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June 1986

Heat treatment of ferrous materials

Heat treatment methods

Hardening and tempering of tools

DIN 17 022 Part 2

Wärmebehandlung von Eisenwerkstoffen; Verfahren der Wärmebehandlung; Härten und Anlassen von Werkzeugen

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

1 Scope and field of application

This standard describes heat treatment procedures and provides information on the hardening and tempering of tools made from tool steels, e.g. from those specified in DIN 17 350.

2 Concepts

The terminology associated with heat treatment as used in this standard has been adopted from DIN 17 014 Part 1 which also gives the relevant definitions.

3 Principle of heat treatment

3.1 Hardening

Hardening consists of austenitizing and cooling at a rate suitable for the intended application.

3.1.1 Austenitizing

Austenitizing is effected by heating and soaking at austenitizing temperature, the hardening temperature being generally identical with the austenitizing temperature. Heating may be effected in stages, this being the usual procedure for alloy steel tools. The austenitizing conditions are primarily governed by the chemical composition and the required final condition of the material by the shape and dimensions of the tool being hardened and by the initial condition of the material. The interrelationship of the material-related factors is illustrated by time-temperature austenitizing diagrams (see subclause 5.2.1).

3.1.2 Cooling

Austenitizing is followed by cooling at a rate suitable for imparting the required hardness.

Cooling may be carried out with the temperature lowered in stages, this being the usual procedure for alloy steel tools. The cooling process is a function of the chemical composition of the steel, the austenitizing conditions, the shape and dimensions of the tool being hardened and by the required final condition of the material. Cooling may be continued below ambient temperature (see subclause 5.2.3).

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3.2 Tempering

After hardening, the tools shall be tempered either once or several times. The tempering temperature and duration of tempering are functions of the required hardness and other functional properties of the tool, the tempering behaviour being governed by the chemical composition of the material and the prevailing structure condition.

4 Indicating the heat-treated condition

On drawings, the heat-treated condition shall be indicated as specified in DIN 6773 Part 2.

Detailed specifications of the heat treatment procedure may require the provision of a heat treatment instruction as specified in DIN 17 023, or a heat treatment schedule. For denoting details of the heat treatment procedure, the symbols given in DIN 17 014 Part 3 shall be used.

5 Hardening and tempering procedure

5.1 Preparation and pretreatment

The preparation and conditioning of tools is intended to eliminate any undesirable influence of internal stresses on distortion, or of the surface condition on the final condition, and to ensure that heat treatment is not interrupted by workpiece failure.

5.1.1 Stress relieving

Stress relieving is necessary if internal stresses present in the material influence its susceptibility to distortion to an unacceptable extent, the resulting changes in size and shape being taken into account by the provision of an adequate machining allowance. The temperature shall lie below the transformation temperature Ac_1, but should be as close to this temperature as possible. This being the case, soaking after heating is not required. Heating and cooling shall be performed so as to prevent additional internal stresses arising.

In the case of cold-formed tools, normalizing is to be preferred if stress relieving is likely to result in grain coarsening due to recrystallization.

5.1.2 Hardening and tempering (pretreatment)

The internal stresses present in the tool blank may also be reduced by heating to austenitizing temperature instead of stress relieving, this also making the material more homogeneous.

If the tool blank is then cooled as in the case of hardening, the changes in dimensions and shape likely to result during subsequent hardening of the machined tool can be reduced, and the extent and direction of the likely changes can be estimated.

Following this, the tool blank shall be tempered so as to allow further machining and correction of the changes in size and shape that have occurred.

This so-called "pretreatment" of the blank including intermediate machining prior to hardening of the tool has proved its value, particularly when exacting demands have to be met in respect of behaviour in terms of changes in size and shape.

5.1.3 Tool preparation

Depending on the level of surface impurities and the quality requirements to be met, it will be necessary for tools to be prepared, prior to hardening, by washing, drying, pickling, sand-blasting, flash-trimming, machining or other suitable measures to ensure that, for example, salt baths are not contaminated by flash, adherent chips, rust, scale or skin due to rolling, forging or casting;

no eruptions occur in salt baths due to sudden evaporation of water;

soft skin, soft spottiness and cracks do not occur as a result of decarburized surface layers.

Bolts or screws used for closing bores or tapped holes shall be removed prior to heat treatment or even prior to cleaning.

5.2 Hardening

5.2.1 Austenitizing

The temperature in the surface zone and in the core of a tool of simple geometry and of more or less uniform cross section, when it is brought to austenitizing temperature, is shown as a function of time in a graph in figure 1. Tools of non-uniform cross section, however, yield different heating curves for surface zone and core in each cross section.

The hardening temperature to be applied as a function of the material shall be taken from DIN 17 350 or corresponding documentation provided by the steelmakers.

The sum of heating and soaking time is the holding time of a tool in a furnace.

During heating, temperature differences arise between the surface zone and the core of the tools. The bigger the cross sections of the tools to be heated, the higher the rate of heating and the lower the thermal conductivity of the material, the more pronounced are these temperature differences. These differences and the resulting structural transformations at different points in time are the cause of stresses occurring. Distortion may result. Tools with big differences in cross section and/or large dimensions, particularly when made of alloy steel, shall therefore be heated slowly or in stages (see figure 2).

Guidance on the heating time for various thermal cycles is given in figure 3, which also gives guideline values for circular, square or rectangular tool cross sections and for heating procedures using salt baths. Corresponding guideline values for heating in air-circulating furnaces and chamber furnaces can be taken from figure 4.

The time-temperature austenitizing diagram shown in figure 5 illustrates, for X 38 CrMoV 5 1 hot work steel, the structural transformation occurring during heating to austenitizing temperature.

Figure 5 shows that, as the heating rate increases, both austenite formation and carbide dissolution are displaced towards more elevated temperatures. With the aid of the different heating rate curves the temperature or time required to achieve a given structure condition can be estimated.

As the alloy content increases, the austenite formation and carbide dissolution are delayed and shifted towards more elevated temperatures, both these processes being also dependent on the initial condition. Complete dissolution of the carbide is not generally desirable.

Austenitizing of tools should take place in salt baths, in a controlled atmosphere or inert gas or in a vacuum furnace (see subclause 6.1).

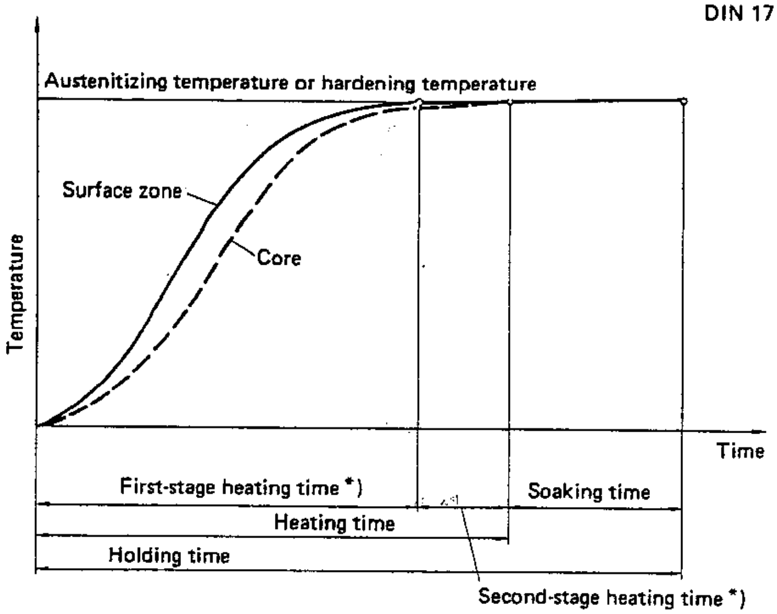

Figure 1. Thermal cycle for austenitizing (schematic)

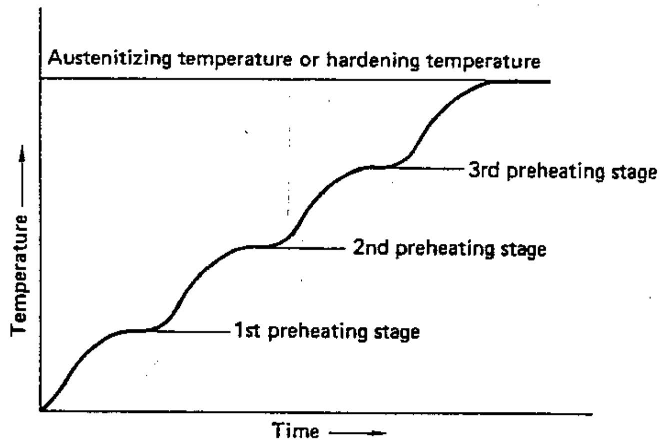

Figure 2. Thermal cycle for austenitizing with preheating in three stages (schematic)

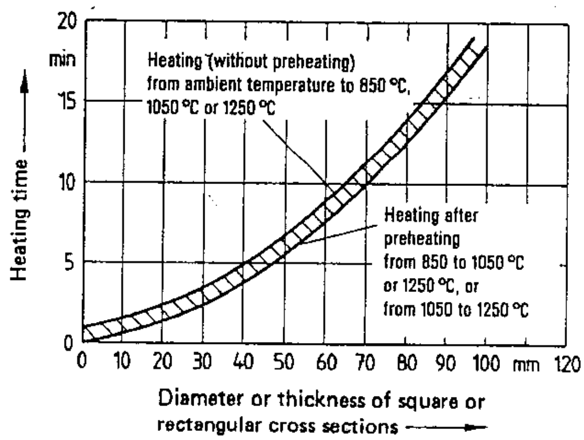

Figure 3. Heating time for heating in salt baths, with and without preheating (guideline values based on tests carried out on specimens made from S 6-5-2 steel)

*) Translator's note. As there is no English equivalent for the German terms *Anwärmdauer* and *Durchwärmdauer*, the terms used in this translation have been derived from the definitions given in EURONORM 82 – 1983 corresponding to the German terms.

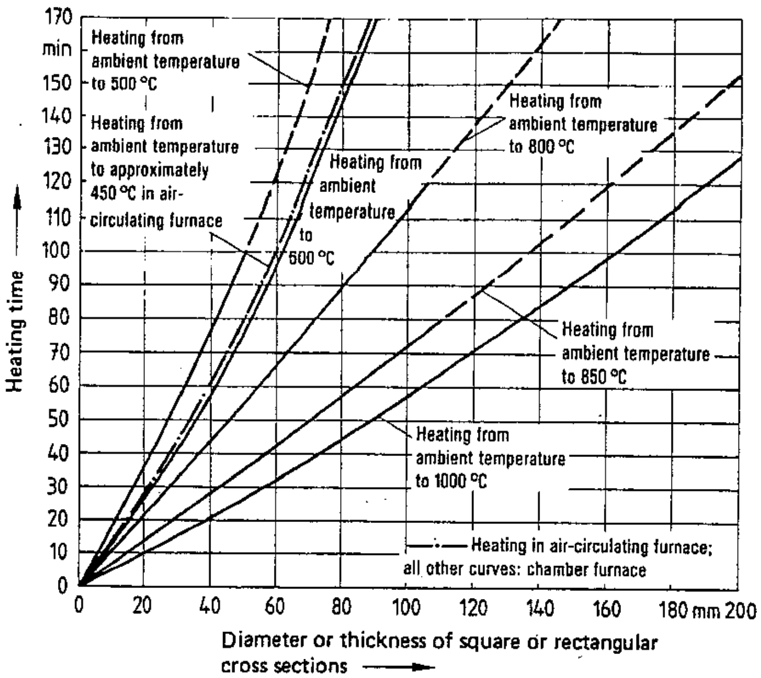

Figure 4. Heating time when using air-circulating furnaces and chamber furnaces (determined on the basis of tests)

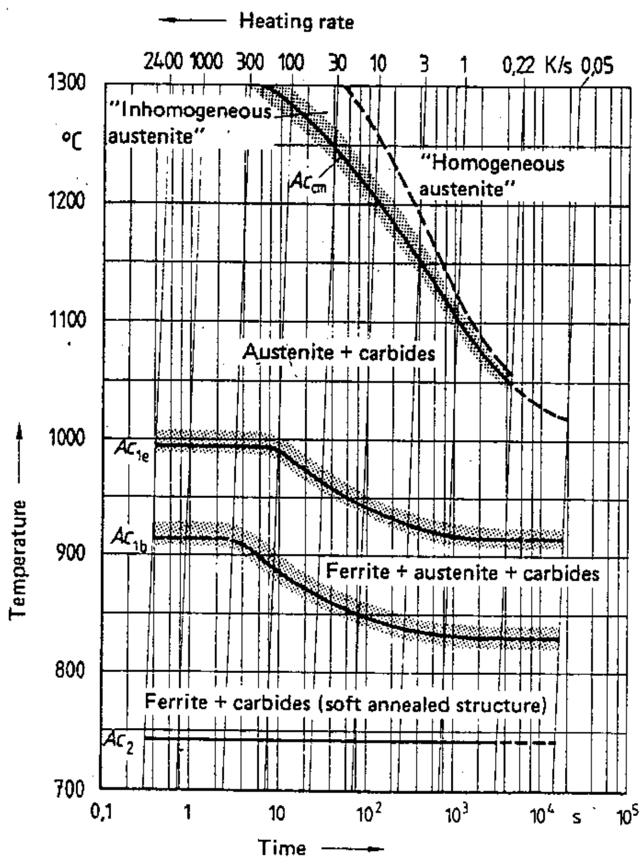

Figure 5. Time-temperature austenitizing diagram for continuous heating of X 38 CrMoV 5 1 steel (material number 1.2343) (from *Atlas zur Wärmebehandlung der Stähle* (Steel heat treatment atlas))

5.2.2 Cooling

During cooling, as with heating, temperature differences occur between the surface zone and the core of tools. With regard to the magnitude and effect of such differences, similar considerations apply as in the case of heating. Therefore, in order to keep the internal stresses as small as possible after cooling, tools that are susceptible to cracking or distortion shall be cooled in stages.

In this case it is necessary, from the aspect of the hardness required, to use materials possessing adequate hardenability. Information on hardenability shall be taken from DIN 17 350 or corresponding documentation provided by the steelmakers.

To ensure that the hardening is not unacceptably impaired at critical points in the surface zone, and to keep distortion and the risk of cracking as small as possible, the batch shall be so stacked and the material to be heat-treated introduced into the cooling medium so that the entire surface zone is covered.

In figure 6, possible cooling curves are shown schematically.

When cooling is effected in stages, the process is interrupted at a temperature that lies between the pearlite and martensite stage and is preferably just above the M_s temperature. This is intended to effect the maximum temperature equalization in the tool possible, thereby preventing the occurrence of stresses, or reducing any stresses present through plastic deformation. Following temperature equalization, the tools undergo further cooling in air, in oil or in salt water. To reduce the risk of cracking, tools should not be cooled to ambient temperature prior to tempering, except for those made of high speed steels (see subclauses 5.4.1 to 5.6.1 and figures 12, 13, 14 and 15).

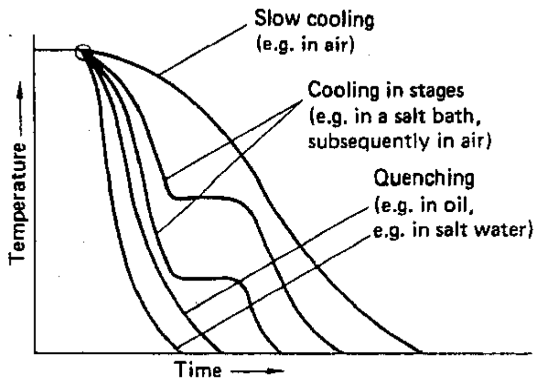

Figure 6. Cooling curves (schematic)

Figure 7 gives guideline values of cooling time for tools having circular, square or rectangular cross section when quenching in a hot bath (550 °C) or cooling in air to ambient temperature.

The transformation processes during cooling from austenitizing temperature are illustrated, taking the X 38 CrMoV 5 1 hot work steel as an example, in figure 8 in the form of a time-temperature-transformation (TTT) diagram for continuous cooling.

The TTT diagrams show for each steel the ranges within which structural changes occur. Their position and the progress of the transformation processes are subject to the influence of the steel composition and the austenitizing conditions. From the TTT diagrams for continuous cooling it is possible, on the basis of the cooling curves, to assess the structure condition likely to be obtained at ambient temperature and the associated hardness.

The aim during hardening is to effect transformation at the martensite stage, this only being possible if the critical cooling rate, K_m, which is characteristic to each steel, can be achieved (see figure 8).

The transformation of austenite does not end until the so-called M_f temperature has been reached, which, for the majority of tool steels, is below ambient temperature. M_f decreases as the amounts of carbon and alloying elements dissolved in the austenite increase.

The proportion of retained austenite is all the higher the larger the amount of carbon and alloying elements dissolved in the austenite; it varies with the cooling rate (see subclause 6.2).

After cooling, the structure consists of martensite and retained austenite, and possibly includes bainite components. Hypereutectoid steels may also contain proeutectoidally separated carbides in addition to the undissolved carbides.

5.2.3 Deep freezing

The retained austenite present at ambient temperature may be reduced by subsequent deep freezing. In this connection, it has to be borne in mind that stabilization of the retained austenite may occur as a result of prolonged holding at ambient temperature or tempering at low temperatures (e.g. 200 °C).*) For guidance on deep freezing media, see subclause 6.2.3.

5.3 Tempering

The principal effects of tempering performed after hardening (and possibly deep freezing) are:

- alteration of hardness;
- alteration of toughness;
- decrease in internal stresses;
- reducing the risk of cracking;
- decrease in the amount of retained austenite (but refer also to subclause 5.2.3);
- alteration of size, and possibly of shape.

*) The deep freezing of tools is carried out in practice mainly for achieving adequate stability of dimensions and of shape, e.g. for gauges, gauge blocks or fine-edge blanking tools.

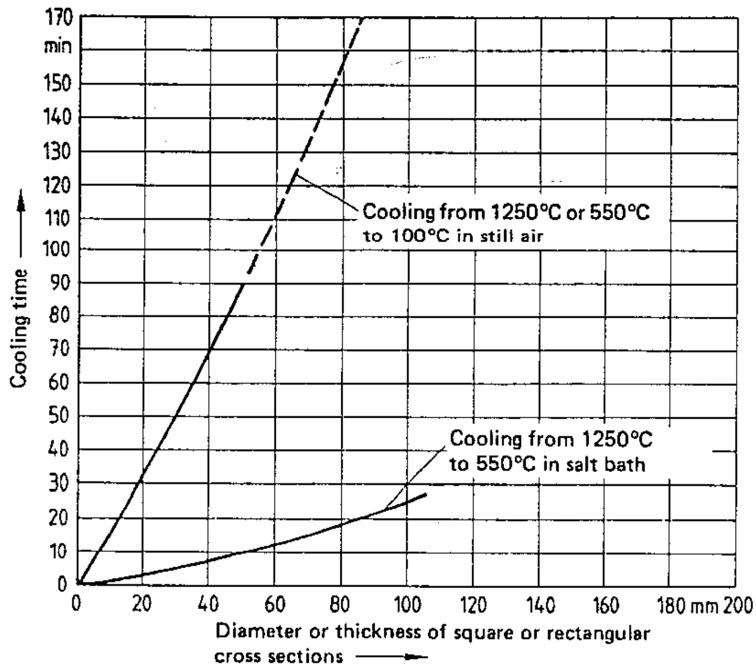

Figure 7. Guideline values of cooling time in the core in still air or in a hot bath (550°C) (determined on the basis of tests)

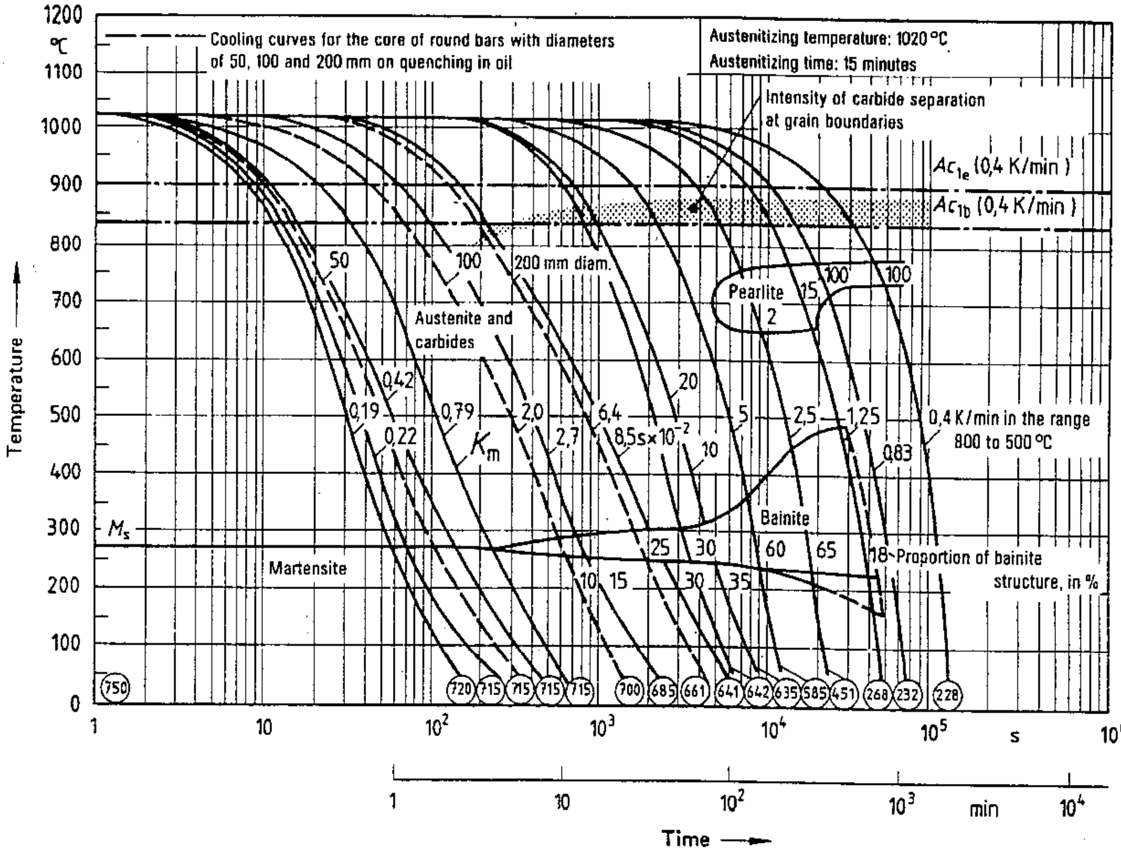

Figure 8. Time-temperature transformation (TTT) diagram for continuous cooling of X 38 CrMoV 5 1 steel (material number 1.2343) (from Supplement 1 to DIN 17 350, October 1980 edition)

The tempering temperature depends on the properties required.

Information on the relationship between hardness and tempering temperature can be found in DIN 17 350 or other relevant documentation.

Tempering is usually performed either between 180 and 250 °C or between 550 and 650 °C; see subclauses 5.4.2, 5.5.3 and 5.6.2.

Where stringent requirements have to be met in respect of toughness, the temperatures between 250 and 550 °C shall be avoided because of temper embrittlement (300 °C or 500 °C embrittlement). The temperatures just stated may vary with tempering time, since the embrittlement effects involve time-dependent diffusion processes.

500 °C embrittlement may occur even after tempering at higher temperatures if cooling is performed too slowly in the critical temperature range. This can be reversed, however, by renewed tempering above 550 °C followed by rapid cooling to ambient temperature ("reversible temper embrittlement").

Martensite, bainite and retained austenite undergo changes due to tempering. Carbides are separated from the martensite and bainite, and dislocations are reduced. This is associated with a reduction in hardness. Following a previous stage of deformation recrystallization may occur at elevated tempering temperatures and/or long tempering times. In the case of highly alloyed steels containing special carbide-forming elements, carbides are formed above 450 °C and on cooling from tempering temperature the retained austenite transforms into martensite and/or bainite. Both processes involve an increase in hardness which is termed secondary hardening.

The processes described above are more or less pronounced, depending on the composition of the steel. Their superposition yields the tempering curve, which is characteristic to each steel grade (see figure 9).

The tempering temperature and tempering time are interrelated. For temperatures above 450 °C, this interrelationship can be described by the following equation:

$$P = T \cdot (a + \lg t)$$

where

P is the tempering parameter;

T is the temperature, in K;

t is the time, in h;

a is a constant for hot work steels; here, a = 20.

By means of a so-called primary tempering curve for the steel concerned a rough estimate may be made of the probable hardness values as a function of temperature, and the length of time for which the temperature is effective (see figure 10). The curves for 40 and 200 hours may also be used for estimating the residual hardness after a prolonged operating period at temperatures above 450 °C.

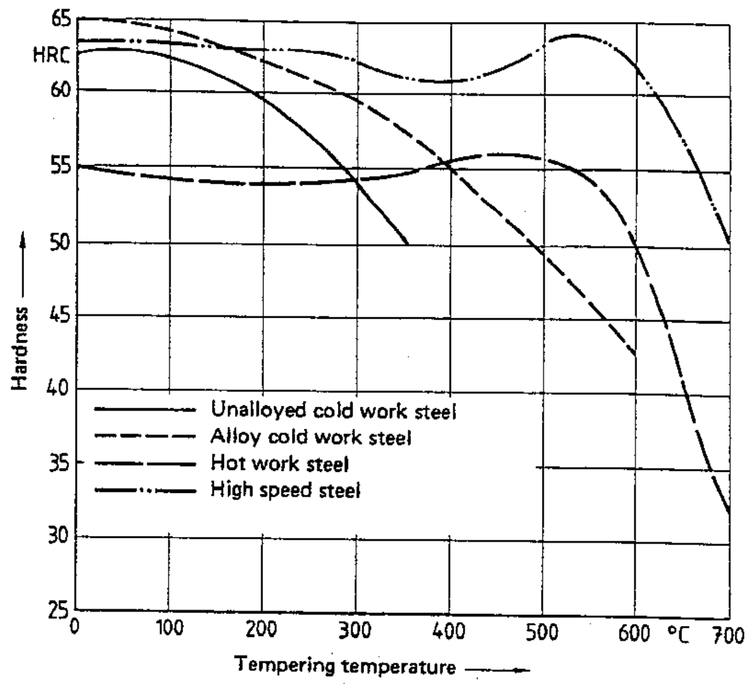

Figure 9. Characteristic tempering curves for tool steels

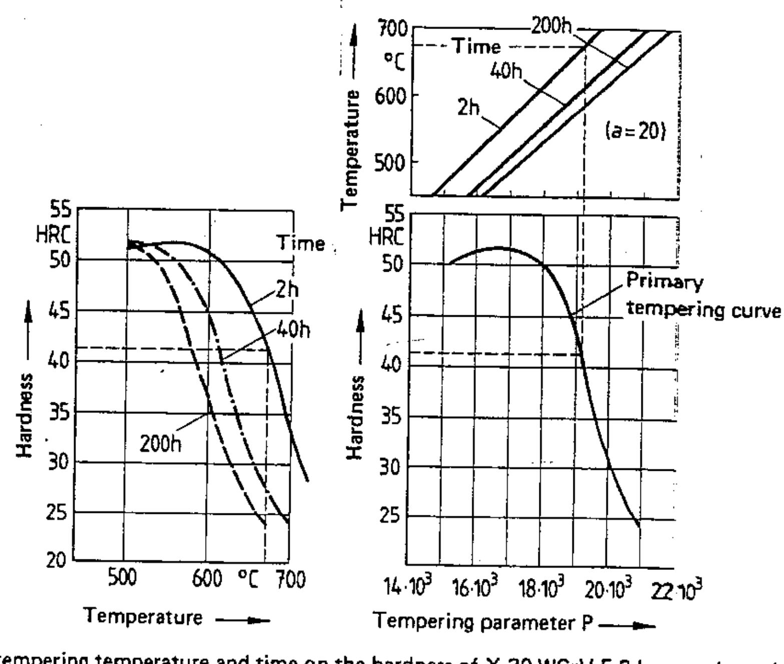

Figure 10. Effect of tempering temperature and time on the hardness of X 30 WCrV 5 3 hot work steel (material number 1.2567) (from *Stahl-Eisen-Werkstoffblatt* (Iron and steel materials sheet) 250-70)

The hardness obtainable after tempering is a function of the austenitizing conditions, which are illustrated in figure 11 showing the tempering curves for high speed steels subjected to differing austenitizing conditions. The more carbides were in solution prior to quenching, the more pronounced is the secondary hardening.

Tempering may be performed in oil, salt baths, gas [1]) or vacuum. The proper choice of the tempering medium can reduce or even preclude impairment of the surface of the tool, such as may result from oxidation or undesirable nitriding (see clause 6).

[1]) In this case, circulation of the heating medium is recommended.

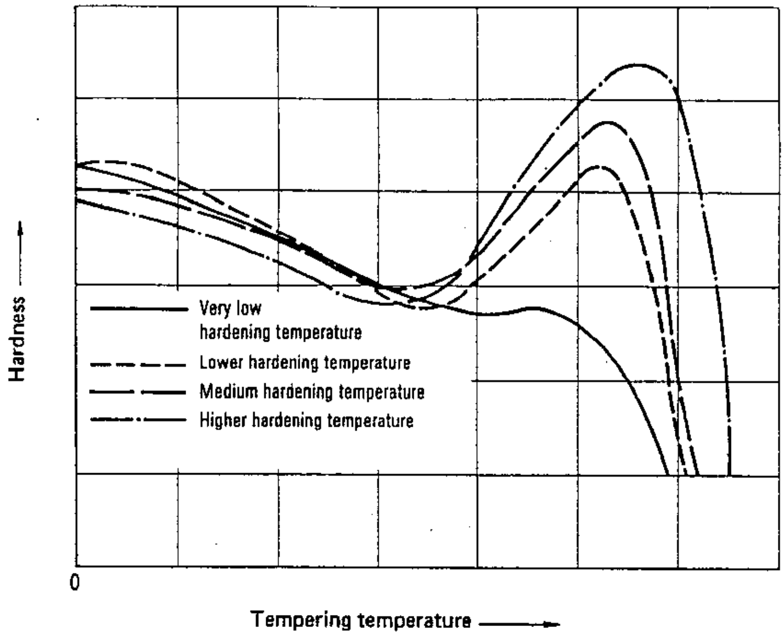

Figure 11. Effect of differences in hardening temperatures on the shape of the tempering curve for high speed steels (schematic)

5.4 Hardening and tempering of unalloyed steel tools

Figure 12 shows a diagram of the thermal cycle for hardening and tempering of unalloyed steel tools.

5.4.1 Hardening

When tools have large dimensions, or big differences in cross section are involved, heating should be as slowly as possible, or proceed in stages, to minimize the temperature differences and hence the stresses. Figure 3 gives guideline values of heating time when using salt baths, and figure 4 when using chamber furnaces.

The soaking time at austenitizing temperature should be 10 to 20 minutes in order to dissolve a sufficient amount of carbides to ensure hardening. Depending on the hardenability of the material and on the tool size and shape, quenching shall be carried out either in water (10 to 70°C) or in oil (40 to 120°C). It may be advisable for the tools to be moved about in the quenchant and/or to circulate the quenchant to achieve an adequate and uniform quenching effect. When water is used, suitable additives, such as common salt in a concentration of 8 to 12%, may be employed to reduce the formation of steam bubbles on the tool surface and thereby to improve the quenching effect in the elevated temperature range (see table 2 for soft spottiness). To reduce the risk of cracking, tools susceptible to this should be cooled only to about 80 to 100°C, then soaked at 100 to 150°C until temperature equalization in the tool has been reached, and then immediately tempered (see figure 12).

5.4.2 Tempering

The tempering temperature is primarily governed by the hardness required. The soaking time should be not less than one hour.

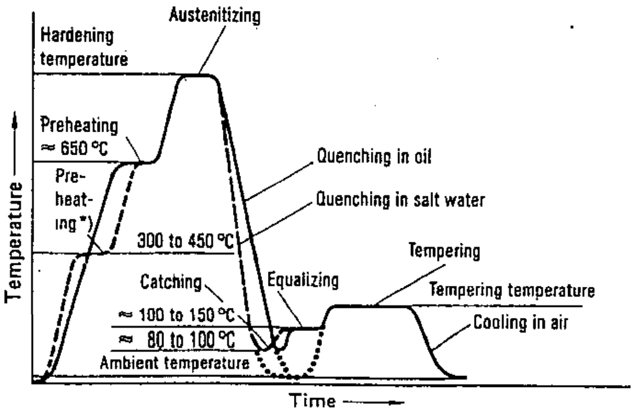

Figure 12. Thermal cycle for hardening and tempering unalloyed steel tools (schematic)

*) Preference should be given to this preheating stage when preheating is carried out in salt baths at about 650°C.

5.5 Hardening and tempering of tools made from cold work and hot work alloy steels

Figures 13 and 14 show diagrams of thermal cycles associated with the hardening and tempering of tools made from cold work and hot work alloy steels at hardening temperatures below and above 900 °C respectively.

5.5.1 Hardening

The recommended practice is heating in stages with soaking at each stage until complete temperature equalization in the tool is reached.

When heating to austenitizing temperature in salt baths it is normal to use a separate crucible furnace for each preheating stage. If other furnaces are used, the tools may be placed in the cold furnace, or in one that has been heated to the next highest preheating temperature or to austenitizing temperature, and then raised to hardening temperature. Where tools of complex shape are involved it may be expedient to carry out additional soaking at a temperature just below the hardening temperature.

Guideline values of heating time in salt baths or in chamber furnaces are given in figures 3 and 4.

After second-stage heating to austenitizing temperature, soaking for a further 15 to 30 minutes shall be carried out in order to dissolve a sufficient amount of carbides to ensure hardening.

If ledeburitic steel tools are required to exhibit greater retention of hardness, e.g. in conjunction with subsequent nitriding or nitrocarburizing, higher austenitizing temperatures than normal shall be used; see DIN 17 350, October 1980 edition, table 3.

Depending on the hardenability of the material and on the dimensions and shape of the tool, quenching shall be carried out either in oil (40 to 120 °C) or in a hot bath (180 to 220 °C or 500 to 600 °C); in the case of steels with adequate hardenability, it may also be sufficient to cool in air or in a gas flow; see subclause 6.2.2. Tools which, by reason of their shape and size, are susceptible to cracking should be cooled only to about 80 to 100 °C, then soaked at 100 to 150 °C until temperature equilibrium in the tool has been reached, and then immediately tempered.

See figure 7 for guideline values of cooling time when quenching in a hot bath for cores differing in size.

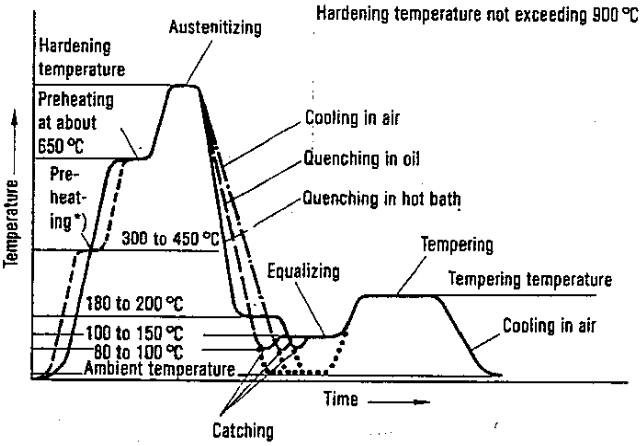

Figure 13. Thermal cycle for hardening and tempering tools made from cold work alloy steels (schematic)

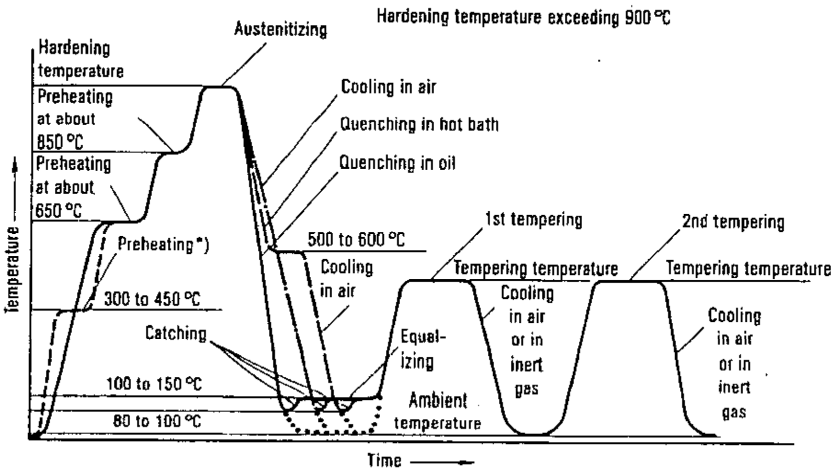

Figure 14. Thermal cycle for hardening and tempering tools made from cold work and hot work alloy steels (schematic)

*) See page 8.

5.5.2 Deep freezing

The temperature to be used for deep freezing is governed by the intended effect. In most cases, a temperature of not less than −75 °C is required; see subclause 5.2.3.

After deep freezing, the tools shall be tempered.

5.5.3 Tempering

The tempering temperature is governed by the hardness and toughness required. The soaking time should be not less than one hour. In the case of tools made from hot work steels, a second tempering is recommendable, and is in fact required for tools made from secondary-hardening steels in order to ensure that the required service properties are definitely obtained.

If the required hardness has already been imparted after the first tempering, the second tempering temperature should be 30 to 50 K below the first tempering temperature. If the hardness is above the required values after the first tempering, the next tempering should be performed at a temperature not less than that of the first tempering or just above it. The relationships between tempering temperature and time have been described in subclause 5.3.

5.6 Hardening and tempering of high speed steel tools

Figure 15 shows a diagram of the thermal cycle for hardening and tempering high speed steel tools.

5.6.1 Hardening

For austenitizing, the tools are to be preheated. Because of the high hardening temperatures it is particularly important to heat in stages. For austenitizing in salt baths, a first stage of 300 to 450 °C is recommended, otherwise the temperature of the first stage should be at about 650 °C, of the second stage at about 850 °C and that of the third stage at about 1050 °C; see figure 15. Figures 3 and 4 give guideline values of heating time.

For austenitizing it is then normally sufficient to soak for 80 s. Only if more or less complete carbide dissolution is required will it be necessary to soak for up to 150 s. As the specified time for soaking is so short, particular attention must be paid not to exceed it, as otherwise irreparable damage to the material may result; see table 2.

In practice it is usually impossible to determine the heating time and soaking time separately. The holding time (= heating time + soaking time), when austenitizing in salt baths, has been specified in figure 16 as a function of the cross-sectional dimensions for preheating at 850 °C, and in figure 17 for preheating at 850 and 1050 °C.

In the case of preheating in salt baths to 850 and 1050°C, it is recommended that the holding time be the same or longer than that specified for austenitizing in figures 16 and 17.

After austenitizing in salt baths, quenching should be carried out in a hot bath (500 to 600 °C) followed, after temperature equalization in the tool, by further cooling in air down to ambient temperature. When austenitizing in gas or in a vacuum furnace, an inert gas shall be used for cooling. See subclause 6.2 for information on cooling media.

Tempering of the tools shall follow directly after cooling to ambient temperature; see subclause 5.6.2.

5.6.2 Tempering

The tempering temperature is governed by the required service properties of the tool and shall normally be between 540 and 590 °C, depending on the steel grade and the hardness required. The soaking time should be not less than one hour.

Depending on the cooling equipment available, cooling of the tempered tools shall be carried out either in air or in an atmosphere prevailing in the furnace, used for tempering.

High speed steel tools shall be tempered at least twice, but if cobalt is one of the alloying constituents, tempering shall be carried out at least three times. Tempering three or four times is particularly advantageous if high stability of crystalline structure and an optimum combination of service properties are required.

Tempering shall be carried out using salt baths, gas or a vacuum furnace.

6 Heat treatment media

6.1 Heating media

Heating may be carried out in liquid, solid [2] or gaseous media or in a vacuum furnace, the medium selected depending on the required heating rate and possible reactions between the surface zone of the tool and the heating medium (e.g. decarburizing, oxidizing, scaling).

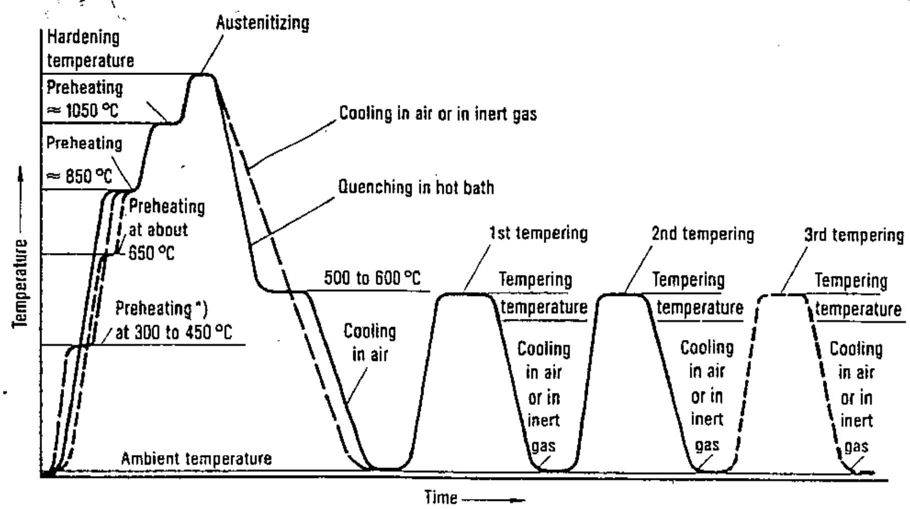

Figure 15. Thermal cycle for hardening and tempering high speed steel tools (schematic)

*) See page 8. 2) Solid media are now obsolescent.

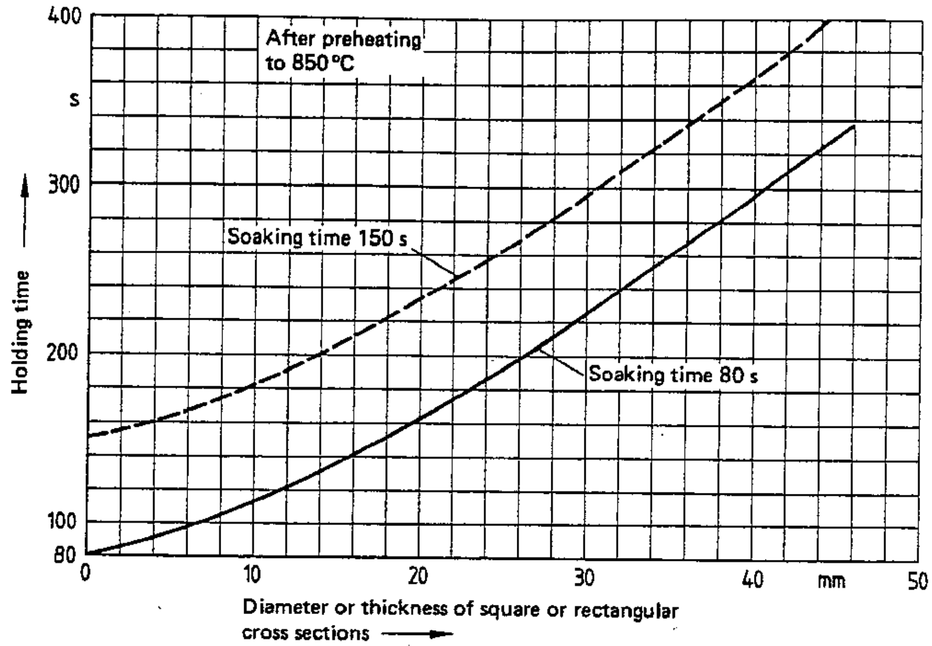

Figure 16. Holding time in salt baths for austenitizing high speed steel tools at austenitizing temperatures as specified in DIN 17 350 after single-stage preheating at 850 °C

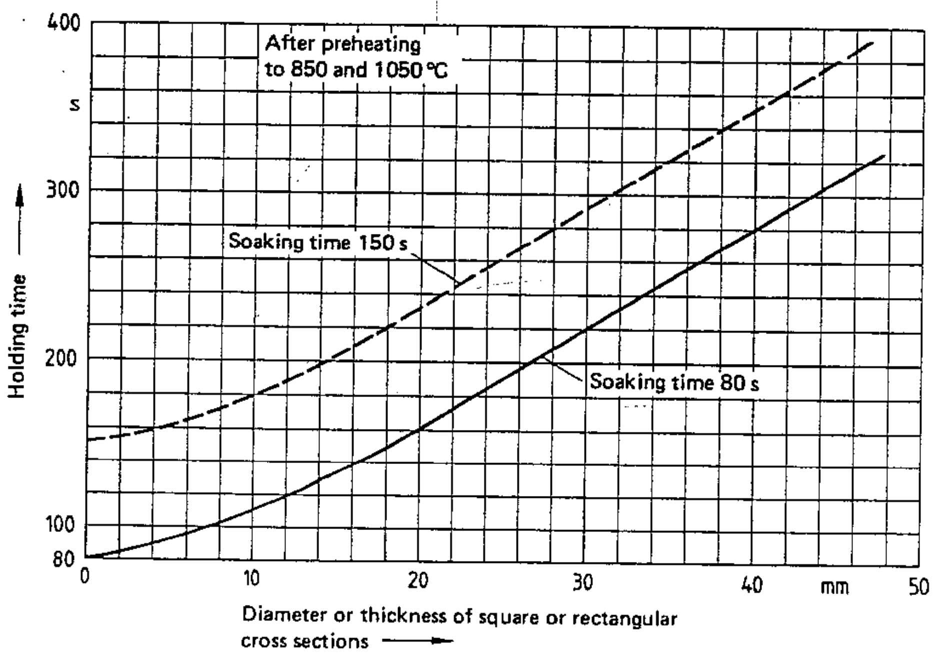

Figure 17. Holding time in salt baths for austenitizing high speed steel tools at austenitizing temperatures as specified in DIN 17 350 after two-stage preheating at 850 and 1050 °C

6.1.1 Liquid heating media

Hot water may be used as the heating medium for temperatures up to about 100 °C, oil may be used for temperatures up to about 250 °C, and salt baths for temperatures between 160 and about 1300 °C.

Changes in the composition of the material in the surface zone (due to carburization or partial carburization, oxidation, or nitriding) likely to impair the service properties of the tool can be reduced or even precluded by choosing salt baths that are more suitable, less active and compatible with one another. When heating in stages, in which the tools are immersed successively in salt baths differing in composition, special care shall be taken to ensure that the salt baths used are compatible. Otherwise, the efficacy of the process would be adversely affected.

The effect of liquid heating media is also obtainable when using 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 surface zone of the tool, and on the working temperature needed. Both air and controlled atmospheres are to be considered suitable gaseous heating media, controlled atmospheres being understood to include nitrogen, cracked gases and gases produced endothermally or exothermally.

Nitrogen is easy to handle, but its protective action is limited, particularly if the gas is of low purity and when high temperatures are involved. In the case of other gases, consideration must be given of the flashpoint because of the proportion of combustible constituents they contain, particularly at temperatures below 750 °C.

6.1.3 Vacuum

By definition, vacuum is not a heating medium. Industrial-type vacuum furnaces are operated at a pressure at which the gas traces still present are so negligible that no impairment of the surface zone of the tool need be feared. The pressure in the furnace space has, however, to be adjusted to the vapour pressure of the individual alloying elements in the steel so as to prevent evaporation of these elements.

6.2 Cooling/quenching media

Cooling/quenching shall be carried out using gaseous or liquid media. The principal criteria governing selection of the medium are the tool shape and size, the hardenability of the materials, the hardening temperature, the required cooling effect and the heat treatment equipment used.

6.2.1 Liquid cooling media

Liquid cooling media shall be used when extremely high cooling rates are required.

The media to be used include water with or without additives, oils and salt baths. Water without additives shall be used at temperatures up to not more than 25 °C, and water with additives at temperatures up to 70 °C. Oils shall generally be used at temperatures up to 70 °C and in special cases, up to 150 °C. Salt baths shall be used at a temperature of 160 °C and more, and fluidized beds at temperatures from 20 to over 600 °C.

When selecting a quenchant, consideration has to be given to its compatibility with the heating media used.

At high hardening temperatures the quenchant may cause changes in the surface zone of the tool. An unacceptably high rise in the quenchant temperature due to the tools being quenched may affect its action adversely. The same applies to the presence of scale and salt residues on the tool surface.

6.2.2 Gaseous cooling media

The gaseous cooling media to be used include still or moving, dry or moistened air, nitrogen and other gases. Their cooling effect is very much smaller than that of liquid media, but it can usually be increased by raising the pressure or the flow velocity. Therefore, when taking a decision for cooling in gas, particular attention is to be paid to the hardenability of the tool materials involved and to the tool shape and size.

Because the cooling action is greatly dependent on the flow velocity and the temperature of the cooling medium, the tools to be cooled should be so immersed in the medium that it can reach the entire surface zone including all critical points.

In cases of controlled-atmosphere installations and in fluidized beds cooling may be effected using nitrogen or the gases given in subclause 6.1.2. In vacuum installations, cooling is generally to be effected using nitrogen, where necessary, under increased pressure.

6.2.3 Deep freezing media

Cooling down to about − 60 °C may be carried out in cooled air (using a conventional freezer). Special design freezers allow temperatures as low as − 140 °C to be reached. Temperatures below − 60 °C can also be reached by using dry ice, alcohol mixtures or liquefied gases (liquid nitrogen: − 196 °C).

7 Notes on heat treatment equipment

The following notes are intended to facilitate the specification of heat treatment procedures, but they make no claim to be exhaustive; the information provided by the manufacturer shall be observed for the particular equipment.

7.1 Heat treatment furnaces

Selection of the heat treatment furnace shall be based, among other things, on the following criteria:

- heat treatment temperature, temperature distribution in the furnace space, permissible deviations in temperature;
- type of heating medium;
- type of cooling medium;
- shape, dimensions and quantity of tools to be treated;
- process scheme and process control.

Table 1 gives further guidance on furnace selection.

Table 1. Guide to furnace selection

Heat treatment	Treatment temperature °C	Permissible deviations in temperature K 6)	Parameters to be controlled	Usual heating media (see subclause 6.1)	Furnace type	Notes
Stress relieving	600 to 650	± 25	Time, temperature	Air, controlled atmosphere	Shaft, pot, bell-type, chamber f., bell-type lifting f.	Preference shall be given to forced-ventilation furnaces.
Preheating	Up to 500	No requirements.	No requirements.	Air, controlled atmosphere	Shaft, pot, bell-type, bell-type lifting f., chamber f.	
	500 to 900	± 25	C level, where required.	Controlled atmosphere, salt bath 1)	Chamber f., salt bath crucible f. 2)	
				Controlled atmosphere	Chamber f.	
	900 to 1050			Salt bath 1)	Electrode salt bath f. 3)	
Austenitizing	Up to 1050	± 10	Time, temperature, C level where required, furnace pressure.	Salt bath	Salt bath crucible f. 2)	Up to 950 °C
					Electrode salt bath f. 3)	
				Controlled atmosphere, air	Chamber f. 4), shaft f.	These furnaces are normally also used for preheating.
				–	Vacuum f. 5)	
	Over 1050	± 5		Salt bath	Electrode salt bath f. 3)	
				Controlled atmosphere	Chamber f. 4); over 1100 °C, special designs	These furnaces are normally also used for preheating.
				–	Vacuum f. 5)	
Tempering	Up to 700	± 10		Salt bath	Salt bath crucible f. 2)	
				Oil	Crucible f.	Up to 300 °C
				Air, controlled atmosphere	Shaft, bell-type, chamber f.	With forced ventilation.
				– (Nitrogen)	Vacuum f. 5)	

1) The salt bath shall be selected so as to be compatible with the salt baths used for austenitizing.

2) Salt bath crucible furnaces heated externally by fuel or electricity or provided with electrode heating.

3) The maximum tool diameter for electrode salt bath furnaces with circular or polygonal heating space shall be not more than two-thirds of the inside diameter or width of the crucible; if the heating space is oval or rectangular with the electrodes arranged on one side, the minimum distance of the tool from electrodes shall be 100 mm.

4) The chamber furnace installation may incorporate a quench tank with oil or a cooling chamber for cooling by gas. For quenching in water with or without additives, salt baths or fluidized beds the cooling device is located outside the chamber furnace.

5) Cooling in the furnace under nitrogen or in oil. Outside the furnace, quenching in oil, water with or without additives, in salt baths or in fluidized bed.

6) For austenitizing and tempering tools made from certain steel grades, it may be desirable to limit the deviations in temperature to 5 to 7 K.

7.2 Cooling/quenching equipment

For cooling and quenching, the following equipment is generally to be used.

When using water with or without additives: tanks incorporating a cooler; extra facilities that may be provided include a system for circulating the medium and means for spraying the medium on the tool surface.

When using oil and salt baths: tanks incorporating heating and cooling facilities, generally also equipped with a temperature control device. They are also often provided with a forced ventilation system. The tanks should be able to hold a quantity of quenchant corresponding to at least six times the mass of the tools to be cooled or the tool batches concerned.

When using gaseous media: tanks or chambers equipped with a blower and, where required, with nozzles and gas-directing facilities to ensure adequate velocity of flow across the tool surface. The device may also have a system allowing the gas to be cooled and returned.

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

7.3 Deep freezing equipment

Deep freezing for transforming retained austenite below ambient temperature is generally to be carried out in freezers operating at temperatures as low as −140 °C, or dip tanks operating at temperatures as low as −196 °C.

8 Defects caused by errors in the heat treatment of tools

Defects or flaws affecting heat-treated tools can rarely be attributed exclusively to a single cause.

Apart from the heat treatment itself, the cause may also lie in the material, the tool shape, the subsequent machining or the service conditions of the tool.

The defects most commonly encountered in practice are listed in table 2, it being assumed that the tools were delivered for heat treatment in satisfactory condition and without any deficiencies in terms of material and machining. Table 2 lists the defects assigning them to the causes and the most significant errors in heat treatment.

The table is based on practical experience and makes no claim to be exhaustive.

9 Design criteria for proper heat treatment

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

mass distribution should be as homogeneous as possible, e.g. by providing additional holes or openings; see figures 18 and 20 to 22;

unduly abrupt changes in cross section should be precluded by adequate radiusing or chamfering. This enables a reduction of the notch effect that may lead to stress peaks; see figures 18 and 21. It may be expedient to give the tool its final shape only after hardening, as shown in figure 19;

a symmetrical shape should be aimed at; see figure 22;

facilities for making attachments to the tools, e.g. suspension holes, tapped holes for fitting suspension eyes and the like should be provided so that the tools can be handled properly during heat treatment.

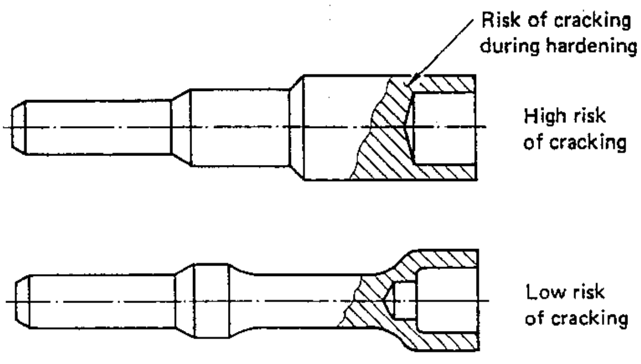

Figure 18. Example illustrating a more homogeneous mass distribution and less abrupt changes in cross section

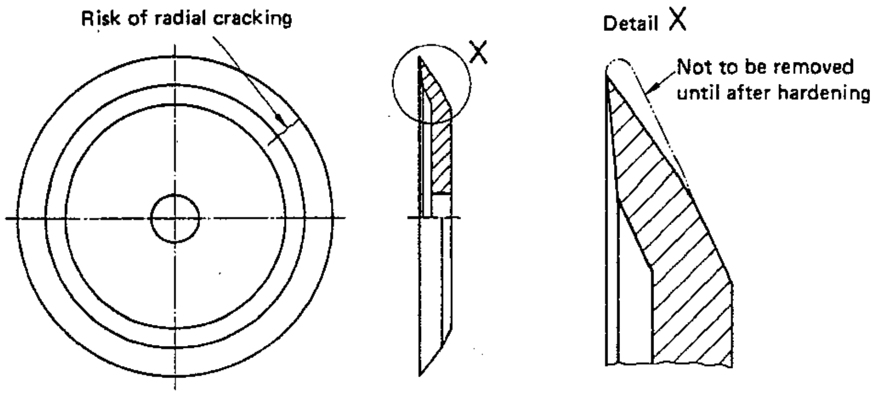

Figure 19. Example of giving the tool its final shape after hardening

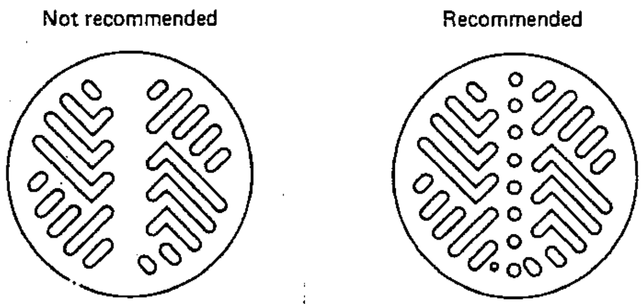

Figure 20. Example of how to make the mass distribution more homogeneous

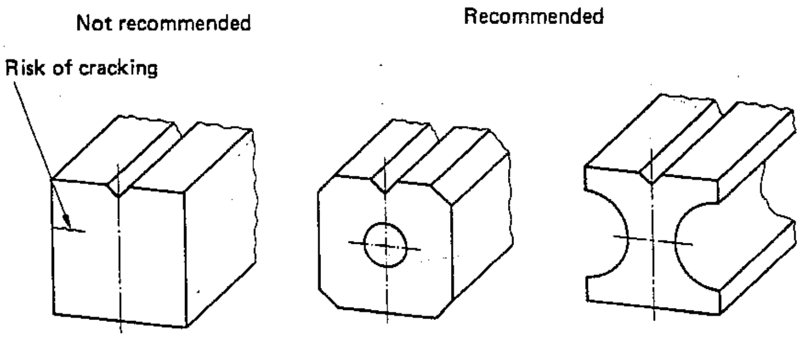

Figure 21. Design examples

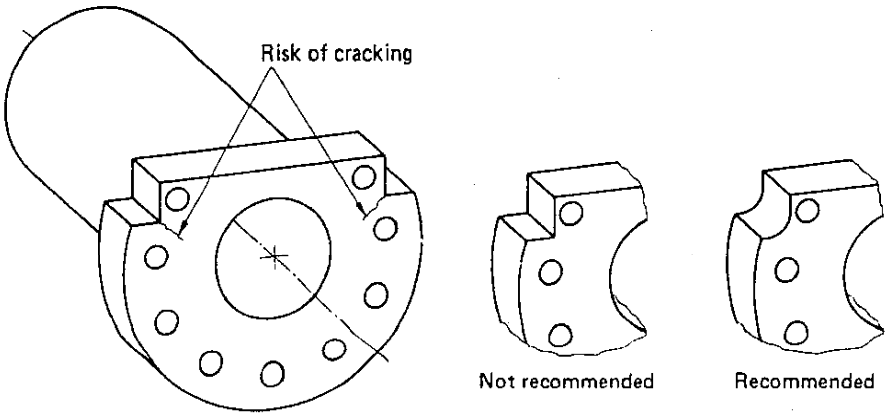

Figure 22. Example illustrating how a cross section can be made less abrupt

Table 2. **Summary of defects affecting heat-treated tools, their cause when due to heat treatment, and errors in heat treatment responsible for them**

Type of defect	Cause due to heat treatment	Error in heat treatment	Refer to subclause
1 Hardness too low	1.1 Non-transformed ferrite or insufficient carbides dissolved	Austenitizing temperature too low Austenitizing time too short	5.2.1, 5.4.1, 5.5.1 5.2.1, 5.5.1, 5.6.1
	1.2 Martensite proportion in whole cross section too small:		3.1.2, 5.2.3
	1.2.1 due to formation of bainite and/or pearlite and/or ferrite	Austenitizing temperature too low Austenitizing time too short Quench effect too small (quenchant: quantity too small, cooling capacity too small; temperature unsuitable, lack of circulation or circulation too low; scale, vapour film, salt residues)	5.2.1 5.2.1 5.3, 5.4.1, 5.5.1 5.3, 6.2.1 7.2
	1.2.2 due to retained austenite	Austenitizing temperature too high (overheating) Austenitizing time too long (oversoaking) Too rapid cooling Deep freezing not carried out, not properly timed or inadequate Lack of tempering, not properly timed or inadequate [1] Soaked too long at hot bath temperature	5.2.1 5.2.1 5.2.2 5.2.3, 5.4.2 5.3, 5.4.2, 5.5.3, 5.6.2
	1.3 Martensite proportion in surface zone too small:		
	1.3.1 due to formation of bainite and/or pearlite and/or ferrite	Quenching not effective enough (cf. 1.2.1) Surface zone oxidation Depletion of alloying elements (vacuum hardening) Decarburization	7.2 6.1 6.1
	1.3.2 due to retained austenite	Nitrogen pick-up Carburization	6.1
	1.4 Martensite too soft (may also be localized)	Tempering temperature too high Tempering time too long	5.3, 5.4.2, 5.5.3 5.6.2
	1.5 Retained austenite proportion too high and/or insufficient carbides [1] precipitated	Tempering not carried out or not properly timed Tempering temperature too low Tempering time too short	5.3, 5.4.2, 5.5.3 5.6.2
2 Hardness too high	2.1 Martensite too hard over the whole cross section	Not tempered Tempering temperature too low [2] Not tempered often enough [2]	5.3 5.3, 5.6.2 3.2, 5.3, 5.5.3, 5.6.2
	2.2 Martensite in surface zone too hard	Carburization and/or nitrogen pick-up	6.1

For [1] and [2], see page 17.

Table 2. (continued)

Type of defect	Cause due to heat treatment	Error in heat treatment	Refer to subclause
3 Changes in dimensions and shape too large	Thermal stresses and/or transformation stresses too large or nonuniformly distributed	Heating carried out too quickly or nonuniformly	5.2.1, 5.5.1, 5.6.1
		Unsuitable position in furnace	5.4.1
		Nonuniformly austenitized	
		Decarburization [3]	6.1
		Carburization and/or nitrogen pick-up	6.1
		Cooling carried out too quickly and/or nonuniformly	5.2.2
		Not cooled in steps	3.1.2, 5.2.2
4 Cracks	Thermal stresses and/or transformation stresses too high (ultimate strength exceeded locally)	Heating carrier out too quickly and/or nonuniformly	5.2.1, 5.4.1, 5.5.1, 5.6.1
		Nonuniformly austenitized	
		Austenitizing temperature too high	5.2.1
		Austenitizing time too long	
		Surface zone decarburized	6.1
		Surface zone carburized and/or nitrogenized	6.1
		Cooling carried out too quickly and/or nonuniformly	5.2.2, 3.1.2
		Not cooled long enough	
		Not tempered	5.3
		Tempering temperature too low	5.3
		Tempering time too short	5.3, 5.3.2, 5.5.3, 5.6.2
		Not tempered often enough or too late	
		Cooled too abruptly after tempering	5.3, 5.5.3, 5.6.2
5 Pitting or superficial attack	Corrosion	Not cleaned prior to heat treatment	5.1.3
		Heated in contaminated salt baths	
		Salt residues not removed or removed too late	
		Heated with salt residues in air or in controlled atmosphere	
		Cleaned with aggressive media or media forming residues (flash rust)	
6 Deformation of corners and edges and/or deformation of surfaces	Fusion	When heating in electrode salt bath furnaces:	
		lack of protection, or inadequate protection, against stray currents	7.3
		distance from electrodes too small	
		surface zone carburized	6.1

1) Applies only for steels subjected to secondary hardening.

2) However, tempering behaviour shall be observed in the case of secondary-hardening steels.

3) Applies particularly for thin-walled components.

10 Notes on straightening

The purpose of straightening is to correct changes in dimensions and shape resulting from heat treatment. The methods used include making compression zones (e.g. by striking with a straightening hammer), applying set to the distorted tool either when cold, or during the process of cooling, under a straightening press, in a straightening machine or on a straightening bench or by localized heating, or cooling from hardening temperature in devices which counteract the development of changes in dimensions and shape (e.g. chills).

Whether tools are straightened before or after tempering depends on the type and extent of distortion, the tool shape and size, the material composition, the condition of the material and practical experience acquired in straightening.

11 Inspection of heat-treated tools

Guidance on the inspection of heat-treated tools is given in table 3. This is intended to facilitate decision as to which inspection methods are to be applied for assessing the heat treatment performed.

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

Table 3. **Notes on the inspection of heat-treated tools**

Inspection criteria		Test method	
Hardness		See DIN 50 103 Parts 1 to 3, DIN 50 133 and DIN 50 351 (see DIN 50 150 for conversion of hardness values)	
Corrosion, incipient fusion		Visual examination in the cleaned condition without further pretreatment of the tools	
Soft spottiness		Hardness measurement; visual examination/macroscopic assessment of the etched (preferably in the ground *) condition) or blasted surface	
Cracks		Visual examination after appropriate cleaning; metallographic examination (macro- or microscopic); dye penetration test; ultrasonic test; eddy current test; magnetic crack test	
Structure:	structural components according to type, formation, quantity and arrangement (martensite, bainite, pearlite, ferrite, retained austenite, carbides)	Metallographic examination	
	grain size and shape		See DIN 50 601 for the determination of the austenite and ferrite grain size.
	decarburization, carburization, surface zone oxidation		See DIN 50 192 for the determination of the depth of decarburization.

*) Grinding shall be performed so that the soft spotty surface zone is not removed.

Standards and other documents referred to

DIN 6773 Part 2	Heat treatment of ferrous materials; heat-treated components; representation and indications in drawings; hardening, hardening and tempering, quenching and tempering
DIN 17 014 Part 1	Heat treatment of ferrous materials; concepts
DIN 17 014 Part 3	Heat treatment of ferrous materials; brief description of heat treatments
DIN 17 023	Heat treatment of ferrous materials; specimen forms; heat treatment instruction
DIN 17 350	Tool steels; technical delivery conditions
Supplement 1 to DIN 17 350	Tool steels; technical delivery conditions; additional information on heat treatment
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 50 103 Part 3	Testing of metallic materials; Rockwell hardness test; modified Rockwell scales Bm, Fm and 30 Tm for thin sheet steel
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 table for Vickers hardness, Brinell hardness, Rockwell hardness and tensile strength
DIN 50 192	Determining the depth of decarburization
DIN 50 351	Testing of metallic materials; Brinell hardness test
DIN 50 601	Metallographic examination; determination of the ferritic or austenitic grain size of steel and ferrous materials

Stahl-Eisen-Werkstoffblatt 250-70 *Legierte Warmarbeitsstähle* **) (Hot work alloy steels)

Atlas zur Wärmebehandlung der Stähle **)

Explanatory notes

This standard has been prepared jointly by the *Normenausschuß Wärmebehandlungstechnik metallischer Werkstoffe (NWT)* (Heat Treatment of Metallic Materials Standards Committee) and Committee 2 of the *Arbeitsgemeinschaft Wärmebehandlung und Werkstofftechnik (AWT)*. In both committees, heat treatment experts from a variety of production plants, contract heat treatment 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 providing all necessary information on performance of heat treatment and which may be used as a guideline.

This standard is part of a planned series of standards dealing with the different stages and methods of heat treatment of ferrous materials, such as

- hardening, hardening and tempering, quenching and tempering of components;
- case hardening;
- surface hardening;
- nitriding;
- annealing.

These standards are intended to fill the gap between DIN 17 014 Part 1 in which the terminology is established, and the quality standards for ferrous materials dealing with the properties attainable by means of heat treatment carried out by the manufacturer.

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

The present standard and the other standards planned for 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 to ensuring the quality and consistency of their products. In addition, such standards are highly suitable for training purposes at all levels.

Neither in this standard nor in the other standards will details be found of characteristic values obtainable by applying a specific type of heat treatment, as this information can be derived from the relevant documentation or standards, such as steel quality standards.

International Patent Classification

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