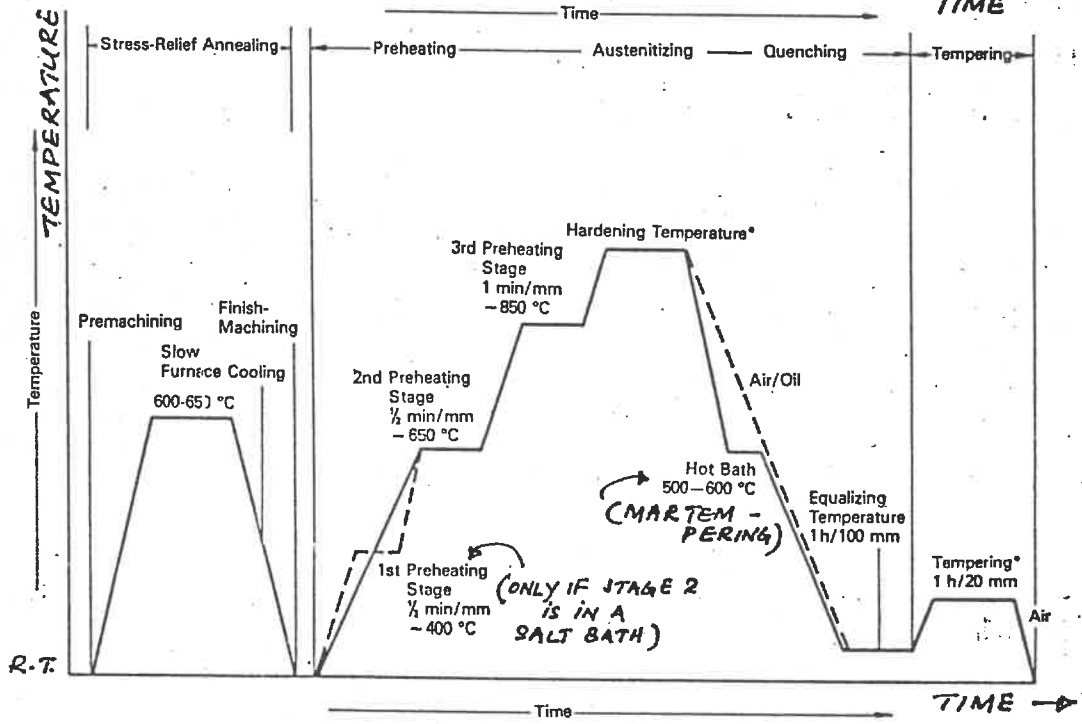
Time-temperature sequence chart for the heat-treatment of unalloyed and alloyed cold and hot work steels with hardening temperatures up to 900 °C.

STEELS: 1045
W1
W2
O1
S1
P 20

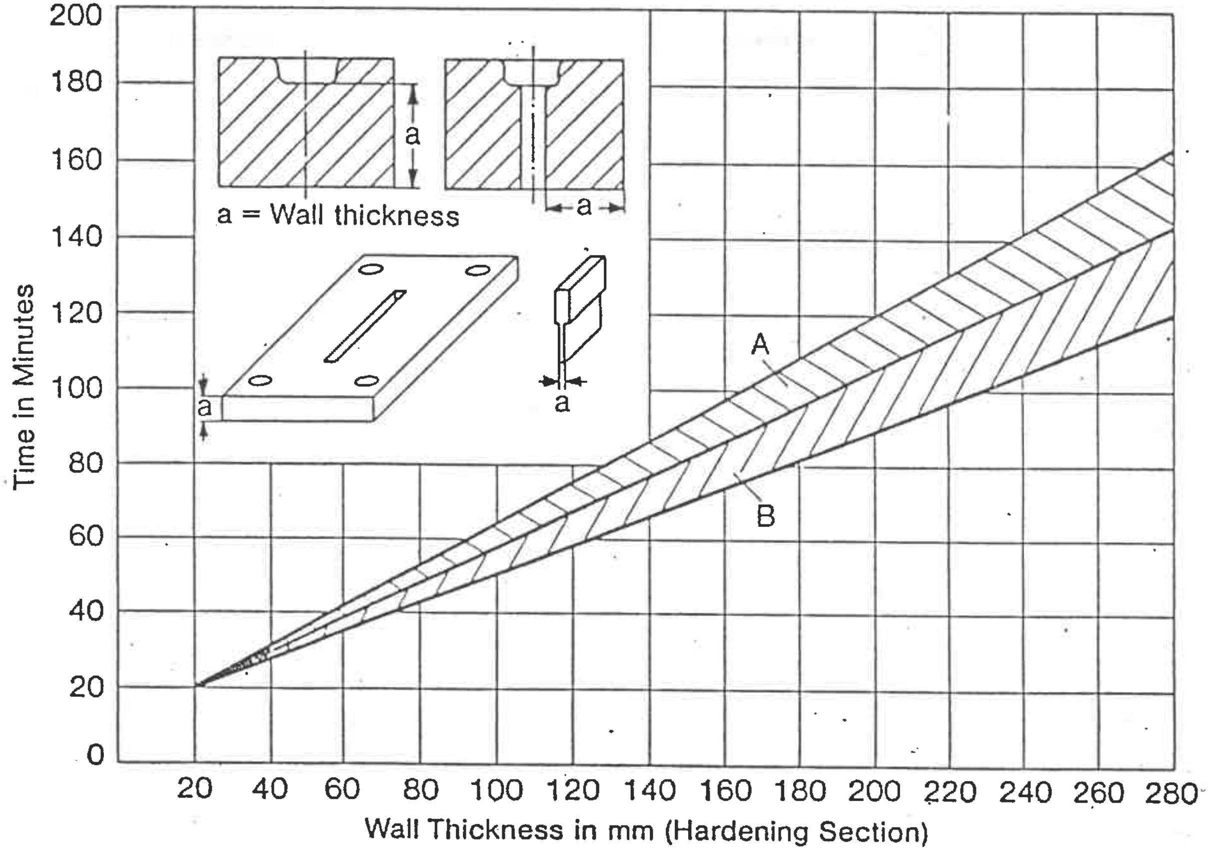


Time-temperature sequence chart for the heat-treatment of alloyed cold work steels with hardening temperatures beyond 900 °C.

STEELS: A2
D2
D6



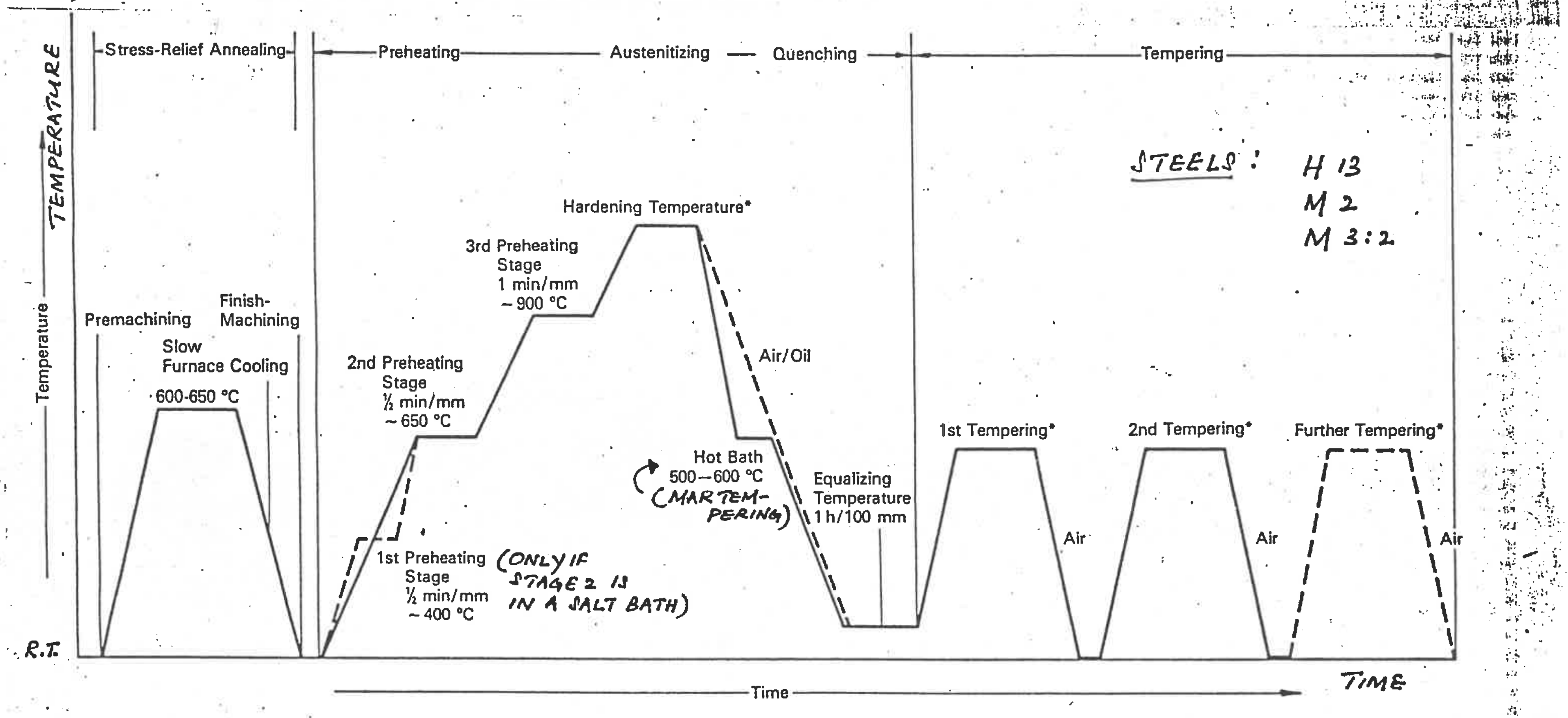
SOAKING TIME AT AUSTENITISING TEMPERATURE !



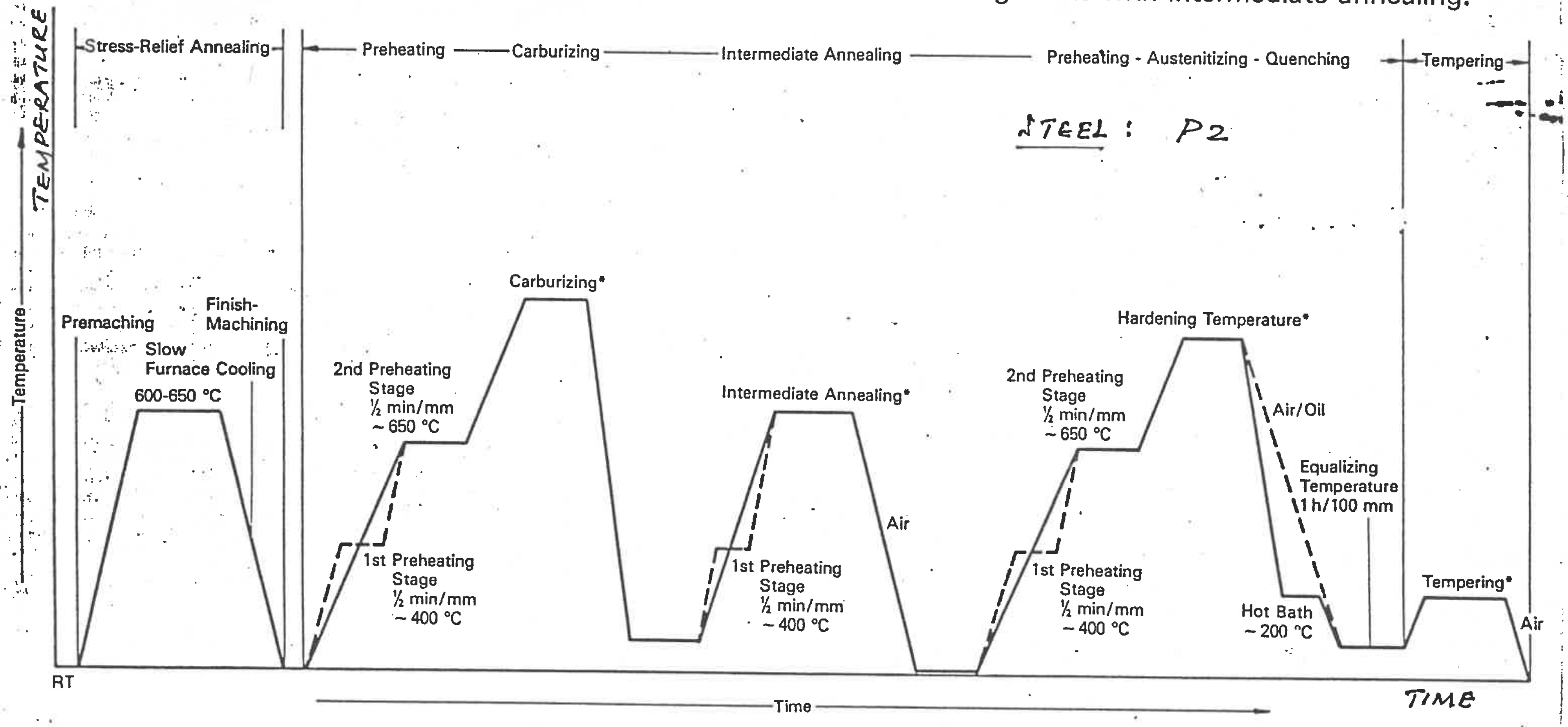
A = High-Alloy-Steels (Ledeburitic High-Carbon High-Chromium-Steels)

B = Carbon, Low and Medium Alloy Steels

Time-temperature sequence chart for the heat-treatment of hot work steels with hardening temperatures beyond 900°C



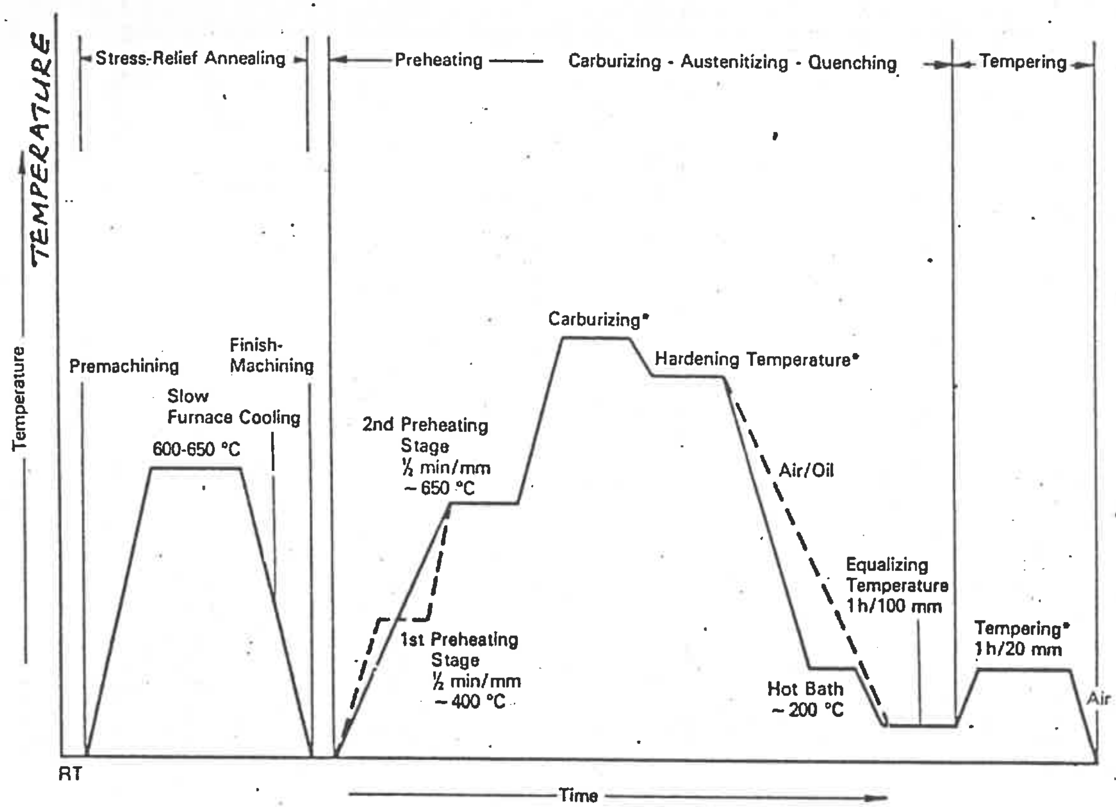
Time-temperature sequence chart for the heat treatment of case hardening steels with intermediate annealing.

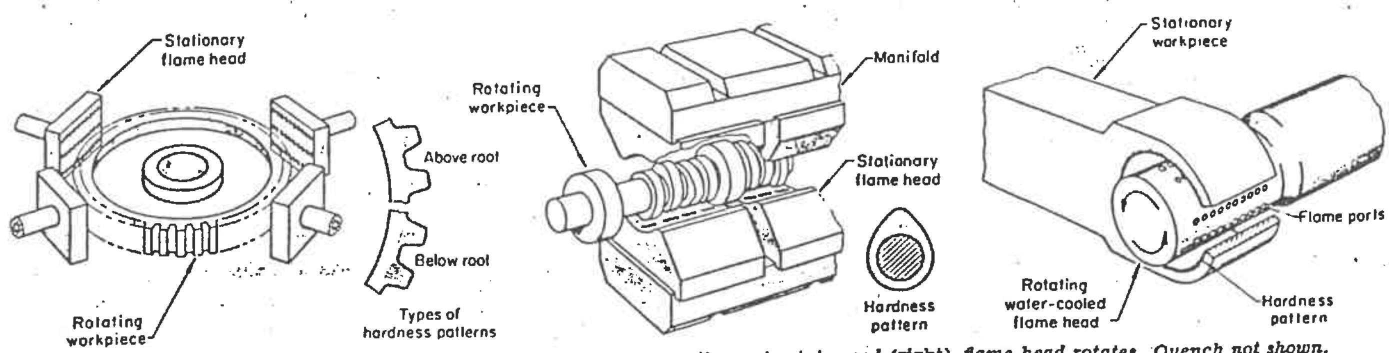


Time-temperature sequence chart for the heat treatment of case-hardening steels with direct hardening.

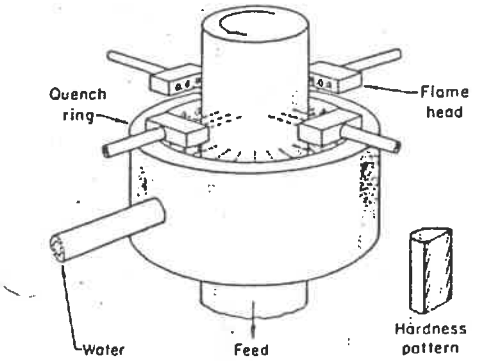
STEEL : P2

NOTE:
DIRECT HARDENING POSSIBLE ONLY WITH GAS OR SALT BATH CARBURIZING.
(NOT WITH POWDER CARBURIZING)



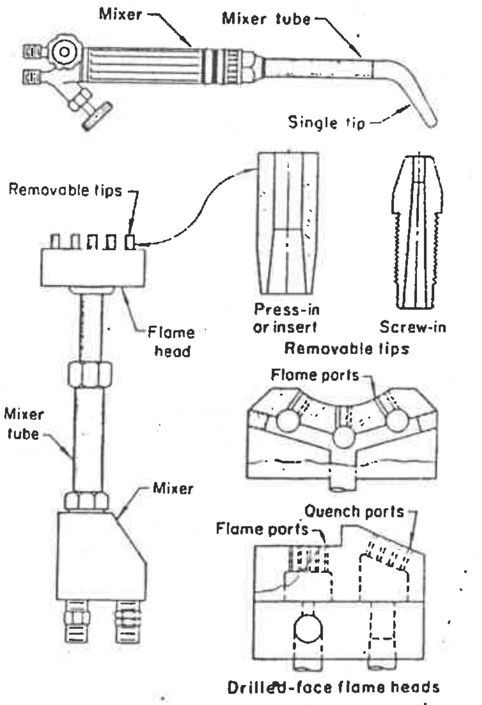


Spinning methods of flame heating, in which (left, center) *the part rotates and* (right) *flame head rotates. Quench not shown.*

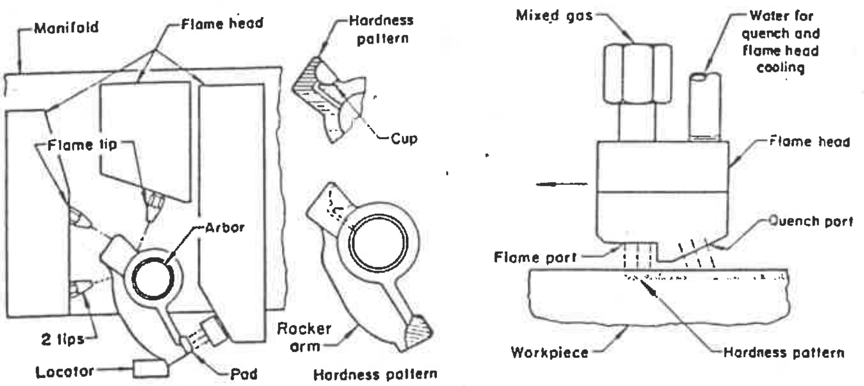


Combination progressive-spinning method of flame hardening

Flame Hardening

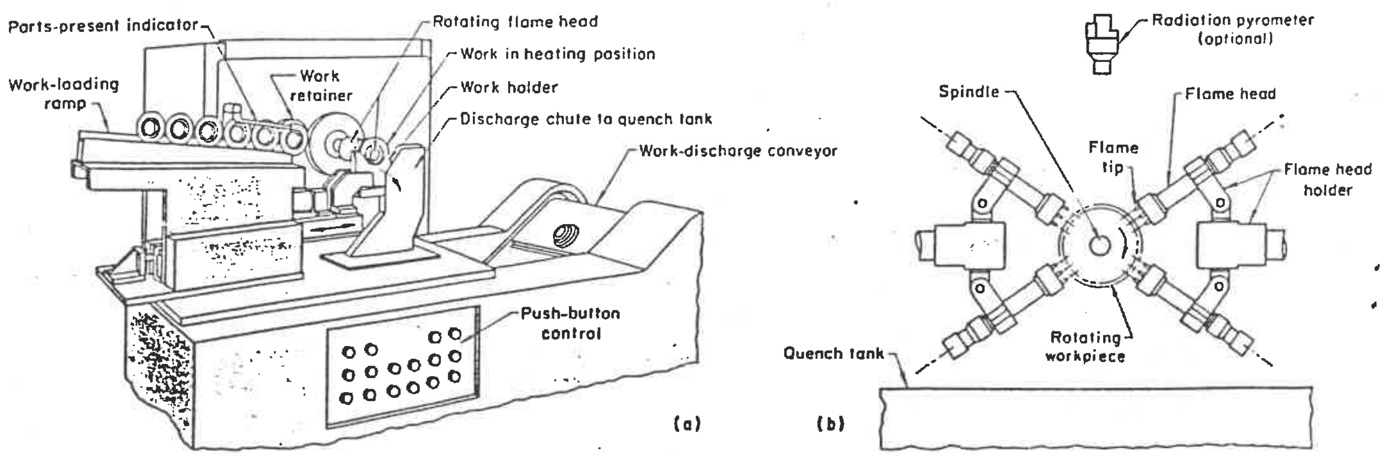


Flame heads for oxy-fuel gas



(Quench not shown)

(a) *Spot (stationary) method of flame heating a rocker arm* (b) *Progressive method.*

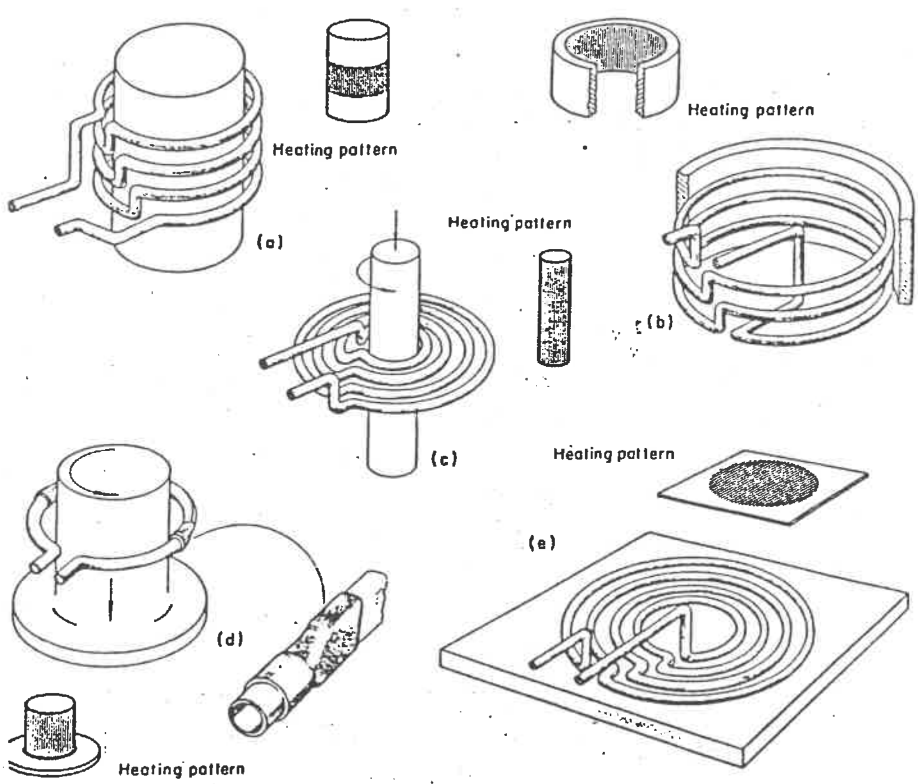


(a) Installation for high production of similar parts: hardening of the 2½-in. bore of hubs to a depth of about ⅛ in. Machine has a standard retractable spindle adapted with a rotary flame head. Spindle is driven by a variable-speed motor. Temperature of agitated quench is maintained by a water-cooled heat exchanger.

(b) Installation for selective oxy-fuel gas heating of small production lots of gears, sprockets and flanges within size limits of the equipment. Radiation pyrometer is used here to control heating cycle, but many operations employ an electric timer instead of the pyrometer. Changing work heads and spindles adapts equipment to various parts.

Typical flame hardening installations using oxy-fuel gas mixtures

INDUCTION HARDENING

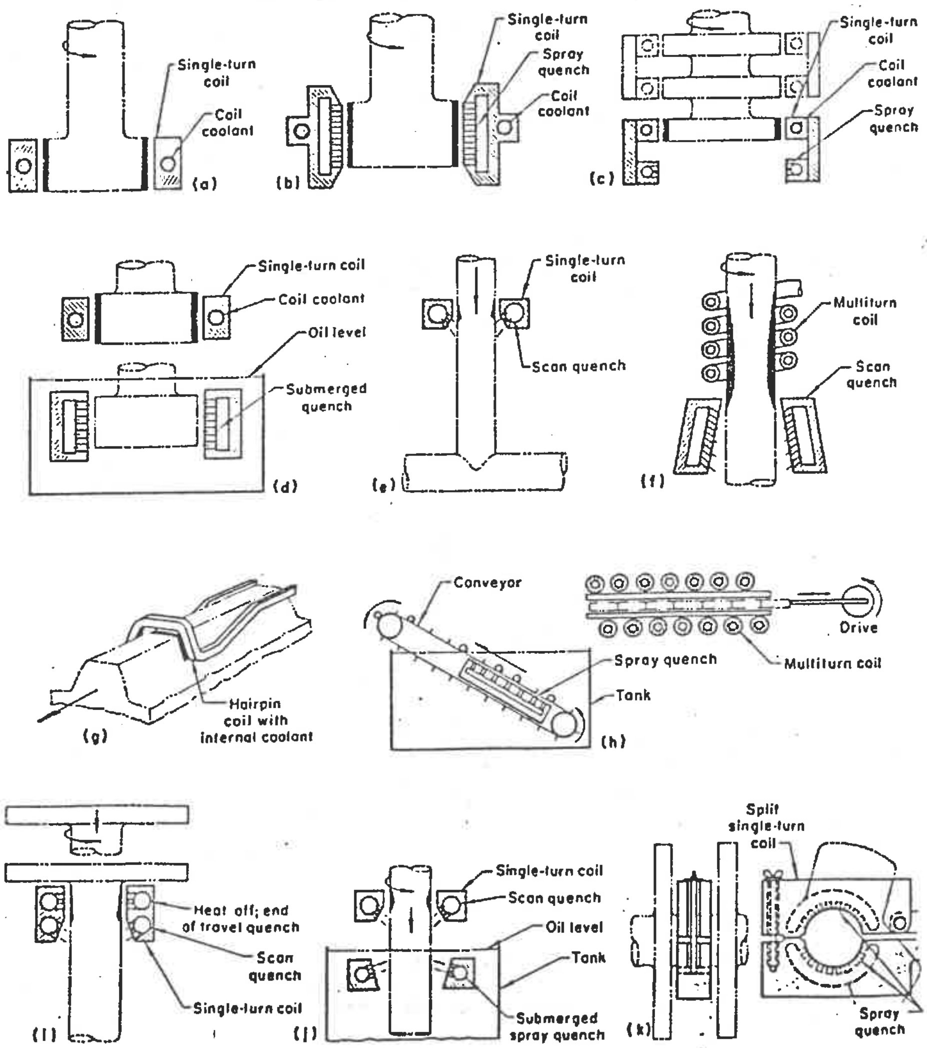


Typical work coils for high-frequency units

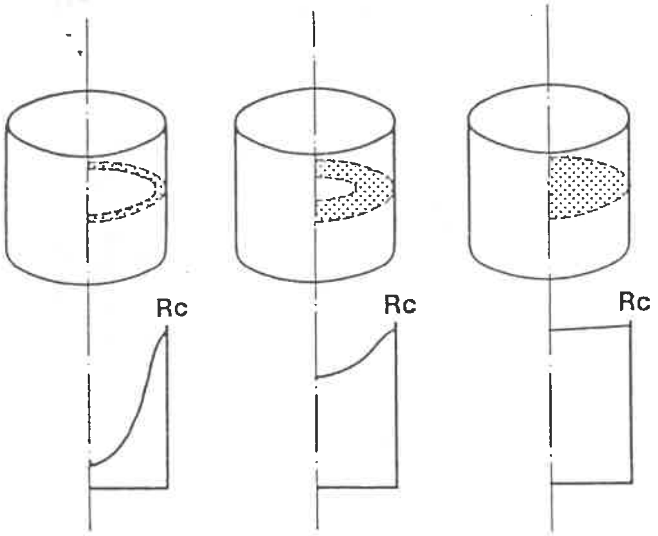
..asic Systems for Quenching

(a) Heat in coil; manually lift part out of coil; submerge part in tank of agitated quench medium. Used where limited production does not warrant the cost of an automated quench.
(b) Heat and quench in one position; quench by means of integral quench chamber in inductor. Called single-shot method.
(c) Heat in coil with part stationary; quench ring moves in place. Single-shot adaptation of scanning method.
(d) Part is hydraulically lowered into quench tank after single-shot heating. Quench medium is agitated by submerged spray ring or propeller.
(e) Vertical or horizontal scanning with integral spray quench. Single-turn inductor. Used for shallow hardening.
(f) Vertical or horizontal scanning with multiturn coil and separate multirow quench ring. Used for deep-case or through hardening.
(g) Coil scans and heats workpiece; self-quench or compressed air quench. Used in special applications with high-hardenability steels.
(h) Horizontal cam-fed parts are pushed through coil, then dropped onto submerged quench conveyor.
Vertical scanning with single-turn inductor in combination with integral dual quench: one quench ring for scan hardening; the second for stationary quenching when the scanning travel stops. Used for parts having a diameter or a flange section too large to travel through the inductor, wherein it is desired to harden up to the shoulder or flange.
:j) Vertical scanning with single-turn inductor with integral spray quench and submerged quench in tank.
:k) Split inductor and integral split quench ring. Used for hardening crankshaft bearing surfaces.

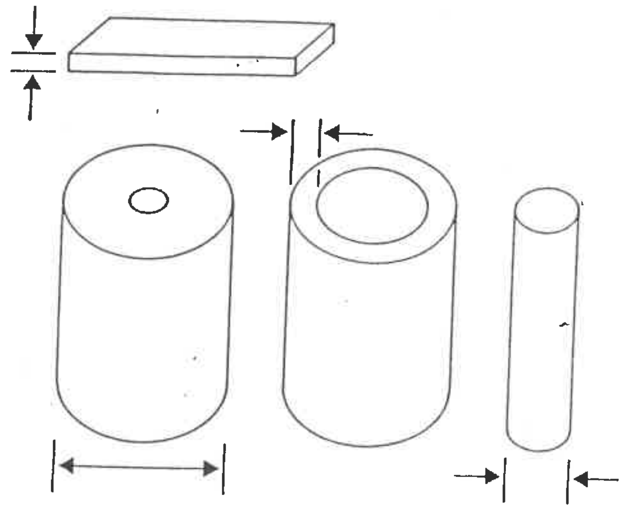
A water spray applied through a ;eparate quench ring or from hollow nductors (for heating and quenching) ıas been used successfully in most ıpplications involving plain carbon and ow-alloy constructional steels; oil is ;pecified for steels of higher hardenıbility, and for parts with nonuniform ;ections when difficulty with cracking ınd distortion is anticipated. Quench-ng in water or oil may also be done ›y submersion in an agitated bath or ›y a combination of a spray quench :ing and submersion in a tank on com-›letion of the heating cycle. Submer-ion in a brine tank may be specified 'or steels of very low hardenability to ›revent occurrence of soft spots on the ;urface of the hardened part.



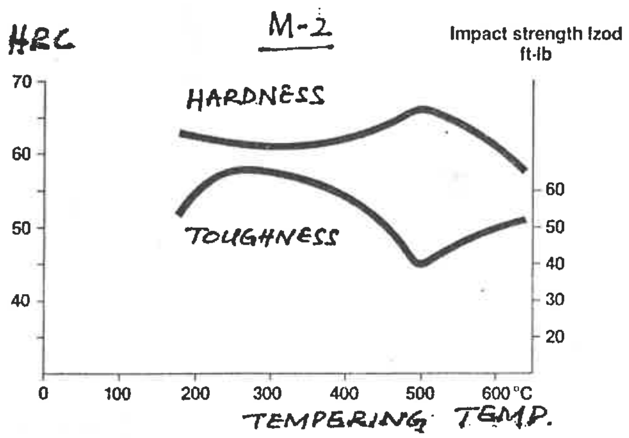
Eleven basic arrangements for quenching induction heated parts; see text for explanation.



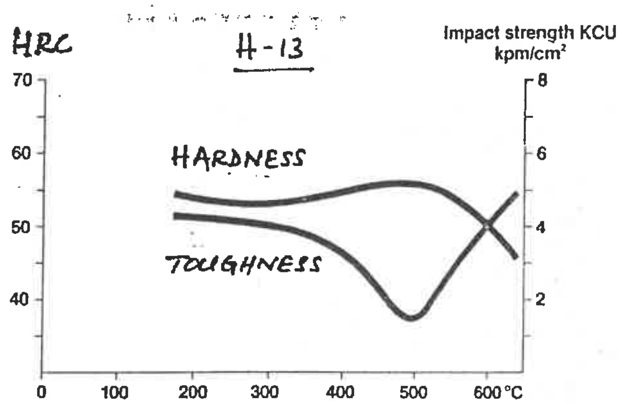
Depth of hardening in steels of three different hardenabilities. Left: low hardenability gives shallow hardening. Right: high hardenability gives through-hardening.



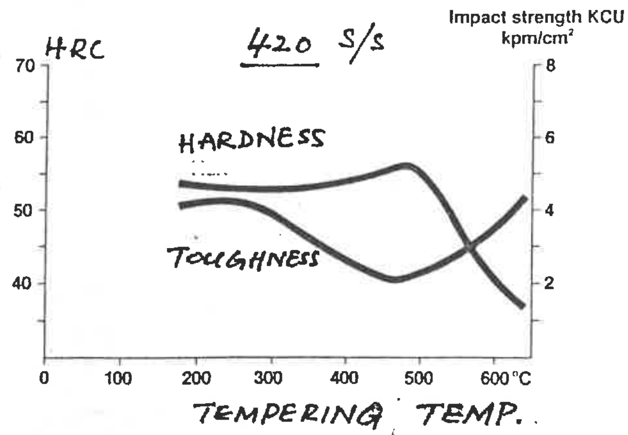
. Dimensions to be regarded as "thickness" in different shapes of steel.



. Hardness and toughness of M2 after tempering at different temperatures. Tempering at 5[illegible]–570°C is most suitable.



. Hardness and toughness of H13 Supreme after tempering at different temperatures. Tempering at 250°C is suitable for cold work tools and plastic moulds, and 550° or higher for hot work tools.



. Hardness and toughness of 420 after tempering at different temperaturєs. Tempering at 250°C gives a good combination of hardness and toughness.