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April 1989

Heat treatment of ferrous materials

Heat treatment methods

Case hardening

DIN
17 022
Part 3

Wärmebehandlung von Eisenwerkstoffen; Verfahren der Wärmebehandlung; Einsatzhärten

In keeping with current practice in standards published by the International Organization for Standardization (ISO), a comma has been used throughout as the decimal marker.

Contents

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1 Scope and field of application

This standard describes case hardening procedures and gives instructions on the case hardening of steel workpieces and tools.

2 Terminology

The terminology associated with heat treatment as used in this standard has been adopted from DIN 17 014 Part 1.

3 Principles of case hardening

Cases hardening is intended to make the case (surface layer) of steel workpieces and tools substantially harder and to improve their mechanical properties. It consists of carburizing or carbonitriding followed by quench hardening carried out either immediately after this treatment or after intercooling and reheating to a quench hardening temperature suited to the particular application. This procedure enriches the case with carbon (carburizing) or carbon and nitrogen (carbonitriding) before quench hardening. As compared with carburizing, enrichment with nitrogen produces a higher degree of hardenability by modifiying the transformation process in the case, and thus results in an improved retention of hardness after quench hardening.

The steel may be tempered again or treated at a temperature below ambient and tempered after quench hardening, depending on the characteristics specified for the product or the requirements of subsequent machining (e.g. grinding).

4 Indication of case-hardened condition in documentation

The case-hardened condition shall be indicated on drawings as specified in DIN 6773 Part 4. Where required, information relating to case hardening shall take the form of a set of heat treatment instructions as specified in DIN 17 023 or of a heat treatment schedule, the designation given in DIN 17 014 Part 3 being used to identify details of the treatment applied.

5 Procedure

5.1 Workpiece preparation and pretreatment

Preparation or pretreatment of workpieces is intended to prevent their final condition being adversely affected by internal stresses (risk of distortion) or by the surface condition, as well as to ensure that heat treatment is not interrupted by workpiece failure. Protective surface treatment may also be applied to limit the extent of carburization.

5.1.1 Workpiece preparation

Depending on the degree of surface impurities and the quality required, it may be necessary to prepare the workpieces before carburizing or carbonitriding by means washing, drying, pickling, abrasive blasting, deburring, chip removal or other suitable processes so

a) that carburizing or carbonitriding is not inhibited, for example, by sulfurous cooling lubricant residues, rust, scale, rolling, forging or casting skins, or other such unwanted coatings;

b) that salt baths are not polluted by burrs, chips, rust, scale, rolling, forging or casting skins;

c) as to prevent splash from salt baths due to the sudden evaporation of water or other liquids.

Bolts or screws used to close threaded or unthreaded holes shall be removed before heat treatment, or before cleaning.

5.1.2 Stress relieving

If internal stresses in the workpiece unduly influence its susceptibility to distortion during case hardening, stress relieving will be required, the resulting changes in size and shape being taken into account by providing an adequate machining allowance.

The temperature for stress relieving shall be close to transformation temperature, Ac_1, but should not exceed it. Soaking after heating is then not required. The heating and cooling process shall be controlled so that no additional or new internal stresses are produced. For cold formed workpieces, normalizing shall be given preference to stress relieving if the latter is likely to result in grain coarsening due to recrystallization.

5.1.3 Normalizing

As stated above, internal stresses in the workpiece blank may be reduced by normalizing which, at the same time, can reduce differences in the microstructure and prevent grain coarsening at critical points of workpieces of complex shape.

The temperatures required may be found in the relevant technical delivery conditions for steel or in documentation provided by the steel supplier.

5.1.4 Hardening and tempering

Another method of internal stress reduction is to heat the workpiece to austenitizing temperature which also increases the homogeneity of the material. Subsequent cooling of the workpiece blank in the same way as in quench hardening will reduce the likely changes in size and shape as a result of quench hardening of the workpiece after machining, and permit the extent and direction of the changes to be estimated.

Following this, the workpiece shall be tempered so as to allow further machining and to compensate for any changes in size and shape.

This treatment of the blank, which includes machining of the workpiece prior to hardening, has proved its value particulary where exacting demands are to be met in respect of dimensional stability.

5.1.5 Preparation for local carburizing or carbonitriding

Where specific parts of a workpiece are to be carburized or carbonitrided, one of the following measures may be taken:

a) application of a coating affording protection against carburizing or carbonitriding (e.g. a paste or an electroplated copper coating), such coating, however, not being effective in the case of salt bath carburizing or carbonitriding;

b) fitting of a protective component (e.g. sleeve on shaft ends); its protective effect is, however, limited or negligible in the case of salt bath treatment;

c) parts of the workpiece may be packed in a solid medium which inhibits carburization, this being only effective where a granulate is used for carburizing.

After quench hardening, the surface hardness in the non-carburized or non-carbonitrided zones corresponds to the carbon content of the steel in its initial condition.

The width of the transition zone between carburized and the non-carburized zones is a function of the method of surface protection used and is narrowest where coatings are applied.

5.1.6 Charging of workpieces

When charging the workpieces, care shall be taken to ensure that their arrangement is such that

a) in the case of carbonitriding, all parts of the surface to be treated are fully exposed to the treatment medium, and

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[1] See appendix A for further measures.

b) In the case of quenching, all zones to be hardened are exposed equally and, at the same flow rate, to the quenching medium.

Accordingly, bulk material shall not be heaped too high or packed too densely, intermediate grids being used to avoid this where necessary, workpieces shall be arranged separately or kept moving in the treatment medium, or forced movement of the medium is to be provided.

Face-on-face contact between workpieces shall be avoided, linear contact may have adverse effects, whereas the effect of point contact is generally negligible.

During quenching, workpieces closed on one side or pot-shaped workpieces shall be arranged with their open end up to allow water bubbles to escape.[2]

Workpieces shall be packed so that they are deformed neither by their self-weight nor by other components lying on them.

5.2 Heating to treatment temperature

The temperature in the surface zone and the core of workpieces of simple geometry and of a more or less uniform cross section, when they are brought to carburizing, carbonitriding or quench hardening temperature, is shown as a function of time in a graph in figure 1. Workpieces of non-uniform cross section yield different heating curves for surface zone and core of each cross section.

The sum of heating and soaking time gives the holding time for a workpiece in a furnace.

When workpieces are heated, differences in temperature at the surface and at the core arise, the differences being a function of the rate of heating and the thermal conductivity of the material. The differences and the microstructural transformation to which they give rise at different points in time produce internal stresses that, in turn, may lead to distortion of the workpieces. Hence, large workpieces or workpieces with large differences in their cross section, particularly when made of alloy steel, shall be heated slowly or in stages (cf. figure 2).

Figure 3 provides guidance on the heating time for circular, square or rectangular workpiece cross sections when heated in a salt bath, figure 4 providing information for heating in air-circulating furnaces and chamber furnaces.

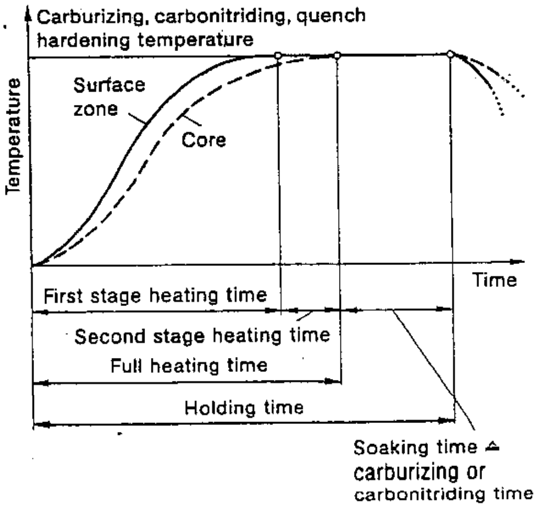

Figure 1. Typical thermal cycle for a workpiece undergoing carburizing, carbonitriding or quench hardening

5.3 Carburizing

In carburizing, which is to be effected at temperatures between 880 °C and 1050 °C, preferentially between 900 °C and 950 °C, the workpieces are fully exposed to the carburizing medium, from which carbon is released and deposited on the workpiece surface. If the carbon activity of the medium is greater than that of the steel, carbon will diffuse into the workpiece surface, this causing an increase in carbon content.

In practice, the carbon activity of the carburizing medium is generally characterized by the carbon content, known as the carbon potential, this being defined as the maximum carbon content, expressed as a percentage by mass, which a pure iron foil will absorb over its entire cross section.

The enrichment of the workpiece surface zone with carbon is represented by the carburization diagram (cf. figure 5), which is mainly a function of the following parameters:

a) the carbon potential;
b) the carbon transition index, β;
c) the rate of carbon diffusion in the steel;
d) the carburizing temperature;
e) the carburizing time.

The carbon content in the surface zone ('surface carbon content', for short) is largely a function of the carbon potential. If the carbon activity of the carburizing medium is less than the saturation limit, C_S[3], the carbon potential is the maximum that can be achieved in the surface zone; if it is greater, the carbon potential cannot be defined and the surface carbon content can reach a level equal to C_S. The rate at which the surface carbon content approaches the carbon potential or the saturation value depends on the level of the carbon transition index, β, and the rate of carbon diffusion in the steel. If the carbon transition rate is significantly higher than the diffusion rate, a short carburizing time will be sufficient.

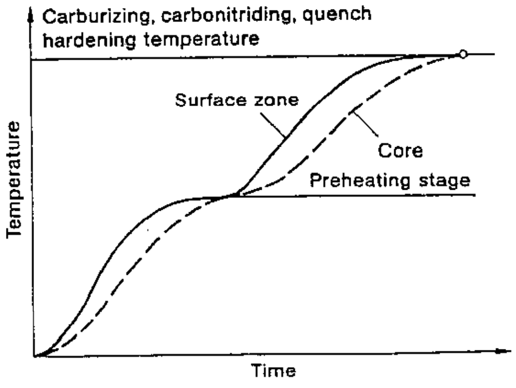

Figure 2. Typical thermal cycle for a workpiece undergoing carburizing, carbonitriding or quench hardening with a single preheating stage

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[2] The resulting loss of quenching medium will have to be accepted.

[3] The saturation limit is the carbon content corresponding to the point at which a line drawn from the carburizing temperature intersects with SE curve associated with the particular content of alloying elements.

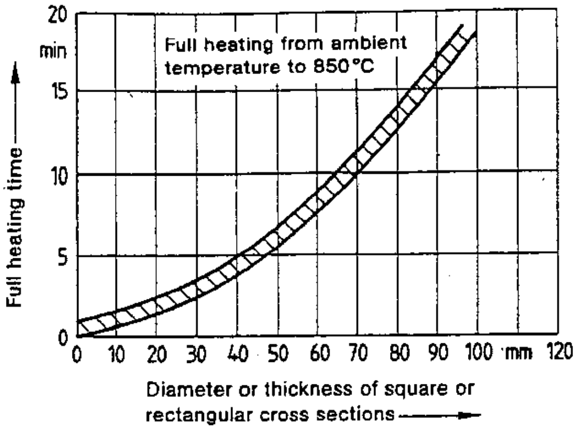

Figure 3. Full heating time for salt bath heating (curves originating from tests on cylindrical test pieces)

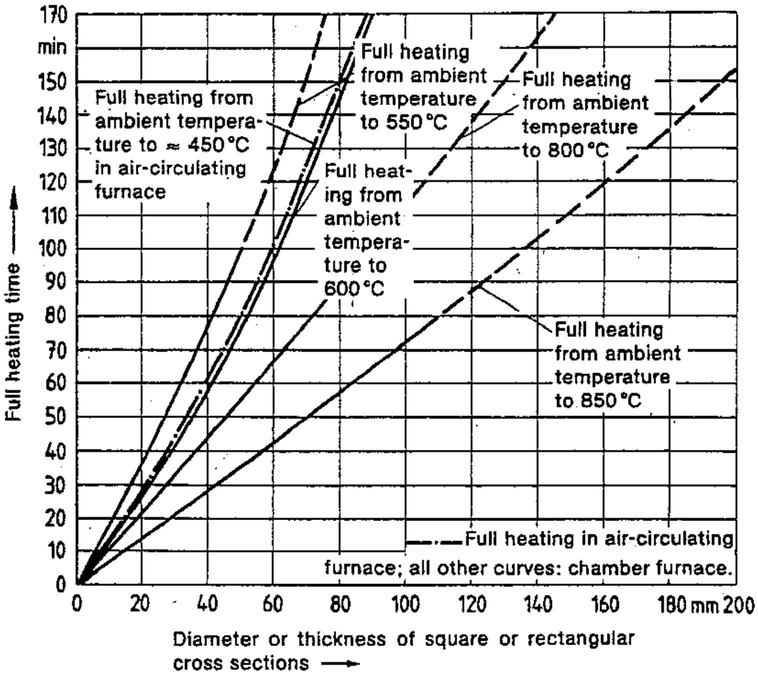

Figure 4. Full heating time in air-circulating and chamber furnaces (curves originating from tests on cylindrical test pieces)

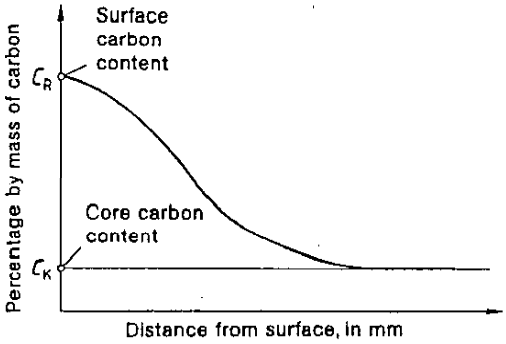

Figure 5. Typical carburization diagram

In some cases, carburizing is required to achieve a specific surface carbon content. Recommended maximum values which will give low retained austenite levels after quench hardening are given in table A.1 for the most common case hardening steels.

To allow for the influence of the alloying elements on the carbon activity in the steel, the carbon potential for carburizing alloy steel shall differ from that for unalloyed steel. The difference in carbon potential may be determined with adequate accuracy using the following equation [1]:

$$\lg \frac{C_p^l}{C_p} = -0{,}055 \cdot \%\,\mathrm{Si} + 0{,}013 \cdot \%\,\mathrm{Mn} + 0{,}040 \cdot \%\,\mathrm{Cr} + 0{,}013 \cdot \%\,\mathrm{Mo} - 0{,}014 \cdot \%\,\mathrm{Ni}$$

C_p is the carbon potential for pure iron;

C_p^l is the corresponding carbon potential for carburizing alloy steel.

5.3.1 Carburizing with constant carbon potential

Assuming a constant carbon potential throughout the carburizing time, the carburization diagrams shown in figure 6 for different carburizing times are obtained, which are a function of the relationship between carbon transition index, diffusion rate and carbon potential.

Type A carburization diagrams are to be expected for carburizing in highly activated salt baths and type B diagrams when carburizing in weakly activated salt baths, in controllable gas atmospheres and in granulate-gas carburizing. Type B diagrams show that the carbon potential in the case is only achieved after a prolonged period. In both diagrams, the carbon potential is lower than C_S.

For types C and D, the carbon potential cannot be defined and the quantity of carbon available is so high that, given a sufficient carburizing time, a surface carbon content exceeding the saturation limit is achieved, i.e carbides are formed. Carburizing in granulate or in very weakly or non-activated salt baths produces type C carburization diagrams. Type D diagrams are obtained when carburizing in gas which cannot be controlled in respect of its carbon potential.

5.3.2 Carburizing with variable carbon potential

Steel may also be treated with the carbon potential varying over time instead of being kept constant. A procedure in which carburizing takes place in two consecutive stages with differing carbon potential ('two-stage carburizing') has proved satisfactory in practice. At the first stage, the carbon potential is maintained at approximately the saturation limit, whereas at the second stage, it is maintained at a lower value, this depending on the surface carbon content required (cf. figure 7).

5.3.3 Case depth

The case depth is a parameter characterizing the carbon enrichment of the case. It is to be derived from the carburization diagram and is designed as the vertical distance between the surface of a workpiece and the point where a given carbon content[4], which is to be agreed, is present (cf. DIN 17 014 Part 1 and figure 7). The case depth increases in proportion to the square root of the carburizing time (cf. figure 6).

Since the rate of carbon diffusion increases with temperature, the case depth is a function of the carburizing temperature, given the same carburizing time. For carburizing conditions that produce type B diagrams as illustrated in figure 6, the time required to achieve a specific case depth may be calculated as a function of the carbon potential and temperature.

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[4] A carbon content of 0,35 % by mass is normally assumed.

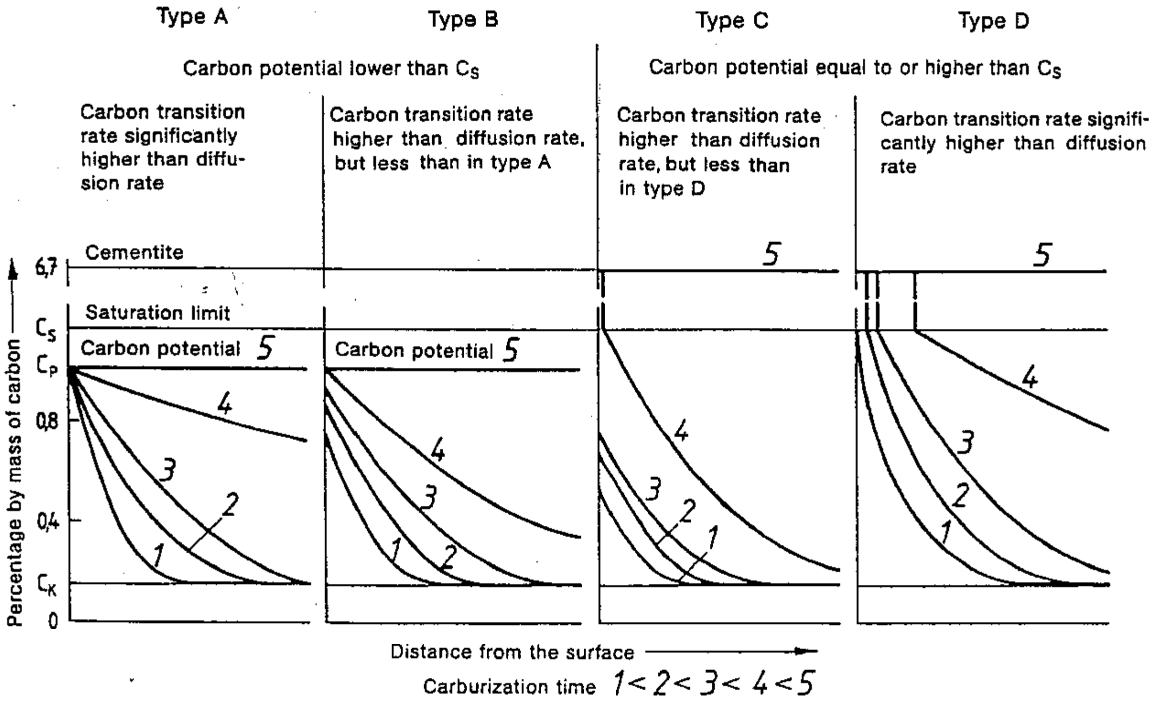


Figure 6. Typical carburization diagrams according to Kopietz

C_S = austenite saturation limit for carbon

C_K = core carbon content

C_P = carbon potential

5.3.4 Carburizing in solid media (granulate)

The normal temperature range limits for carburizing shall be 880 °C and 950 °C.

The workpieces shall be packed in boxes containing the carburizing medium, which shall then be filled up, closed and placed in a furnace which has been preheated to carburizing temperature.

Given the relatively long time taken to heat the boxes in second-stage heating and the slow rise in surface carbon content, the case depth should not be less than 0,6 mm. The carburization process cannot be influenced by varying the temperature over time, which is not normal practice. To achieve a given surface carbon content, commercial granulates are designed for a case depth of about 1 mm. For shallower or deeper case dephts, purpose-made granulate is available. The selection of a suitable granulate avoids the risk of excessive overcarburizing where great case depths are required, another method being subsequent annealing (homogenizing).

For some applications, overcarburizing does not present a problem, but care shall then be taken when grinding that cooling is adequate and the rate of feed of the grinding wheel is not too high.

Once carburizing is completed, the boxes shall be removed from the furnace and, normally, cooled in air.

5.3.5 Salt bath carburizing

The normal temperature range limits for salt bath carburizing shall be 850 °C and 980 °C, temperatures between 900 °C and 930 °C being given preference.

The workpieces shall be immersed in crucibles filled with molten salt, the carbon potential of which cannot be influenced and during carburizing generally lies between 0,8 and 1,2 % C.

The active constituents of the salt bath are consumed as the salt bath is used. They shall be replaced by topping up the bath in accordance with the manufacturer's instructions.

The surface of the bath shall be covered with coke to prevent excessive oxidation of the bath content, and to restrict its loss of heat by radiation.

On completion of carburizing, the workpieces shall be removed from the salt bath and cooled in an appropriate manner, or subjected to one of the processes illustrated in the graphs in figure 9.

5.3.6 Gas carburizing

The normal temperature range limits for gas carburizing shall be 850 °C and 950 °C; the upper limit may be 1050 °C. The carburizing atmosphere may be produced by different methods (cf. figure 14), a distinction being made between controllable and non-controllable atmospheres.

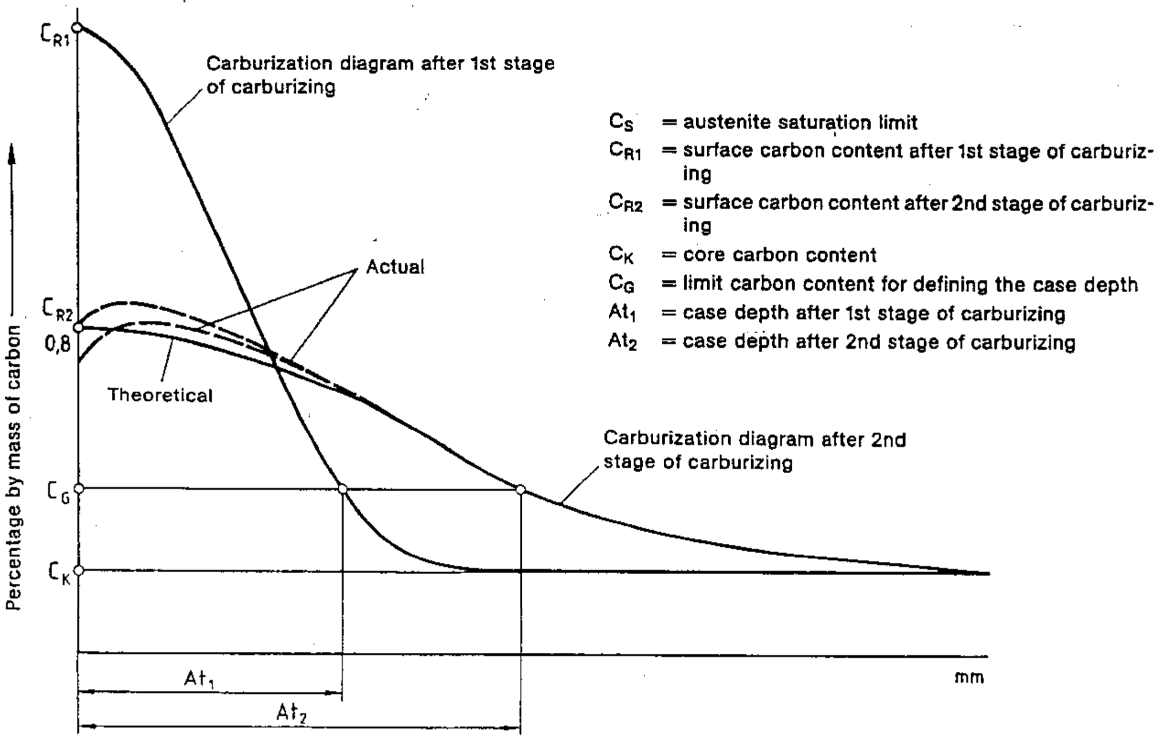
5.3.6.1 Gas carburizing with carbon potential control

The atmosphere for gas carburizing where the carbon potential is controlled is to contain a concentration of carbon monoxide and hydrogen greater than 10 % by volume, varying nitrogen and methane contents and traces of carbon dioxide and water vapour. Its carbon potential can be determined by measuring the dew point (i.e. the moisture content), the carbon dioxide content or the oxygen content, the data obtained permitting conclusions to be drawn as to the possible carburizing effect under equilibrium conditions. With the aid of the above data, the carbon potential can be controlled by varying the amount of gas introduced during carburizing.

The relationship between carbon potential and temperature, and the dew point, CO_2 content and oxygen probe voltage is illustrated in Appendix A.

5.3.6.2 Gas carburizing without carbon potential control

Atmospheres with a concentration of carbon monoxide of less than 5 % by volume, higher methane contents and contents of free oxygen that cannot be detected by standard measurement techniques cannot be controlled in respect of their carbon potential.



Distance from surface ⟶

Figure 7. Typical carburization diagrams in the case of two-stage carburizing

5.4 Carbonitriding

The normal temperature range limits for carbonitriding shall be 700 °C and 930 °C, a distinction being made between the temperatures above the Ac_3 point and the temperature range between the Ac_1 and Ac_3 points of the intial material condition.

The level of nitrogen enrichment in carbonitriding is largely a function of the temperature, nitrogen being more readily absorbed in the upper temperature range than in the lower.

Nitrogen enrichment affects the transformation behaviour of the material; points A_1 and A_2 are shifted to lower temperatures and the transformability of austenite decreases, which results in an increase in hardenability. This shift permits lower temperatures to be used in carbonitriding than in carburizing and the increased hardenability, the use of less aggressive quenching media. Owing to the nitrogen enrichment, the risk of retained austenite formation when carbonitrided steel is hardened is greater than after carburizing.

Carbonitriding at higher temperatures is preferred where the hardenability of the case is of particular significance and at lower temperatures, where the design performance of the product is dependent on a specific nitrogen enrichment.

Carbon diffusion in carbonitriding follows the patterns described in subclause 5.3, whereas no such pattern can be described for nitrogen diffusion. For this reason, the carbon potential is also used to assess the carbonitriding effect.

5.4.1 Salt bath carbonitriding

The normal temperature range limits for salt bath carbonitriding shall be 700 °C and 870 °C.

The workpiece to be carbonitrided shall immersed in crucibles filled with molten salt, the carbon potential of which cannot be controlled.

The active constituents of the salt bath are consumed as the salt bath is used, and shall be replaced by topping up the bath in accordance with the manufacturer's instructions.

As oxidation of the salt bath by atmospheric oxygen increases the cyanate content which in turn enhances the effect of nitriding, salt baths shall not be covered.

On completion of carbonitriding, the workpieces shall be removed from the salt bath and directly hardened.

5.4.2 Gas carbonitriding

The normal temperature range limits for gas carbonitriding shall be 750 °C and 930 °C.

The atmosphere to be used shall be the same as that used for carburizing, except that ammonia is added in a concentration of 0,65 % (780 °C) to 10 % (930 °C) by volume, according to the temperature used. The carbon potential is normally adjusted to a value between 0,7 and 1,1 % by mass of carbon. The presence of atmospheric ammonia influences the reactions in which carbon is released in that the carbon monoxide content is reduced and not increased as in the case of carburizing so that the carbon potentials produced differ. If this difference is ignored, the carbon potential in carbonitriding atmospheres based on endothermally produced gas ('endogas', for short) can be derived from figure 8 following measurement of the CO_2 content.

5.5 Quench hardening

5.5.1 General

Figure 9 illustrates typical thermal cycles for case hardening.

The quench hardening temperature is a function of the particular core hardness and/or the required microstructure in the case and core, and of the requirements regarding susceptibility to distortion. The technical delivery conditions for steel (e.g. DIN 17 210, DIN 1651, DIN 1654 Part 3) or relevant documentation issued by the steel manufacturer, provide information on the quench hardening temperatures most commonly used for quench hardening. Attention should be paid to differences in transformation behaviour of the carburized or carbonitrided case and the unmodified core.

Quenching of carburized or carbonitrided workpieces for hardening purposes shall be carried out

a) directly after completion of the carburizing or carbonitriding process either from the carburizing or carbonitriding temperature or from a lower suitable temperature (cf. figure 9, method A), or

b) after cooling to ambient temperature and reheating to quench hardening temperature (cf. figure 9, method B, D or E), or

c) after transformation/regenerative annealing by cooling to a temperature between 650 °C and ambient temperature and reheating to quench hardening temperature (cf. figure 9, method C, dash line), or

d) after cooling to a temperature between 550 °C and 650 °C, isothermal transformation by soaking at this temperature and reheating to quench hardening temperature (cf. figure 9, method C, continuous line).

When cooling from quench hardening temperature, temperature differences between workpieces case and core will occur, the magnitude of which is a function of cooling rate and workpiece thickness. In practice and particulary where salt baths are used, cooling is effected in stages to minimize such differences (cf. figure 10). This method is especially recommended for workpieces susceptible to distortion or cracking.

Whe cooling in stages, the cooling process is interrupted at a temperature just above or below the temperature at which quench hardening starts in the carburized or carbonitrided case as a result of the transformation of austenite to martensite. In order to achieve as complete a transformation into martensite as possible, and to suppress or limit the formation of bainite, it has proved expedient to limit the time of soaking in the hot bath to 15 to 20 minutes.

Once temperature equilibrium is reached, the workpieces shall further be cooled in air to ambient temperature, the transformation into martensite starting or continuing in the case.

The transformation processes during cooling from the quench hardening temperature can be illustrated separately for the carburized case and the non-carburized core using the time-temperature-transformation (TTT) diagrams (cf. figure 11). No TTT diagrams have yet been prepared for carbonitrided cases.

The TTT diagrams show the ranges within which austenite transformation occurs for each cooling characteristic of a steel, the form of the diagrams and the process of transformation being a function of the influence of the steel composition and the austenitizing conditions, and of the carbon and nitrogen contents, as modified by carburizing or carbonitriding.

The aim of hardening is to effect transformation of the case preferably in the martensitic stage, which thus determines the required cooling rate. Transformation of austenite is not concluded until the M_f temperature is reached. In the case, this temperature lies below ambient temperature owing to its higher carbon content there (cf. figure 12).

An approximate indication of the microstructural condition and the associated hardness to be expected after cooling to ambient temperature can be obtained from the continuous-cooling-transformation (CCT) diagrams. Owing to its lower carbon content, the case will exhibit a lower hardness, which may further be reduced by precipitated ferrite and/or non-martensitic transformation products such as pearlite and/or bainite.

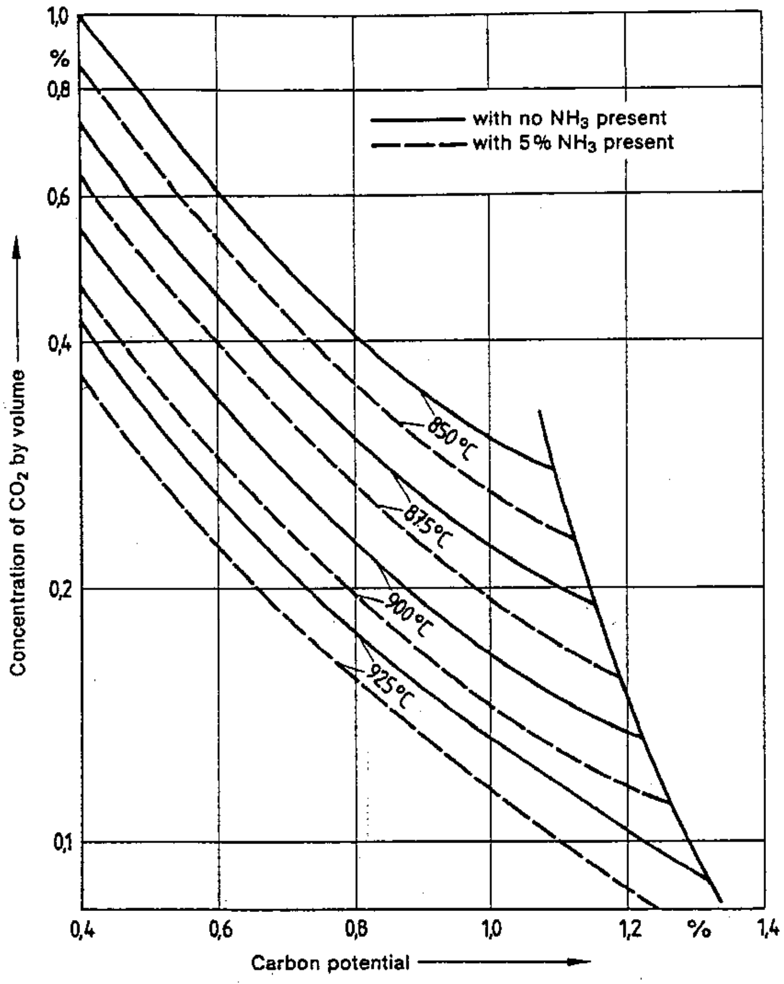


Figure 8. CO_2 content as a function of carbon potential in the case of gas carburizing or carbonitriding (propane produced endothermally)

Figure 13 shows combined hardness carburization diagrams for a hardened workpiece carburized with a constant (cf. subclause 5.3.1), relativity low (see figure 13a) or relatively high carbon potential (see figure 13b).

The resulting hardness characteristic is a function of the carbon characteristic, the hardenability of the steel concerned and the given austenitizing and cooling conditions.

5.5.2 Direct hardening

Direct hardening from the carburizing or carbonitriding temperature is the most commonly used case hardening method (method A in figure 9). It is employed

a) for workpieces not susceptible to distortion or those not required to meet close dimensional tolerances;

b) for workpieces, any distortion of which can be rectified by subsequent machining;

c) after carbonitriding.

Although direct hardening may cause grain coarsening or involve greater or lesser retained austenite contents in the case, it permits the largest possible case hardness to be obtained.

For most applications, however, a lower hardening temperature is recommended as this enables distortion and retained austenite content to be minimized. For workpieces subjected to direct hardening, the use of fine grain steel is recommended.

5.5.3 Single hardening (method B or E in figure 9)

Single hardening is mainly used

a) after carburizing in solid media;

b) if jig, chill or hardening mandrels are used in quenching to minimize dimensional changes and distortion;

c) if workpieces are to be given a local case hardening treatment and the carburized case of certain parts of the surface is to be removed prior to case hardening (method E);

d) if the surface layer is to be subjected to a regenerative annealing treatment to obtain the properties required.

5.5.4 Double quench hardening (method D in figure 9)

Double quench hardening is intended for workpieces not susceptible to distortion if quench hardening from surface hardening temperature is required and a core hardness lower than that achieved by direct hardening is to be obtained. It permits the retained austenite level in the case to be minimized.

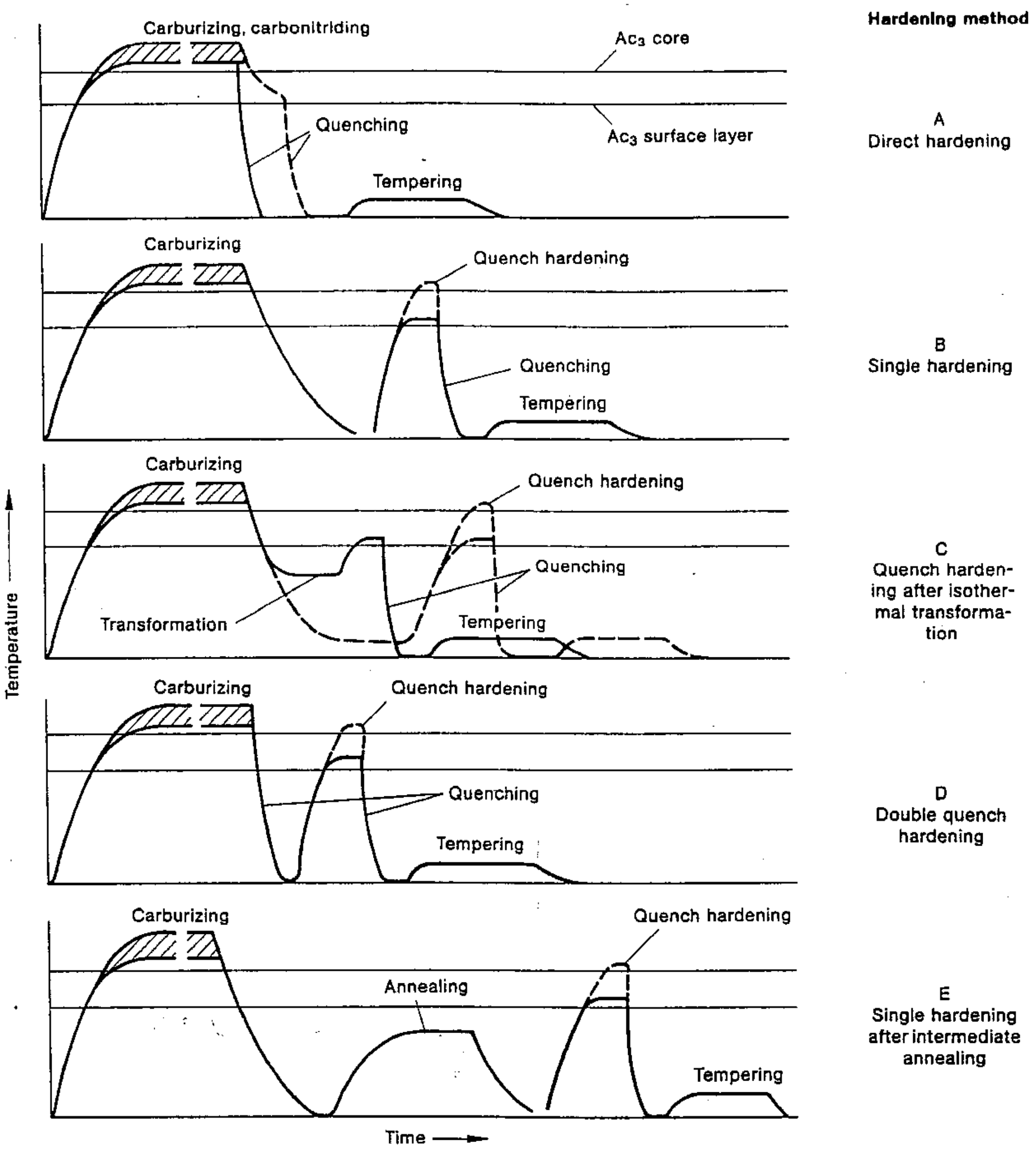


Figure 9. Typical thermal cycles in case hardening

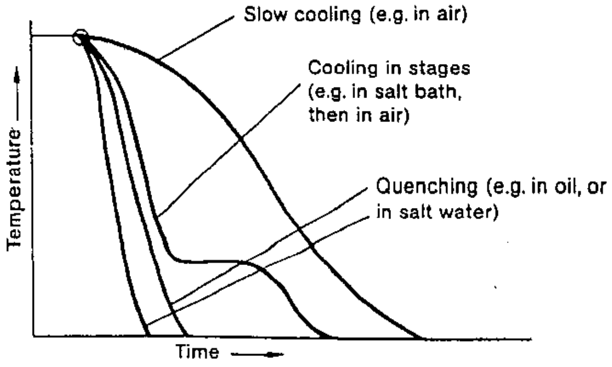
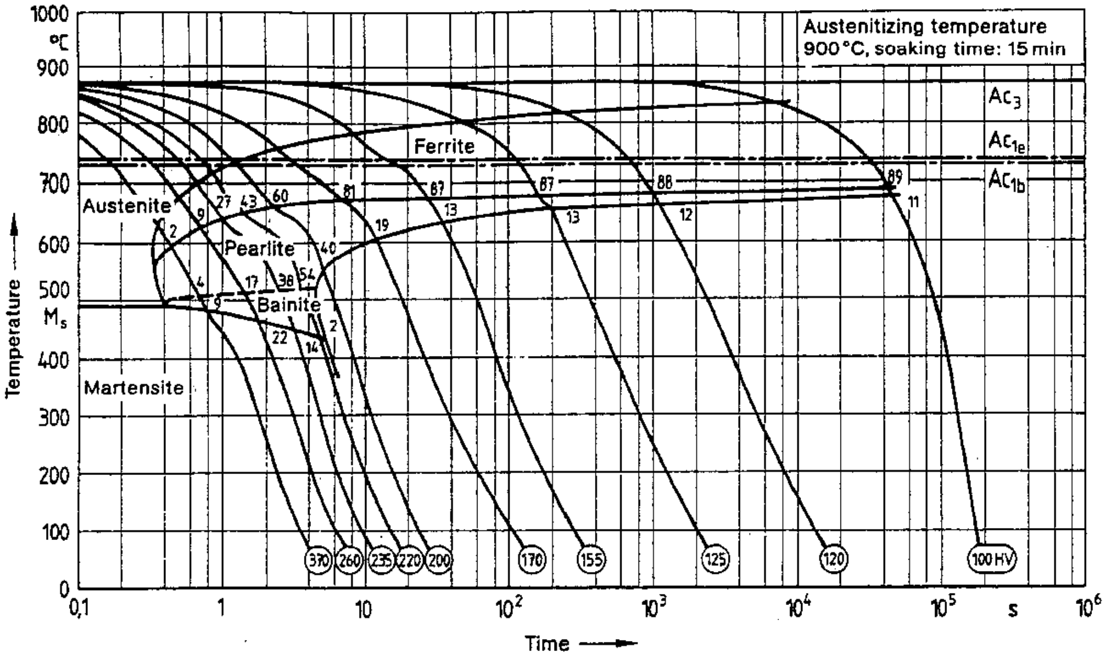
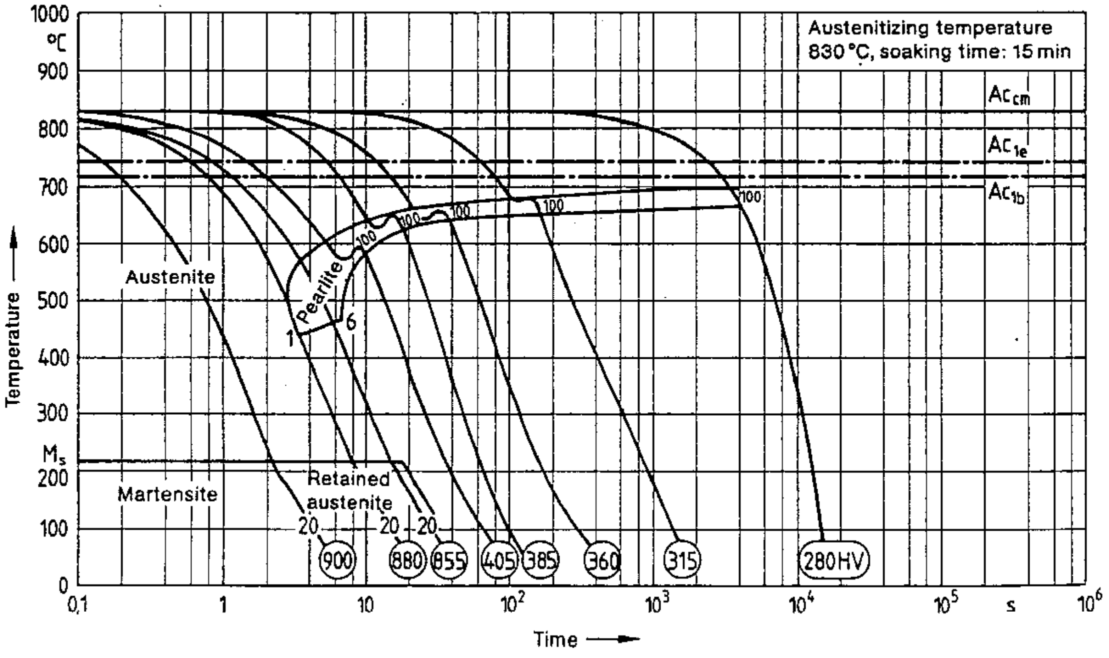


Figure 10. Time-temperature characteristic for cooling of carburized or carbonitrided workpieces



a) Continuous-cooling-transformation (CCT) diagram for non-carburized Ck 15 steel [2]



b) Continuous-cooling-transformation (CCT) diagram for Ck 15 steel carburized to have a surface carbon content of 0,90 % by mass [2]

Figure 11. Time-temperature-transformation (TTT) diagrams

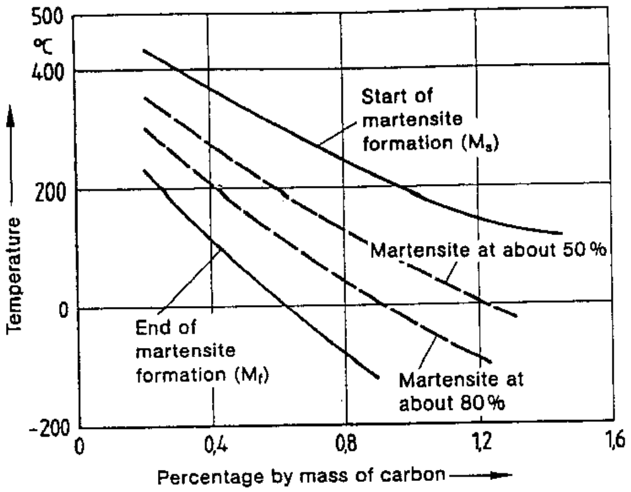
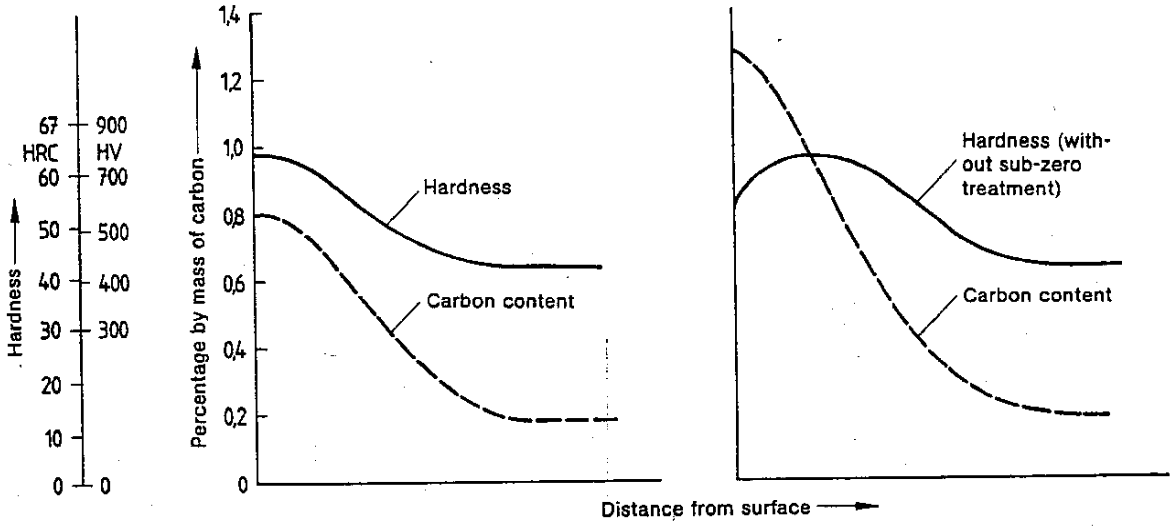


Figure 12. Carbon content of unalloyed steel as a function of temperature during martensite formation



a) Surface carbon contents as specified in table A.1

b) Surface carbon contents higher than specified in table A.1

Figure 13. Combined hardness/carburization diagrams for different carburizing conditions

5.6 Sub-zero treatment

The retained austenite present after case hardening can be transformed by subsequent sub-zero treatment, due allowance being made for the fact that the retained austenite may be stabilized by longer periods of storage at ambient temperature or by tempering at low temperatures to such an extent that the transformation is inhibited.

The temperature for sub-zero treatment is to be selected according to the effect intended (cf. figure 12). See subclause 6.3.3 for information regarding the refrigerant to be used.

After sub-zero treatment, the workpieces shall be tempered as normal (cf. subclause 5.7).

5.7 Tempering

The main aims of tempering after case hardening (and sub-zero treatment, if appropriate) are as follows:

a) reduction in hardness;
b) increase in toughness;
c) reduction in internal stresses;
d) reduction of the risk of cracking;
e) reduction of the retained austenite level (see, however, subclause 5.6);
f) change in dimensions, and form where required.

The tempering temperature is a function of the properties required. Workpieces made from case hardening steels complying with DIN 17210 shall normally be tempered between 180 °C and 250 °C, tempering temperatures for workpieces made from other steels being found, for example, in DIN 17350 or other relevant documents.

The normal soaking time shall be 30 to 120 minutes, the media used being oil, salt baths, gaseous media, or a fluidized bed.

6 Heat treatment media

6.1 Heating media

Workpieces may be heated in liquid or gaseous media, in a fluidized bed or a vacuum furnace, the medium selected depending on the required heating rate and temperature, with due consideration being given to the possible interaction between workpiece case and heating medium (e.g. decarburization, oxidation or scaling).

6.1.1 Liquid heating media

Oil may be used for heating to temperatures up to 250 °C and salt baths, for temperatures between 150 °C and 1000 °C.

Changes in the composition of the material in the workpiece case (due to carburization, partial decarburization, oxidation or nitriding) likely to impair the workpiece performance can be reduced or avoided by using suitable salt baths that are of low reactivity and chemically compatible. This is particularly important when heating in stages (i.e. when workpieces are immersed sucessively in salt baths differing in composition). Much the same effect can be achieved by heating in fluidized beds.

6.1.2 Gaseous heating media

Whether gaseous media are suitable for heating depends on the permissible reactions between the heating medium and the workpiece case, and on the working temperature required. Air or controlled atmospheres may be used as gaseous heating media, controlled atmospheres being understood to include nitrogen, cracked gases and gases produced endothermally or exothermally.

The effectiveness of nitrogen, although easy to handle, is limited, particularly if of low purity and when used at high temperatures. Care is required in the use of the other gases listed above, particularly at temperatures below 750 °C owing to the risk of explosion of the combustible constituents they contain.

6.1.3 Vacuum

A vacuum, by definition, is not a heating medium; heat is transferred by radiation. The vacuum generated by industrial-type vacuum furnaces ensures that residual gas quantities are negligible and can thus have no detrimental effect on the workpiece case. The pressure in the furnace shall, however, be adjusted to the vapour pressure of the alloying elements of the steel so as to prevent their evaporation.

6.2 Carburizing and carbonitriding media

6.2.1 Solid media (granulate)

Granulate, which is predominantly used for carburizing, generally consists of broken or moulded coke with a grain size between 0,5 and 6 mm. To assist the chemical reaction of unalloyed steel, the granulate also contains catalyzing agents.

6.2.2 Salt baths

Carburizing salt baths consist of activating alkaline earth chlorides with additives of alkaline chloride and alkaline cyanide, and contain reaction products of alkaline cyanate and carbonate, whereas carbonitriding salt baths have a lower alkaline earth chloride and a higher alkali cyanide content.

Salt baths may be activated or non-activated. When in operation, their cyanide content will range between 10 and about 30 %, and the alkaline earth content between 20 and 60 %, depending on the particular application.

6.2.3 Gases

6.2.3.1 Gases for carburizing

Gases used for carburizing include hydrocarbons or cracking products of liquid or gaseous compounds containing C, O and H, and gases generated by the gasification of granulate.

The gases are used to produce an atmosphere in the furnace which is suitable for carburizing, a distinction being made between

a) processes in which an endothermic carrier gas is generated by means of a cracking retort, located either inside or outside the furnace, and then mixed in the furnace with other gaseous additives (C, H compounds);

b) processes in which gases are fed into the furnace or organic liquids are introduced in droplet form, or a granulate containing carbon is placed in the furnace.

The processes may be further classified according to the carbon monoxide and methane contents of the gas used, i.e. into atmospheres with carbon potential control and those without carbon potential (cf. figure 14).

Propane or natural gas (or methane) is normally incompletely combusted with air or methanol is thermally cracked to produce atmospheres using a cracking retort.

The normal composition of endogas and methanol cracked gas is shown in table 1.

Table 1.

Base material	Composition of carrier gas (percentage by volume)
Propane	23,7 CO; 31,5 H_2; 44,8 N_2
Natural gas or methane	20,5 CO; 40,5 H_2; 39,0 N_2
Methanol	33,3 CO; 66,7 H_2
Nitrogen and methanol (40:60)	20,0 CO; 40,0 H_2; 40,0 N_2

Since the carburizing effect of the carrier gas alone is not adequate, carbon releasing gases, normally propane or natural gas (or methane), are to be added in amounts such as to keep the carbon potential below the saturation limit.

In practice, the following methods are used to produce the required atmosphere without using a cracking retort.

a) Gaseous or liquid methanol and nitrogen are fed into the furnace where the methanol is thermally cracked and the cracking products are diluted by the nitrogen present. A mixing ratio of 60 parts of gaseous methanol to 40 parts of nitrogen gives an atmosphere similar to the endogas. Propane or natural gas (or methane) are added to control the carbon potential.

b) Propane or natural gas (or methane) and air are fed directly into the furnace chamber, where the combustion process is similar to the reaction in the cracking retort (direct gassing). The atmosphere can be adjusted to the desired carbon potential using the carbon monoxide thus generated.

c) Liquid hydrocarbons or their oxygen derivates are fed into the furnace as drops or in the form of a jet and there atomize and split into the constituents active in carburizing. In order to control the carbon potential, it is normal to supply one liquid to generate the carrier gas and a further liquid to intensify the carburizing effect.

d) Granulate is placed either directly in the furnace or in a separate, heated chamber, where the granulate reacts with air to form carbon monoxide. It has proved expe-

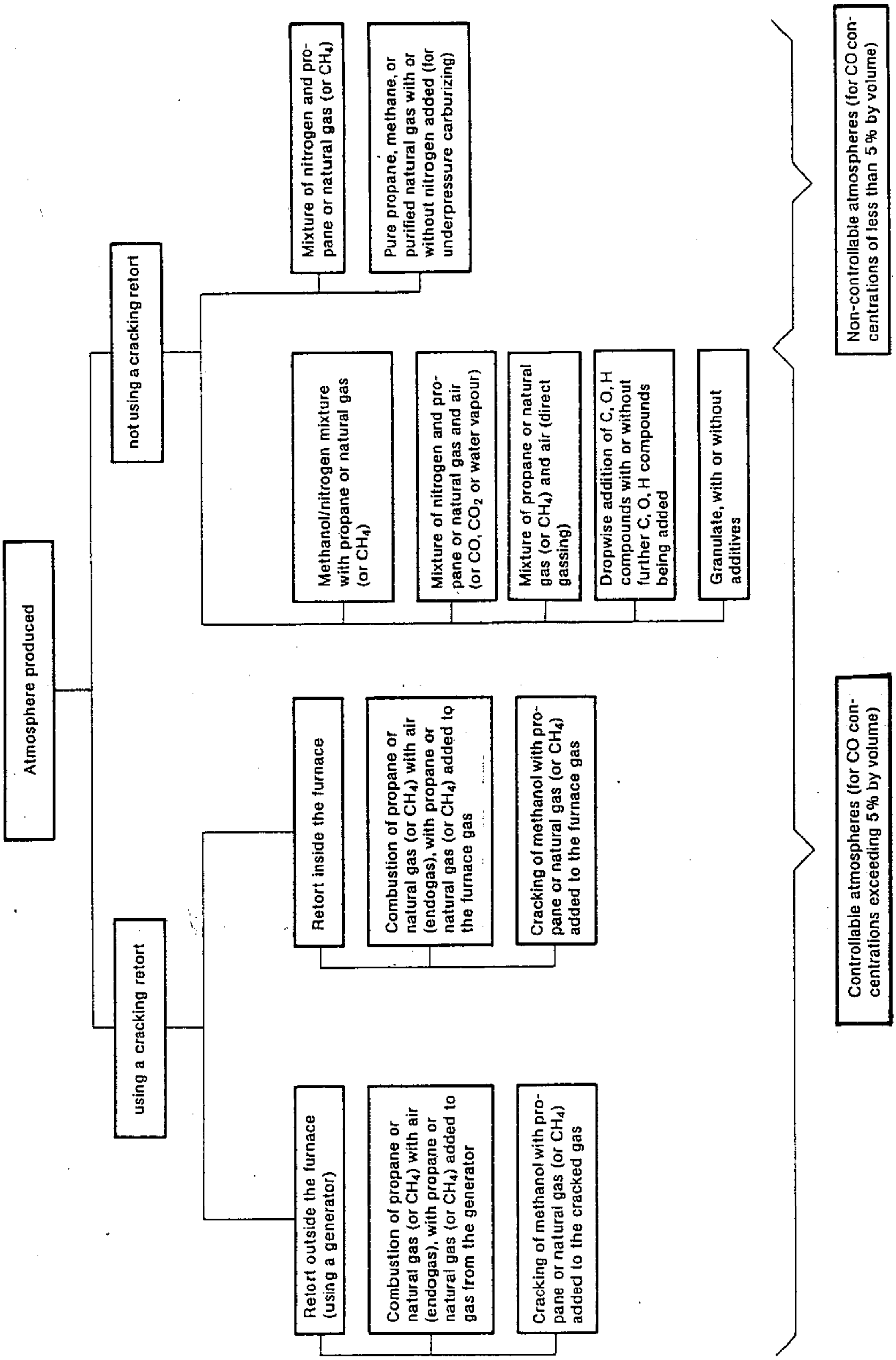


Figure 14. Summary of methods of producing carburizing atmospheres

dient to add carbon releasing gases or liquids to intensify the carburizing effect. Dilution of the gas released by the granulate with nitrogen has proved an effective means of reducing the carburizing effect.

In the case of athmospheres in which the carbon potential cannot be controlled, the atmosphere is produced, without the use of a cracking retort,

a) by feeding nitrogen and propane or natural gas (or methane) into the furnace, where the hydrocarbons are thermally cracked or,

b) by feeding in pure propane, pure methane or purified natural gas with or without nitrogen added, below atmospheric pressure.

6.2.3.2 Gases for carbonitriding

Gaseous ammonia shall be added to the carburizing atmosphere for carbonitriding purposes.

6.3 Cooling and quenching media

Cooling and quenching shall be carried out using gaseous or liquid media. They shall be selected as a function of the workpiece shape and cross-sectional dimensions, the hardenability of the material, the hardening temperature, the cooling effect required and the equipment used for heat treatment.

Since the cooling effect is a function of the flow rate and temperature of the cooling medium, the workpieces to be cooled should be placed in the medium in such a way that the cooling medium can reach all parts of the workpiece surface significant for hardening.

6.3.1 Liquid quenching media

The liquid quenching media to be used when particularly high cooling rates are required include water with or without additives, oil or salt baths.

Water with additives shall be used at temperatures up to 70 °C and water without additives, at temperatures up to 25 °C. The normal temperature for oil is between 40 °C and 80 °C and, exceptionally, up to 200 °C, whilst salt baths shall be used for temperatures in excess of 160 °C. Much the same results can be obtained using fluidized beds for quenching at temperatures between 20 °C and 600 °C.

When selecting the quenching medium, attention should be paid to its compatibility with the heating media used. The workpieces to be quenched shall not be packed too densely for quenching in salt baths containing nitrites or nitrates, to permit uniform heat dissipation and to prevent localized overheating of the salt bath.

At high hardening temperatures, the quenching medium may cause changes in the workpiece case. Conversely, should the batch being quenched produce an unacceptably high rise in the temperature of the quenching medium, the effectiveness of the medium may be diminished. Cooling performance may also be adversely affected by scale and salt residues on the workpiece surface.

6.3.2 Gaseous cooling media

The gaseous cooling media to be used include still or moving, dry or moistened air, nitrogen and other gases. They are very much less effective than liquid media, their cooling effect, however, can usually be intensified by increasing the pressure or the flow rate. Thus, when deciding whether to cool in gas or not, attention should be paid to the hardenability of the material used and to the workpiece shape and size.

Nitrogen or the gases listed in subclause 6.1.2 may be used for cooling in process gas plant and in fluidized beds. In vacuum furnaces, cooling shall normally be effected using nitrogen, under increased pressure where necessary.

6.3.3 Cooling media for sub-zero treatment

Cooled air permits workpieces to be cooled down to about −60 °C (using a conventional freezer), purpose-made equipment allowing temperatures of −140 °C to be reached. Temperatures below −60 °C may be obtained by using dry ice, alcohol mixtures or liquefied gases (liquid nitrogen having a temperature of −196 °C).

7 Instructions on equipment used in heat treatment

The following instructions are intended to facilitate the specification of heat treatment procedures but are not to be regarded as comprehensive. For the particular application, the information provided by the equipment manufacturer shall be taken into account.

7.1 Heat treatment furnace

The following criteria will also need to be considered when selecting a furnace:

a) treatment temperature, temperature distribution in the furnace chamber and permissible differences in temperature;

b) type of heating medium;

c) type of carburizing or carbonitriding medium;

d) type of cooling medium;

e) shape, size and number of workpieces;

f) processing sequence and control.

Table 2 gives further guidance on furnace selection.

7.2 Cooling and quenching equipment

The following equipment is normally to be used for quenching or cooling.

a) When using water with or without additives: tanks incorporating a circulating device or means for spraying the medium onto the workpiece surface may additionally be fitted.

b) When using oil and salt baths: tanks incorporating heating and cooling facilities, generally also fitted with thermostat control; they are often fitted with a circulating device. The tanks should be able to hold a quantity of quenching medium equal to at least seven times the workpiece mass or workpiece batches concerned.

c) When using gaseous media: tanks or chambers equipped with a blower and, where required, with nozzles and gas-directing facilities to ensure an adequate rate of flow across the workpiece surface. The equipment may also be provided with a system allowing the gas to be cooled and returned.

For cooling in gas, vacuum furnaces may be provided with pressurizing equipment and a device for cooling the gas.

7.3 Sub-zero treatment equipment

Sub-zero treatment for transforming retained austenite at temperatures below ambient is normally to be carried out using freezer chests or cabinets operating at temperatures as low as −140 °C, or dip tanks operating at temperatures as low as −196 °C.

Table 2. **Guide to furnace selection**

Heat treatment	Treatment temperature, in °C	Permissible deviation from temperature selected, in K	Parameters to be controlled	Usual heat treatment media	Usual furnace type for discontinuous processing in batches	Usual furnace type for continuous processing
Stress relieving	600 to 700	± 25	Temperature and time	Air and controlled atmosphere	Pot, shaft, chamber, bogie hearth, hood-type, fluidized bed and bell-type furnaces	Continuous pusher-type furnaces and roller hearth furnaces 6)
Preheating	Up to 500 1)	No requirements.	No requirements.	Air and exhaust gases	Shaft, hood-type, chamber, fluidized bed and crucible furnaces	Continuous pusher-type furnaces and roller hearth furnaces 6)
Carburizing	Up to 950	± 10	Temperature, time and carbon potential	Salt baths	Crucible and tank furnaces 3)	–
	Up to 1050	± 15	Temperature, time, carbon potential, gas volume and gas pressure	Gases and gas mixtures	Chamber 4), vertical retort, shaft, bell-type, fluidized bed, rotary retort and vacuum furnaces 5)	Conveyor belt, jerking table, oscillating retort, conveyor screw, rotary tubular, continuous pusher-type, pusher-type shell and turnover pusher-type furnaces
	Up to 1050	± 15	Temperature and time	Granulate	Chamber furnaces and shaft furnaces	Continuous pusher-type furnaces
Carbonitriding	Up to 930	± 10	Temperature, time and carbon potential	Salt baths	Crucible and tank furnaces 3)	–
	Up to 930	± 10	Temperature, time, carbon potential and gas volume	Gases and gas mixtures	Chamber, vertical retort, fluidized bed, bell-type and rotary retort furnaces	Conveyor belt, jerking table, oscillating retort, conveyor screw, rotary tubular, pusher-type shell, turnover pusher-type and continuous pusher-type furnaces
Austenitizing for hardening	Uo to 920 2)	± 10	Temperature and time	Neutral or inert salt baths	Crucible and tank furnaces 3)	–
			Temperature, time, carbon potential, and gas volume	Controlled atmosphere	Chamber 4), vertical retort, shaft, fluidized bed, and bell-type furnaces	Continuous pusher-type furnaces and rotary hearth furnaces
			Temperature, time, and pressure	Highest grade nitrogen	Vacuum furnaces 5)	–
Tempering	Up to 250	± 10	Temperature and time	Salt baths and oil	Crucible and tank furnaces 3)	–
			Temperature, time, and gas volume	Air and controlled atmosphere	Chamber, shaft fluidized bed, bell-type furnaces	Conveyor belt furnaces and continuous pusher-type furnaces

For 1) to 6), see page 16.

Table 2 (concluded).

Heat treatment	Treatment temperature, in °C	Permissible deviation from temperature selected, in K	Parameters to be controlled	Usual heat treatment media	Usual furnace type for discontinuous processing in batches	Usual furnace type for continuous processing
Tempering	Up to 250	± 10	Temperature, time, and pressure	Highest grade nitrogen	Vacuum furnaces	-
Intermediate annealing	Up to 700	± 20	Temeperature and time	Salt baths	Crucible and tank furnaces[3].	-
				Air and controlled atmosphere	Pot, shaft, fluidized bed, chamber, bogie hearth, hood-type and bell-type furnaces	Continuous pusher-type furnaces[6] and roller hearth furnaces[6]

[1] Preheating to higher temperatures may be necessary in special cases (for large, solid, or complex workpieces).

[2] Austenitizing at temperatures up to 1050 °C may be necessary for carburized stainless steel workpieces.

[3] The maximum workpiece diameter for electrode salt bath furnaces with round heating chamber shall be not larger than two-thirds of the crucible inside diameter; the minimum distance of the workpiece from the electrodes in oval or rectangular heating chambers with the electrodes arranged on one side shall be 50 mm.

[4] Chamber furnace installations may include an oil-filled quenching tank or a controlled atmosphere or inert gas-filled cooling chamber. The cooling equipment for quenching in water or without additives, salt baths or fluidized beds shall be fitted outside the chamber furnace.

[5] Medium for cooling in the furnace: nitrogen or oil, and for cooling from outside the furnace: oil, water with or without additives, salt baths or fluidized beds.

[6] Less commonly used.

8 Defects on heat treated workpieces

Defects or imperfections on heat treated workpieces can rarely be attributed exclusively to a single cause. They may be caused by the heat treatment itself, but also be due the material, the workpiece shape, the machining conditions or the conditions under which the workpiece is used. The most frequent defects are listed in table 3, which is based on the assumption that the workpieces have been sent for heat treatment in a perfect condition. The table lists the defects collating them with the probable causes and the corresponding significant errors in heat treatment. It is based on experience and makes no claim to be exhaustive.

Table 3. **List of defects in case-hardened workpieces, their cause when due to heat treatment, and the corresponding significant errors in heat treatment**

Type of defect	Cause	Error in heat treatment	Refer to subclause
1 Surface hardness too low	1.1 Martensite content too small		
	1.1.1 due to formation of ferrite and/or pearlite and/or bainite	Quench hardening temperature too low.	5.2 and 5.5
		Austenitizing time too short.	5.2 and 5.5
		Surface carbon content too low (partial decarburization or carburized to too low a surface carbon content).	5.3
		Inadequate quenching (quantity of quenching medium insufficient and/or quenching medium temperature unsuitable; no or insufficient motion of quenching medium; scale or salt residues on workpieces; vapour film).	5.2, 5.5, 5.1.6 and 6.3
		Surface oxidation.	6
		Surface nitrogen content (in carbonitriding) too small.	5.4 and 6.2
	1.1.2 due to retained austenite being present	Surface carbon content too high.	5.3 and 6.2
		Quench hardening temperature too high.	5.2 and 5.5
		No or insufficient sub-zero treatment.	5.6
		Sub-zero treatment not properly timed.	5.6
		Tempered before sub-zero treatment.	5.6 and 5.7
		Surface nitrogen content too high.	5.4 and 6.2

Table 3 (concluded).

Type of defect	Cause	Error in heat treatment	Refer to subclause
1 **Surface hardness too low**	1.2 Martensite too soft	Surface carbon content too low (as a result of decarburization or inadequate carburization). Tempering temperature too high. Tempering time too long. Surface nitrogen content too low (in carbonitriding).	5.3, 5.5 and 6.2 5.7 5.7 5.4 and 6.2
2 **Surface hardness too high**	Martensite too hard	Not tempered. Tempering temperature too low. Tempering time too short. Surface carbon content too high. Surface nitrogen content too high.	5.7 5.7 5.7 5.3 and 6.2 5.4 and 6.2
3 **Core hardness too low**	Martensite content too small	Quench hardening temperature too low. Austenitizing time too short. Cooled too slowly to quench hardening temperature or soaking time too long at quench hardening temperature in the case of direct hardening. Quenching effect too small (owing to quantity of quenching medium being insufficient and/or quenching medium temperature being inadequate; no or insufficient motion of quenching medium; scale or salt residues on workpieces; vapour film).	5.2 and 5.5 5.2 and 5.5 5.2 and 5.5 5.1.6, 5.2, 5.5 and 6.3
4 **Effective case depth after carburizing too shallow**	4.1 Case depth too shallow	Temperature during carburizing or carbonitriding too low. Carburizing or carbonitriding time too short. Carbon potential too low. Insulating effect of shielding media.	5.3 and 5.4 5.3 and 5.4 5.3 and 5.4 5.1.5
	4.2 Case depth correct; martensite too soft	Carbon content too low. Quench hardening temperature too low. Austenitizing time too short. Tempering temperature too high. Tempering time too long.	5.3 and 6.2 5.2 and 5.5 5.2 and 5.5 5.7 5.7
	4.3 Martensite content too small due to formation of bainite and/or pearlite and/or ferrite	Quench hardening temperature too low. Austenitizing time too short. Quenching effect inadequate. Surface nitrogen content too low (in carbonitriding). Surface carbon content too low.	5.2 and 5.5 5.2 and 5.5 5.1.6, 5.2, 5.5 and 6.3 5.4 and 6.2 5.3 and 6.2
5 **Effective case depth after carburizing too great**	Case depth too great	Carburizing temperature too high. Carburizing time too long. Carbon potential too high. Nitrogen content too high (in carbonitriding). Not tempered. Tempering temperature too low. Tempering time too short.	5.3 5.3 5.3 and 6.2 5.4 and 6.2 5.7 5.7 5.7
6 **Tolerances on dimensions and form exceeded**	Thermal and/or transformation stresses too high, or nonuniformly distributed	Not properly heated. Unfavourable workpiece position in furnace. Nonuniform austenitization. Nonuniform carburization. Retained austenite in case. Case nitrided. Nonuniform cooling.	5.1.6 and 5.2 5.1.6 5.1.6 and 5.2 5.1.6 and 5.3 5.3, 5.5 and 6.2 5.4 and 6.2 5.1.6, 5.5 and 6.3
7 **Cracks**	Thermal and/or transformation stresses too high, ultimate strenght locally exceeded	Heating inadequate or carried out too quickly. Surface layer decarburized. Surface layer overcarburized. Quenching inadequate, nonuniform, or carried out too quickly. Not tempered, or tempered too late.	5.1.6 and 5.2 5.5 and 6.1 5.3 and 6.2 5.1.6, 5.5 and 6.3 5.7

9 Heat treatment as a criterion in design

The workpiece shape and size are major factors influencing the stresses arising in quench hardening and the resulting changes in shape and size. By giving proper attention to the design of the workpiece, such changes can be kept within reasonable limits, the risk of failure reduced and workpiece life often extended. The following basic rules are to be observed in design.

a) The mass distribution should be made as uniform as possible, e.g by providing additional holes or chases (see figure 15 or figure 16).

b) Unduly abrupt changes in cross section should be precluded by adequate radiusing or chamfering, thus reducing the notch effect liable to induce stress peaks (see figure 17). It may be expendient to give the workpiece its final shape only after quench hardening (see figure 18).

c) A symmetrical shape should be aimed at (see figure 19).

Where required, facilities for making attachments to the workpieces, e.g. suspension holes, tapped holes for fitting suspension eyes, etc., should be provided so as to facilitate handling of the workpieces during heat treatment.

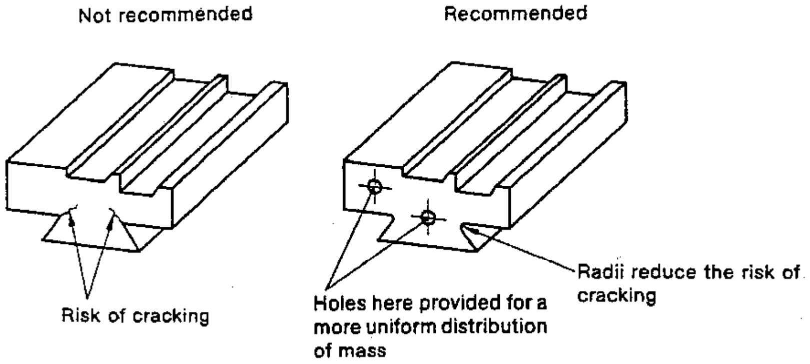


Figure 15. Favourable and unfavourable distribution of mass in workpieces

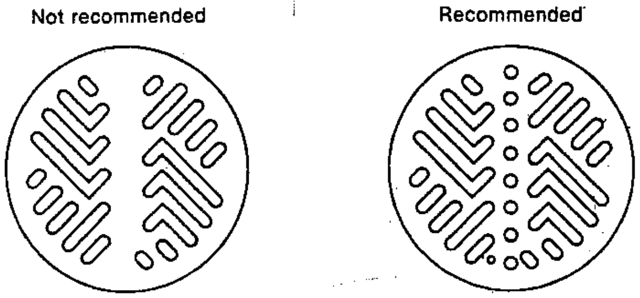


Figure 16. Favourable and unfavourable distribution of mass in workpieces

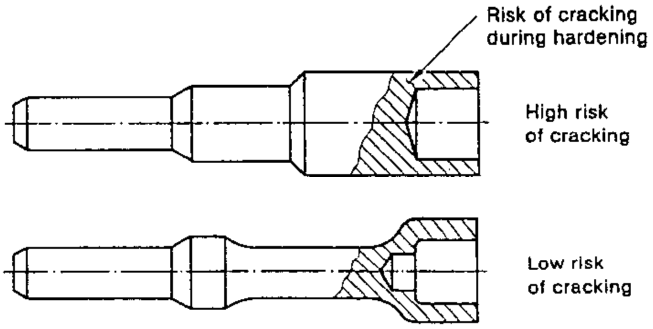


Figure 17. Favourable and unfavourable design of cross section transition

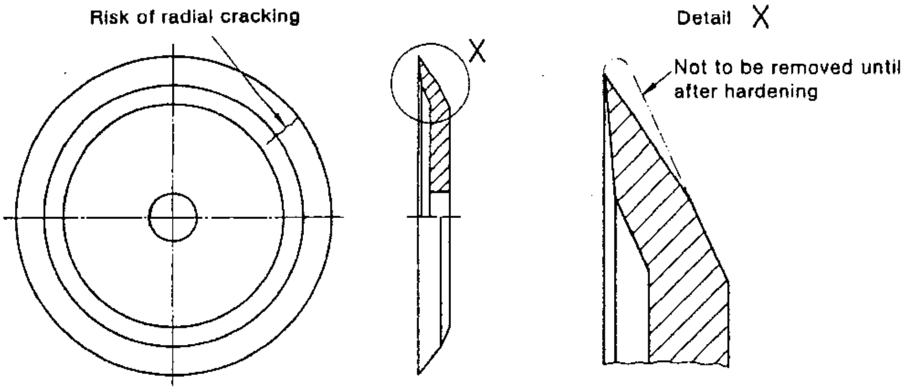


Figure 18. Example of modification of cross-sectional shape to reduce the risk of cracking

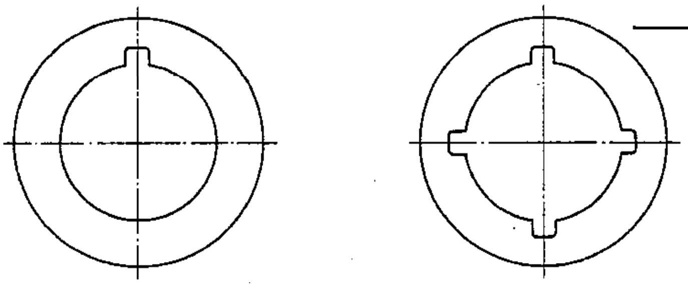


Figure 19. Example of design modification to enhance symmetry

10 Instructions on straightening

The purpose of straightening is to correct changes in dimensions and shape resulting from heat treatment. This can be achieved by making compression zones (e.g striking with a straightening hammer), bending the distorted workpiece either when cold or during the cooling process under a straightening press, in a straightening machine or on a straightening bench, or by localized heating in a jig, which counteracts the development of dimensional changes.

Whether workpieces are to be straightened before or after tempering depends on the type and extent of workpiece distortion, the workpiece shape and size, the material composition and condition and practical experience.

11 Inspection of heat treated workpieces

Table 4 provides information on the inspection of carburized, carbonitrided or case hardened workpieces designed to facilitate decisions on the method to be employed for assessing the effect of the heat treatment performed.

It shall be the responsibility of the workpiece user to decide whether the test results may usefully be employed to assess the probable performance of the workpiece in service.

Table 4. **Information regarding the inspection of heat treated workpieces**

Object of inspection	Test methods
Hardness	As in DIN 50 103 Parts 1 and 2 and DIN 50 133 (see DIN 50 150 for conversion of hardness values)
Corrosion and incipient fusion	Visual examination of workpieces in the cleaned condition without further pretreatment
Soft spottiness	Hardness measurement Visual examination or macroscopic assessment of etched (preferably, ground*)) or abrasive blasted surface
*) Grinding shall be carried out so as not to remove the soft spotty case.	

Table 4 (concluded).

Object of inspection		Test methods	
Cracks		Visual examination after appropriate cleaning Microscopic examination Penetrant inspection Ultrasonic testing Eddy current testing Magnetic testing	
Micro-structure	Constituents according to type, form, quantity and arrangement (martensite bainite, pearlite, ferrite, retained austenite)	Metallographic examination using a microscope	
	Carbide precipitations according to size, quantity and arragement		
	Grain size		
	Decarburization; depth of decarburization		DIN 50 601
	Surface oxidation; depth of surface oxidation		DIN 50 192
	Case depth	Microscopic spectral analysis and chip fraction analysis	
	Effective case depth after carburizing		DIN 50 190 Part 1

Appendix A

A.1 Recommended surface carbon content for low retained austenite levels

It has proved expedient not to exceed the surface carbon contents specified in table A.1 if a low retained austenite level in the workpiece case is required.

The workpiece may be carburized with carbon potential kept constant during the entire carburizing process or, alternatively, the desired surface carbon content may be achieved at the final stage of carburizing by adjustment of the carbon potential (cf. subclause 5.3.1).

Table A.1. **Recommended maximum surface carbon contents for low retained austenite levels in the case**

Steel	Carbon content, as a percentage by mass
20 MoCr 4	0,75
20 NiMoCr 6	0,73
16 MnCr 5	0,72
20 MnCr 5	0,70
15 CrNi 6	0,65
18 CrNi 8	0,63

A.2 Relationship between carbon potential and gas composition in the case of gas carburizing

For controllable atmospheres (cf. subclause 5.3.6.1), the CO_2 content, the moisture content (dew point) or the oxygen content of the carburizing atmosphere are normally used to determine the carbon potential.

From the following reactions:

$$2\,CO \rightleftarrows (C) + CO_2 \qquad (A.1)$$

$$CO + H_2 \rightleftarrows (C) + H_2O \qquad (A.2)$$

$$CH_4 \rightleftarrows (C) + 2\,H_2 \qquad (A.3)$$

$$CO \rightleftarrows (C) + \tfrac{1}{2}\,O_2 \qquad (A.4)$$

one obtains the carbon activity, a_c, in accordance with the law of mass action, using the mass action constants specified by *AWT-Fachausschuß* (AWT Technical Committee) 5:

$$\lg a_c = \lg\left(\frac{P^2_{CO}}{P_{CO2}}\right) + \frac{8817}{T} - 9{,}071 \qquad (A.5)$$

$$\lg a_c = \lg\left(\frac{P_{H2}\cdot P_{CO}}{P_{H2O}}\right) + \frac{7100}{T} - 7{,}496 \qquad (A.6)$$

$$\lg a_c = \lg\left(\frac{P_{CH4}}{P^2_{H2}}\right) - \frac{4791}{T} + 5{,}789 \qquad (A.7)$$

$$\lg a_c = \lg\left(\frac{P_{CO}}{P^{1/2}_{O2}}\right) - \frac{5927}{T} - 4{,}545 \qquad (A.8)$$

where T is the carburizing temperature, in K, and P denotes the relevant partial pressures of the gas components.

The relationship between a_c and C_p is expressed by the following simplified equation:

$$\lg a_c = \frac{2300}{T} - 2{,}21 + 0{,}15\cdot C_p + \lg C_p \qquad (A.9)$$

By equating equation (A.9) with equations (A.5) and (A.6) one obtains the following partial pressures of CO_2, O_2 and water vapour:

$$P_{CO2} = 10^a;\quad a = \left(\frac{6517}{T} + \lg P^2_{CO} - 6{,}861 - 0{,}15\cdot C_P - \lg C_P\right) \qquad (A.10)$$

$$P_{H2O} = 10^b;\quad b = \left(\frac{4800}{T} + \lg\,(P_{H2}\cdot P_{CO}) - 5{,}286 - 0{,}15\cdot C_P - \lg C_P\right) \qquad (A.11)$$

$$P_{O2} = 10^c;\quad c = \left(-\frac{16454}{T} + 2\cdot\lg P_{CO} - 13{,}510 - 0{,}30\cdot C_P - 2\lg C_P\right) \qquad (A.12)$$

If the oxygen partial pressure is measured using a solid state electrolyte (e.g. a zirconium dioxide-oxygen probe), the probe voltage is obtained, using the following equation:

$$E = 0{,}0496\cdot T\cdot\lg\frac{P_{O2}}{0{,}209}\ \text{mV} \qquad (A.13)$$

From this, the carbon potential is derived as follows:

$$E = 0{,}0992\cdot T\cdot(\lg P_{CO} - 1{,}995 - 0{,}15\cdot C_p - \lg C_p) - 816{,}1\ \text{mV} \qquad (A.14)$$

With either parameter (CO_2 content, moisture content or oxygen probe voltage) measured, equations (A.10), (A.11) and (A.14) may be used to calculate, for the relevant gas composition in terms of CO and H_2 content (cf. table 1), at the relevant temperature, T, the carbon potential, C_p, obtaining in the state of equilibrium, or, for a given carbon potential, the CO_2 content, moisture content or oxygen probe voltage can be determined.

A.3 Local case hardening

The following measures may be taken to achieve local case hardening.

a) Protection of specific surface areas against carburizing and the effect of subsequent quench hardening of the whole workpiece.

b) Carburizing part of the workpiece by partial immersion in the carburizing medium and subsequent quench hardening of the whole workpiece.

c) Carburizing of the entire workpiece and removal of the carburized case from the relevant surface areas and subsequent quench hardening of the whole workpiece.

d) Carburizing of the whole workpiece and local quench hardening of the relevant areas by immersion or local heating by flame or by induction.

e) Case hardening of the whole workpiece and removal of the hardened case from the relevant surface areas.

f) Case hardening of the whole workpiece and local tempering by immersion or local heating by flame or by induction.

Which of the measures to be taken will mainly depend on the required properties of the workpiece in service, on the workpiece shape and size and the operating conditions.

Standards and other documents referred to

DIN 1651	Free cutting steel; technical delivery conditions
DIN 1654 Part 3	Cold heading and cold extruding steels; technical delivery conditions for case hardening steels
DIN 6773 Part 4	Heat treatment of ferrous materials; heat treated components; representation and indication on drawings; case hardening
DIN 17 014 Part 1	Heat treatment of ferrous materials; terminology
DIN 17 014 Part 3	Heat treatment of ferrous materials; brief description of heat treatment processes
DIN 17 023	Heat treatment of ferrous materials; specimen forms; heat treatment instructions
DIN 17 210	Case hardening steels; technical delivery conditions
DIN 17 350	Tool steels; technical delivery conditions
DIN 50 103 Part 1	Testing of metallic materials; Rockwell hardness test; C, A, B, F scales
DIN 50 103 Part 2	Testing of metallic materials; Rockwell hardness test; N and T scales
DIN 50 133	Testing of metallic materials; Vickers hardness test; HV 0,2 to HV 100
DIN 50 150	Testing of steel and cast steel; conversion tables for Vickers hardness, Brinell hardness, Rockwell hardness and tensile strength
DIN 50 190 Part 1	Depth of hardness in heat treated materials; determination of effective case depth after carburizing
DIN 50 192	Determination of depth of decarburization
DIN 50 601	Metallographic examination; determination of the ferritic or austenitic grain size of steel and ferrous materials

[1] Gunnarson, St. *Einfluß von Legierungsstoffen auf den Kohlenstoffgehalt von aufgekohlten Einsatzstählen* (Influence of alloying elements on the carbon content of carburized case hardening steels). *Härterei-Techn. Mitt.*, 1967 : **22** (4), 293–295

[2] *Atlas zur Wärmebehandlung der Stähle* (Atlas of the heat treatment of steels), vol. 1 to 4, Düsseldorf: *Verlag Stahleisen mbH*

Explanatory notes

This standard has been prepared jointly by the *Normenausschuß Wärmebehandlungstechnik metallischer Werkstoffe* (Heat Treatment of Metallic Materials Standards Committee) and Technical Committee 2 of the *Arbeitsgemeinschaft Wärmebehandlung und Werkstofftechnik (AWT)*. In both committees, heat treatment experts from a number of production plants, contract hardening shops, manufacturers of heat treatment equipment, steelmakers, and members of the *Verein Deutscher Eisenhüttenleute* (Society of German Ferrous Metallurgy Engineers) and *AWT* were represented.

The committee set itself the aim to prepare a standard which provides all information necessary for heat treatment and which may thus be used as a guideline.

The standard is part of a planned series of standards dealing with the stages and methods of heat treatment of ferrous materials, one of which, DIN 17 022 Part 2, dealing with the hardening and tempering of tools, has already been issued. It is intended to prepare standards relating to quench hardening, hardening and tempering, quenching and tempering of components, surface hardening, nitriding and annealing. The aim of these standards is to fill the gap between DIN 17 014 Part 1 dealing with terminology and the technical delivery conditions for steel.

The present standard and the future standards of the series are intended to provide a ready reference for staff working in design and development offices, in production planning and in hardening shops, as an aid in quality management. In addition, these standards will be highly suitable for training purposes at all levels.

Neither in this standard nor in the other standards will details be found of material characteristics produced by any given type of heat treatment, as this information can be derived from the relevant documentation or standards.

To facilitate application of the standard, it was decided only to include essential information on materials; any further information can be obtained from the extensive technical literature on the subject. Greater emphasis has been given instead to the inclusion of information derived from practical experience.

International Patent Classification

C 21 D 1/18
C 23 C 8/46
G 01 N 33/20