UDC 621.785 : 669.14 : 539.54 February 1976

Heat Treatment of Ferrous Metals

Material Selection

Steel Selection according to Hardenability

DIN 17 021 Part 1

Wärmebehandlung von Eisenwerkstoffen; Werkstoffauswahl; Stahlauswahl aufgrund der Härtbarkeit

Contents

1 Scope

This Standard provides guidance on the selection of steel grades for workpieces to be hardened or quenched and tempered. The information given applies mainly to steels for which, according to the Standards, testing of hardenability by the end quench test (see DIN 50 191) is provided, namely for the alloy quenched and tempered steels according to DIN 17 200, the alloy case hardening steels according to DIN 17 210, the alloy steels for flame and induction hardening (surface hardening) according to DIN 17 212 and for other steels, as necessary, for which the hardenability response is substantiated with sufficient accuracy by the end quench test. These are primarily the alloy steels according to the comparable Euronorms and ISO Standards which can be looked up, for example, in the German Standards indicated above. This Standard applies also to nitriding steels according to DIN 17 211.

This Standard does not apply for the purposes of steel selection on the basis of the prospective hardness penetration depth or case depth after surface layer hardening or case hardening or to steels with only very low hardness gain, i.e. primarily carbon steels, or for the selection of steels for transformation in the bainite range.

Expressly excluded are also tools for which the selection of steel grade is dominated by criteria other than hardenability.

Apart from the approach whereby steel selection is made on the basis of hardenability, it may be necessary to take account of a number of other properties, such as machinability, reformability, joinability, fatigue limit, carburizing behaviour, mechanical strength, tempering behaviour. Another decisive factor may be the cost of procuring and storing.

2 Concepts

The concepts in this section correspond with those in DIN 17 014 Part 1, March 1975 edition.

2.1 Hardening: Austenitizing and cooling at such a rate as to bring about a considerable increase in hardness in more or less extensive regions of the cross-section of the workpiece through martensite formation.

2.2 Tempering: Heating a hardened workpiece to a temperature between ambient temperature and Ac_1 and holding at this temperature, followed by appropriate cooling.

Continued on pages 2 to 10
Explanations on page 11

2.3 Quenching and tempering: Hardening and subsequent tempering in the upper feasible temperature range in order to achieve satisfactory toughness with a given tensile strength.

2.4 Hardenability

Concept comprising potential hardness increase and hardness penetrability, a common method of testing hardenability is the end quench hardenability test (see DIN 50 191).

2.4.1 Potential hardness increase: Maximum hardness attainable in a workpiece through hardening under optimum conditions.

2.4.2 Hardness penetrability: Maximum hardness penetration depth attainable in a workpiece by hardening under optimum conditions.

2.5 Hardened state: Condition of increased hardness attained in a workpiece through hardening.

2.5.1 Hardness increase: Maximum hardness attained in a workpiece after hardening (under the prevailing conditions).

2.5.2 Hardness penetration: Hardening in terms of the cross-sectional region of a workpiece affected by it and the resulting hardness characteristic. A measure of the hardness penetration is the hardness penetration depth.

2.6 Hardness penetration depth: Vertical distance from the surface of a hardened workpiece down to the point at which the hardness corresponds to an appropriately defined *) limiting value.

2.7 Cooling characteristic

Specific temperature distribution in a workpiece during cooling down as a function of time.

Note: In the narrower sense, the cooling characteristic gives a family of cooling curves for various points on a workpiece.

2.8 Cooling rate

Time-related temperature decrease for a given point or a given range on a cooling curve.

Note: The cooling characteristic depends on the heat transfer coefficient, which in turn is determined by the material and the coolant, and on the coefficient of thermal conductivity characteristic of the material. For the steels indicated in Section 1, there are only minor differences in the coefficient of thermal conductivity.

3 Basic considerations concerning hardenability

3.1 Potential hardness increase

For the purpose of this Standard, the potential hardness increase, i.e. the maximum hardness attainable, depends on the portion of the carbon content of the steel which is dissolved in the austenite. The size of the dissolved portion is determined by the austenitizing conditions.

The relationship existing between the carbon portion dissolved in the austenite and the hardness attainable after quenching as a function of the martensite structure is presented in Fig. 1 and Fig. 2 for alloy and carbon steels.

The hardness increase obtained in the workpiece depends not only on the potential hardness increase but also on the cooling conditions.

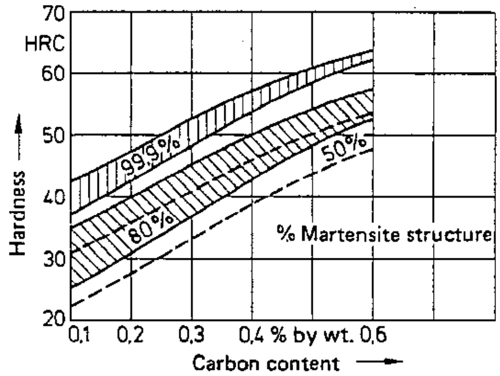

Figure 1. Relationship between as quenched-hardness, carbon content and martensite structure of hardened alloy and carbon steels (according to Hodge/Orehoski, Trans. AIME, 167, 627, 1946)

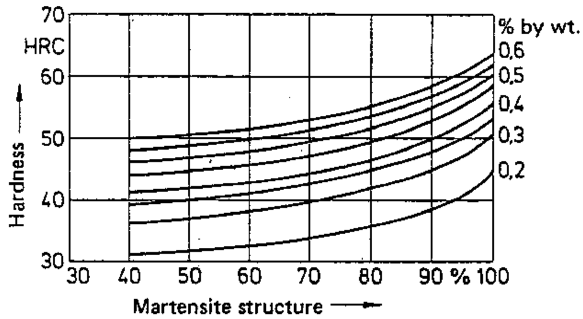

Figure 2. Relationship between as quenched-hardness, carbon content and martensite structure of hardened alloy and carbon steels (according to Hodge/Orehoski, Trans. AIME, 167, 627, 1946)

3.2 Influence of alloying elements

Hardness penetration is determined mainly by the kind and quantity of the alloying elements dissolved in the austenite, also by the dissolved carbon and the cooling characteristic. Increasing proportions of alloying elements intensify the hardness penetration effect. The most effective alloying elements are manganese, chromium and molybdenum.

From certain minimum cross-section onwards it is necessary, if an approximately uniform distribution of hardness over the cross-section is to be obtained when hardening under identical cooling conditions, to use alloy steels instead of carbon steels.

Note: If, for example, hardness penetration right through to the core is required, the use of carbon steels ought only be considered up to diameter of about 20 mm.

*) For determination of hardness penetration depth, see DIN 50 190 Part 2.

The larger the cross-section of a component and the more uniform the desired hardness distribution over the cross-section is, the larger must be the proportion of suitable alloying elements to be brought into solution in the austenite. Assuming the same requirements regarding hardness penetration, the carbon content of alloy steels can be smaller than that of carbon steels; however, this results in a smaller hardness increase.

3.3 Testing hardenability

As a rule the hardenability is determined by the end quench test according to DIN 50 191 and represented in the form of end-distance hardness curves. For this test, a specimen which has undergone austenitizing is placed in a suitable fixture and is quenched only on its bottom end face by a jet of water under constant conditions. The cooling rate decreases with increasing distance from the quenched end face. It is characterized by the cooling period between 800 and 500 °C (see Fig. 3).

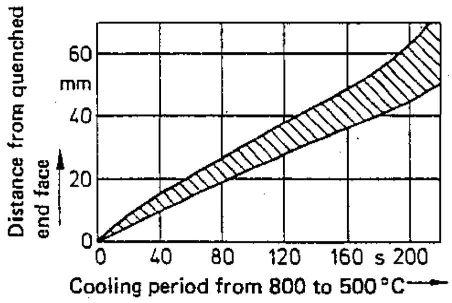

Figure 3. Relationship between cooling period and end distance of end quenched specimens of transformable steels (according to A. Rose, Atlas zur Wärmebehandlung der Stähle (Steel Heat Treatment Atlas), Vol. 1 and H. Brandis/H. Preisendanz, Das Abkühlverhalten in Stirnabschreckproben (Cooling Behaviour in End Quenched Specimens), Bänder, Bleche, Rohre, Oct. 1963)

Hardness measurements made along the cylindrical surface of the specimen generally reveal decreasing hardness values. Their distribution characterizes the hardenability. For steels suitable for testing by the end quench method, it is possible in this way to establish so-called hardenability scatter bands corresponding to the scatter of the heat; for an example see Fig. 4.

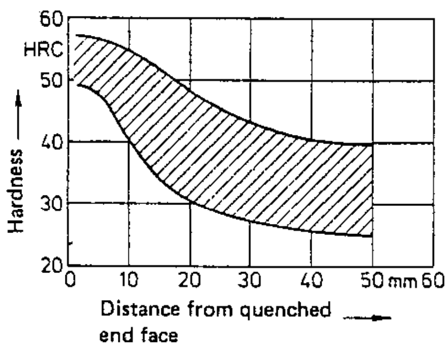

Figure 4. Hardenability scatter band for 34 CrMo 4 steel according to DIN 17 200

4 Factors influencing choice of steel

4.1 Dimensional change, distortion and risk of cracking

For definitions of dimensional change and distortion see DIN 17 014 Part 1.

Points which also need to be given consideration when deciding which type of steel should be used for a given component on the basis of hardness are dimensional change, distortion and the risk of cracking. Distortion and risk of cracking are influenced by the different volume changes taking place throughout the cross-section during hardening. Tests are necessary for obtaining optimum correlation of component shape, dimensional change, distortion, risk of cracking and steel composition.

The internal stresses, varying in their distribution and magnitude as a result of hardening, are the criterion for the magnitude of distortion and the risk of cracking.

The more rapidly cooling from hardening temperature takes place and the more complex the shape of the workpiece, the more adverse are the effects of the stresses likely to be.

Slower cooling can bring about reduced stresses. If the hardenability of the steel is then insufficient for attaining the properties required, it will be necessary to select a steel with greater hardenability.

4.2 Effect of cooling agent

Assuming the same steel grades and dimensions, the heat extraction during hardening is determined by the cooling agent used. Its properties and temperature plus any movement of the cooling agent and/or the item to be cooled will influence the cooling. In individual cases corresponding variations may also occur in the dimensional changes, distortion and risk of cracking.

The cooling agents differ in their cooling capacity in the temperature ranges which are important for hardening. Of the cooling agents commonly used, air provides the slowest cooling and water the fastest. Between these is cooling in oil or fused salt, depending on the physical properties (e.g. viscosity, specific heat, thermal conductivity).

4.3 Effect of tempering during the quenching and tempering process

4.3.1 General information

The effect of tempering on modification of properties, increase of toughness, elongation and percentage reduction of area at break, as well as the decrease of hardness, tensile strength and yield point, depends on the tempering temperature and tempering time. The two factors are interchangeable within certain limits. When it is required to temper steels to the same hardness or strength it is normally found that alloy steels need higher tempering temperatures than carbon steels. Guidance will be found in the tempering diagrams (see, for example, DIN 17 200). By adapting the heat-treatment to the particular application it is possible to impart to workpieces mechanical strength values differing from the data in the Standard.

On the basis of the hardness stipulated after tempering, and with allowance made for the drop in hardness values, compared with the as quenched-condition, brought about by tempering, Fig. 5 indicates the as quenched-hardness needed prior to tempering.

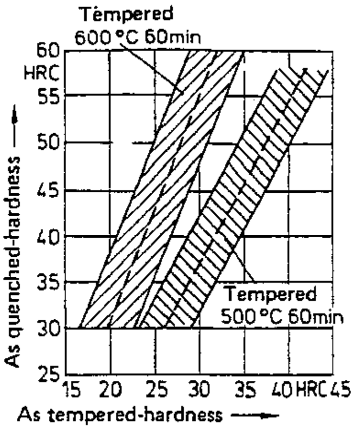

Figure 5. Relationship between hardness before and after tempering when heat treating steels to DIN 17 200 (according to unpublished investigations by H. Brandis)

4.3.2 Embrittlement phenomena

It should be noted that various steels may undergo embrittlement during tempering if certain temperature ranges cannot be avoided. Such embrittlement is a factor to be specially considered when impact loading of components is involved and its existence is proved preferentially by the notched bar impact bending test.

In this connection a distinction is made between a temperature range approximately around 300 °C (termed "300 degree embrittlement") and a range between 350 and 550 °C (termed "temper embrittlement").

To avoid the 300 °C-embrittlement, tempering in the range 250 to 350 °C should be avoided as far as possible.

Temper embrittlement mainly affects steels alloyed with Mn, Cr, MnCr, CrV and CrNi when such steels are cooled slowly after tempering above 600 °C or when tempering is carried out between 350 and 550 °C.

Embrittlement can be reduced by low phosphorus content, using steels alloyed with molybdenum up to about 0.6 % by weight or by cooling rapidly after tempering above 600 °C.

5 Steel selection

5.1 Relationship between the cooling process in the end quench specimen and in workpieces

5.1.1 Principles

When a workpiece is quenched from the austenitizing temperature, the cooling characteristic established in the various areas of the piece depends on its shape and dimensions and also on the action of the quenchant.

The end quench specimen also exhibits similar cooling characteristics. It is, therefore, possible to assign certain points or areas of a component with adequate accuracy to specific points on the cylindrical surface of the end quench specimen having the same rate of cooling.

At these points the same hardness values are obtained. On the basis of this simple relationship it is possible for the hardness characteristics of quenched components and of end quenched specimens of the same steel to be related to one another. If the cooling characteristic at various points on the component is known the hardness likely to be obtained there can be predicted from the results of the end quench test.

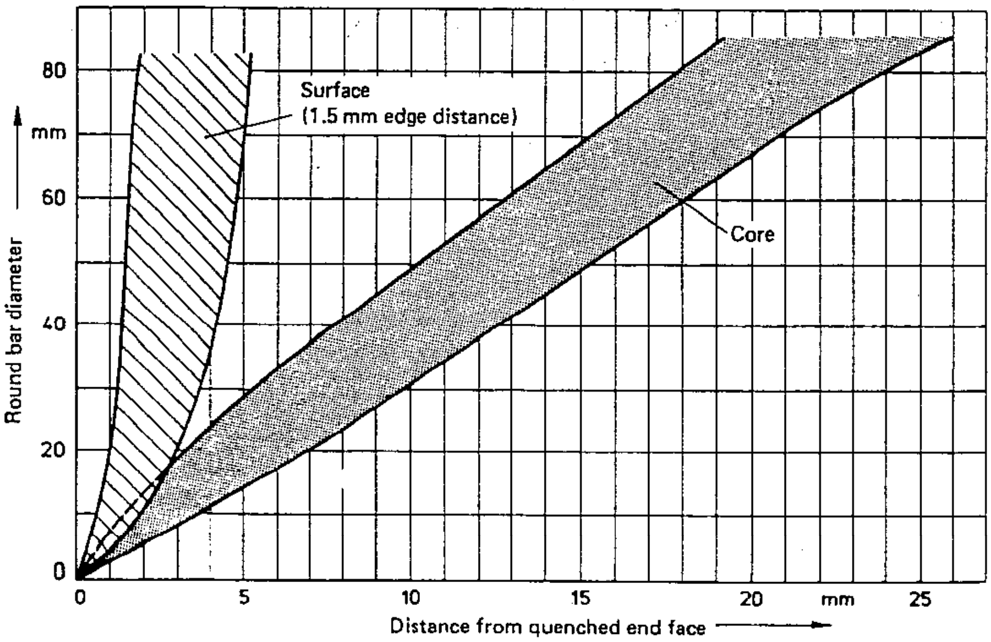

Figure 6. Relationship between water-quenched round specimens of steel and the end quench specimen (according to A. Rose, Atlas zur Wärmebehandlung der Stähle (Steel Heat Treatment Atlas), Vol. 1 and H. Brandis/H. Preisendanz, Das Akühlverhalten in Stirnabschreckproben (Cooling Behaviour in End Quench Specimens), Bänder, Bleche, Rohre, Oct. 1963)

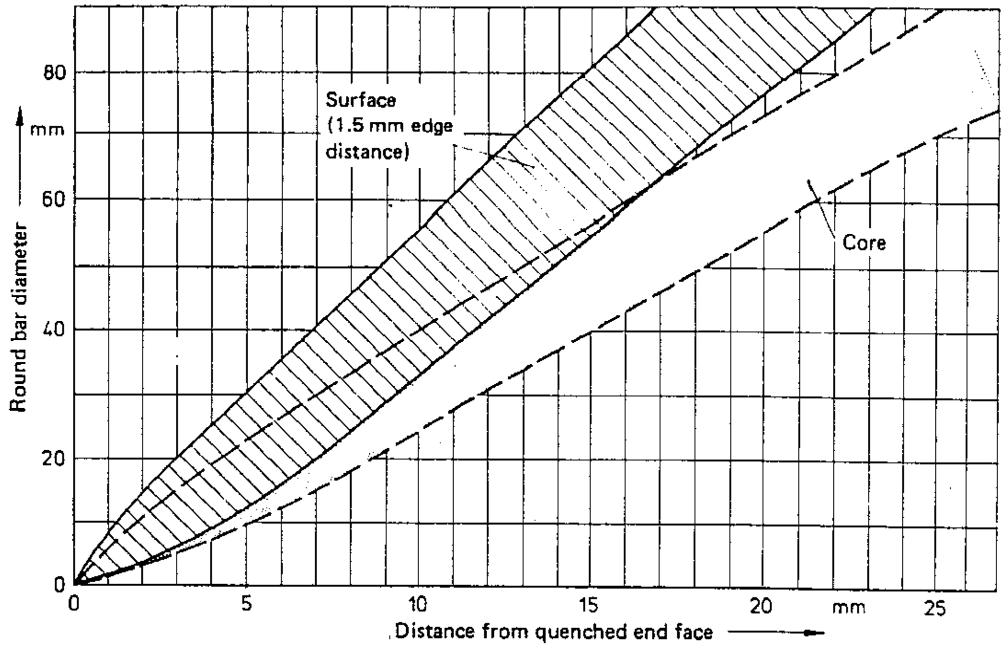

Figure 7. Relationship between oil-quenched round specimens of steel and the end quench specimen (according to A. Rose, Atlas zur Wärmebehandlung der Stähle (Steel Heat Treatment Atlas), Vol. 1 and H. Brandis/H. Preisendanz, Das Abkühlverhalten in Stirnabschreckproben (Cooling Behaviour in End Quench Specimens), Bänder, Bleche, Rohre, Oct. 1963)

5.1.2 Relationship between the cooling characteristic of specimens and the end quench specimen

The relationship between the cooling characteristic in the surface zone and core of cylindrical components up to 100 mm diameter in water and oil and the cooling characteristic of the end quench specimen is shown in Figs 6 and 7. For other cross-sections conversions are possible (see in this connection: VDI-Wärmeatlas, Berechnungsblätter für den Wärmeübergang (VDI Heat Atlas, Heat Transfer Calculation Sheets), VDI-Verlag Düsseldorf, 1963).

The scatter bands shown in Figs 6 and 7 are so far only approximations applicable under the stated quenching conditions for the quenching of individual items. If, under practical conditions, the items are not quenched singly, but instead several simultaneously, further corrections are necessary.

5.2 Relationship between hardness and other mechanical properties at ambient temperature

With rising hardness there is an increase in tensile strength, yield point and 0.2 % proof stress, as shown in Figs 8 and 9. The information in Fig. 9 for the 0.2 % proof stress only applies subject to the precondition that there is at least 50 % martensite in the cross-section under investigation.

Note: A further relationship, e.g. between elongation, notched bar impact strength, fatigue strength and hardness may be possible, but cannot be reliably substantiated in numerical terms for all steels on the basis of the documentation available at the present time. It has, therefore, been decided not to reproduce it here.

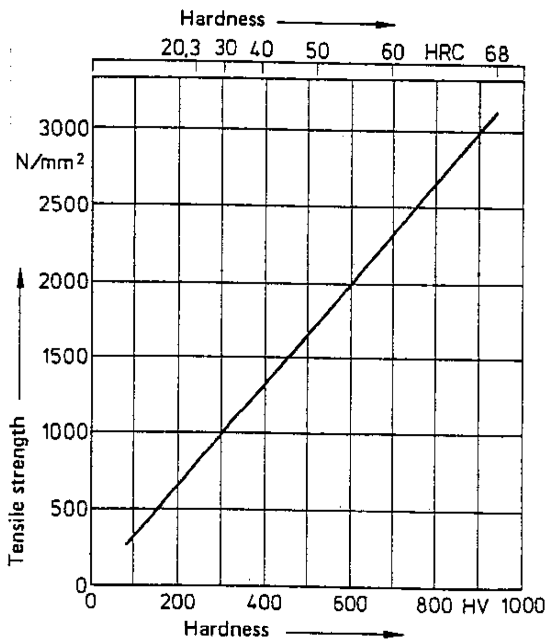

Figure 8. Relationship between tensile strength and hardness of steel

Note: Fig. 8 has been prepared on the basis of draft DIN 50 150, July 1975 edition.

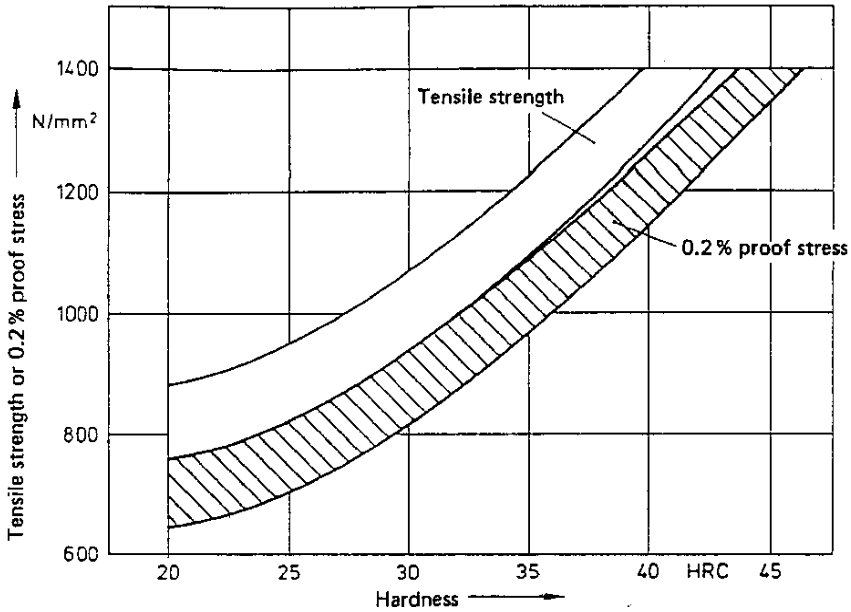

Figure 9. Relationship between tensile strength, 0,2 % proof stress and hardness of steel (according to E. Houdremont, Handbuch der Sonderstahlkunde (Handbook of Metallurgy of Special Steels))

5.3 Examples for steel selection *)

5.3.1 Selection on the basis of cooling

The procedure described below gives reference values of adequate accuracy, subject to observance of Section 5.1.2. For the following examples the mean values of the relevant scatter bands were used.

Example 1

Requirement:

The surface hardness of a component is required to be at least 40 HRC to tempering. Is it possible for this purpose to use one of the two steels already on hand in the plant, namely 41 Cr 4 or 46 Cr 2?

Notes:

The cross-section of the component may be considered equivalent to that of a shaft of 40 mm diameter. For reasons of distortion it is not permissible to quench in water.

Approach to solution:

It is necessary to check whether the hardenability of the two steels is adequate for obtaining the required surface hardness assuming a shaft of 40 mm diameter and quenching in oil.

For a 40 mm diameter round bar Fig. 10 shows that at an edge distance of 1.5 mm following quenching in oil the same cooling rate occurs as at a point on the end quench specimen ≈ 9.5 mm from the quenched end. Since the shaft is required to have ≧ 40 HRC it is necessary to check which steel contains the point 40 HRC at the lower limit of the hardenability scatter band and 9.5 mm end distance.

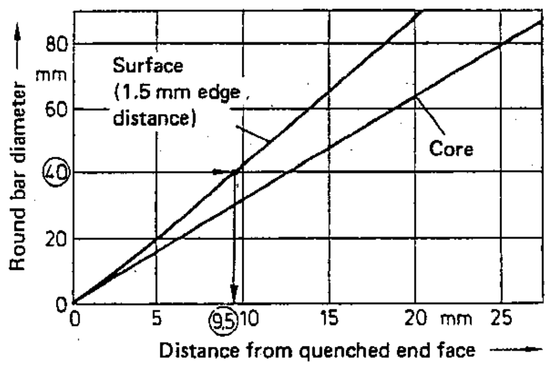

Figure 10. Relationship between round steel specimens quenched in oil and the end quench specimen (mean value curves of the scatter bands shown in Fig. 7)

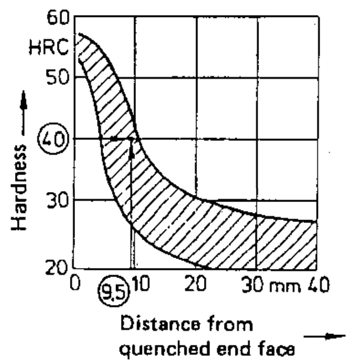

Figure 11. Hardenability scatter band for different deliveries of the 46 Cr 2 grade

*) For economic reasons a check should always be made to determine whether any of the steels already on hand in the plant in a suitable size possess adequate hardenability for the case concerned. It may in certain circumstances be more advantageous to use a steel which is already available in the plant, although carrying a higher price, than to enlarge the stock held by procuring an additional grade.

For the 46 Cr 2 grade on hand in the plant the hardenability was tested during receipt control by the end quench method and different deliveries gave the scatter band in Fig. 11.

When the point corresponding to 40 HRC at 9.5 mm edge distance is marked in Fig. 11 it is seen that not all deliveries would have been able to fulfil this hardenability requirements.

Result:

Hence, because of insufficient hardenability, the 46 Cr 2 grade cannot be used.

From DIN 17 200 it can be seen that with the 41 Cr 4 grade the point 40 HRC/9.5 mm lies below the hardenability scatter band. It is thus assured that the hardenability of this steel is adequate for fulfilling the stipulation made (see Fig. 12).

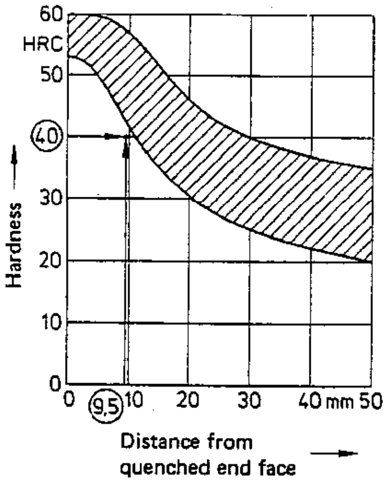

Figure 12. Hardenability scatter band for the 41 Cr 4 grade (to DIN 17 200)

For economic reasons a check should be made to determine whether surface layer hardening can be performed; this would enable the 46 Cr 2 grade to be used.

Example 2:

Requirement:

A shouldered cylindrical shaft with a diameter of 40 mm in the critical area has to be quenched and tempered to give a yield point $\sigma_s \gtrsim 720$ N/mm^2 in the core.

Notes:

To minimize the risk of cracking and for avoiding severe distortion due to the high cost of reworking the component, quenching shall be performed in oil. The impact loading to which the component will be subjected calls for a high degree of toughness. This is to be attained by tempering at 600 °C.

From empirical data available it can be assumed that for the given stressing conditions a structure with not less than 50 % martensite in the core is adequate.

Approach to solution:

The criterion for finding the solution is the yield point in the most severely stressed area. If there is no pronounced yield point the 0.2 % proof stress is used instead.

Fig. 13 shows the hardness corresponding to a 0.2 % proof stress of 720 N/mm^2 as 23 HRC.

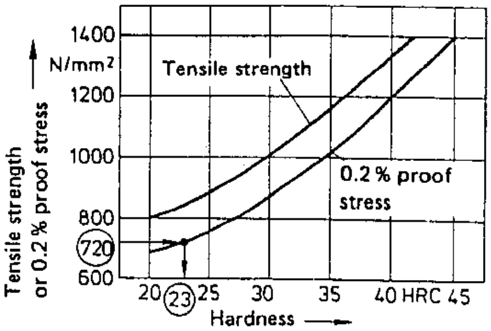

Figure 13. Relationship between tensile strength 0.2 % proof stress and hardness of steel (mean-value curves of the scatter bands shown in Fig. 9)

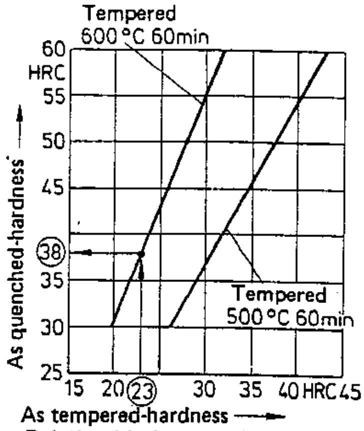

Figure 14. Relationship between hardness before and after tempering steels according to DIN 17 200 (mean-value curves of the scatter bands shown in Fig. 5)

This hardness must exist in the core of the workpiece after quenching and tempering. The tempering applied after hardening lowers the as quenched-hardness. Since the as tempered-hardness is required to be 23 HRC, it is necessary for the further selection process to determine the as quenched-hardness.

For a tempering temperature of 600 °C and an as tempered-hardness of 23 HRC, Fig. 14 shows an average as quenched-hardness of 38 HRC.

To obtain 38 HRC with 50 % martensite a minimum C content of ≈ 0.32 % by wt. is necessary according to Fig. 15.

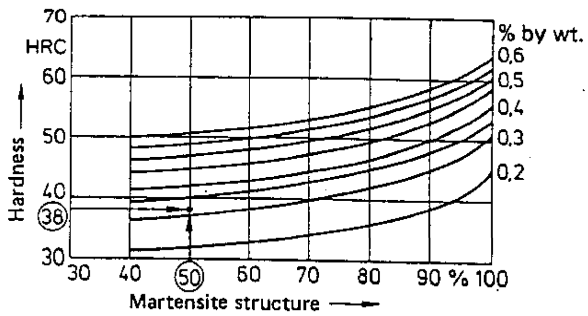

Figure 15. Relationship between as quenched hardness, carbon content and martensite structure of hardened steels (according to Hodge/Orehoski, Trans. AIME, 167, 627, 1946)

From Fig. 16, for cooling in oil, consistent with the relationship between component cross-section and required hardenability, an end distance of 13 mm is found for the core of a round specimen with a diameter of 40 mm. This means that at a distance of 13 mm from the quenched end of the end quench specimen the same cooling rate exists as in the core of a round specimen with a diameter of 40 mm which is quenched in oil.

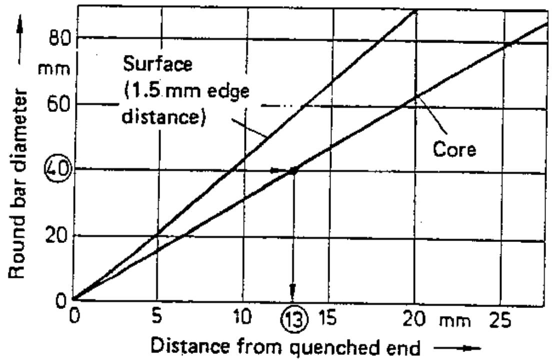

Figure 16. Relationship between oil-quenched round specimens of steel and the end quench specimen (mean-value curves of the scatter bands shown in Fig. 7)

Accordingly it is now a question of examining the hardenability scatter bands of different steels having a carbon content ≧ 0.32 % by weight C to determine whether the respective lower hardenability curve lies above the point corresponding to 38 HRC and 13 mm end distance. Only such a steel definitely guarantees the required minimum values (Fig. 17).

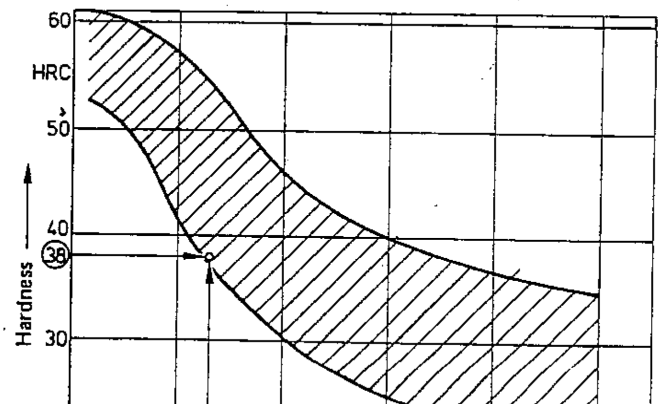

Figure 17. Hardenability scatter band for the 41 Cr 4 grade to DIN 17 200

Results:

In the case concerned here this applies, for example, to the 41 Cr 4 grade, whilst the 34 CrMo 4 grade (cf. Fig. 4) would only be considered subject to agreement with the supplier, in accordance with DIN 17 200, only to supply heats with a hardenability falling within the upper two-thirds of the scatter band.

If it were possible to use a more intensively acting quenchant instead of oil, this would appreciably relax the hardenability requirement. For quenching in water Fig. 18 shows, in similar fashion to Fig. 16, an end distance of 10 mm for the core on the basis of a round bar of 40 mm diameter. This would enable the 34 CrMo 4 grade, for example, to be used.

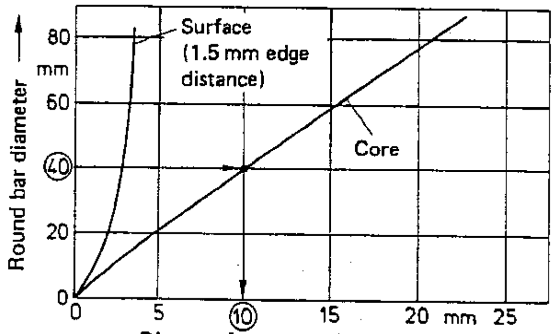

Figure 18. Relationship between water-quenched round specimens of steel and the end quench specimen (mean-value curves of the scatter bands shown in Fig. 6).

By using the tempering diagram for the 41 Cr 4 grade (Fig. 19) it is possible to check whether the requirement $\sigma_s \geq 720$ N/mm^2 is fulfilled.

Note: In the heat-treatment instructions (WBA) or the production schedule the following data must appear:

quenched and tempered

hardness in core ≧ 23 HRC

tempered at 600 °C

as quenched-hardness ≧ 38 HRC.

5.3.2 Selection on the basis of tests under operating conditions

If it is impossible or too difficult to establish an adequately reliable relationship between cooling process in the component and the end quench specimen according to Figs 6 or 7 and to adopt the procedure in Section 3.3.1, the method described below has to be used.

Example 3:

Requirement:

A component is required to have a tensile strength of $\sigma_B \geq 950$ N/mm^2 in its critical cross-section in the core. The required surface hardness is ≧ 37 HRC. Can the 38 Cr 2 grade on hand in the plant be used for this purpose?

Further conditions:

For reasons connected with stressing it is intended to heat-treat with tempering at not less than 500 °C.

Assumption:

The quenching and tempering 38 Cr 2 grade used in the plant for other parts is available in a size which enables test specimens corresponding to the envisaged component to be made. The end quench curve for 38 Cr 2 is on hand. Also known are the conditions under which the intended product parts are to be subsequently quenched and tempered (batch size, heating time and holding time, quenching etc.).

Approach to solution:

From Fig. 20 a hardness of 28 HRC corresponding to a tensile strength of $\sigma_B = 950$ N/mm^2 is found. This is the hardness which must exist in the core of the component after quenching and tempering.

For an as tempered-hardness of 28 HRC in the core and 37 HRC on the surface, Fig. 21 gives an as quenched-hardness of 34 HRC in the core and 48 HRC on the surface assuming tempering at 500 °C.

From the available 38 Cr 2 grade one or more pieces are prepared and hardened under the envisaged operating conditions. The reflect the operating conditions with sufficient accuracy it may be necessary to make up the batch with "blank" parts.

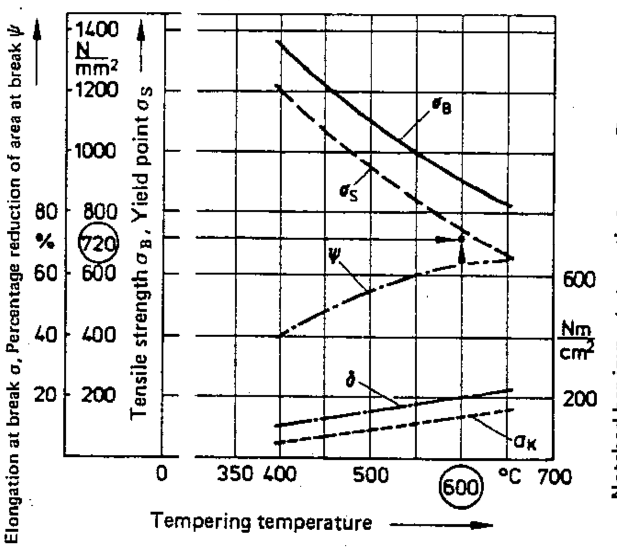

Figure 19. Tempering diagram for the 41 Cr 4 grade (taken from the catalogue of the steelmaker XY)

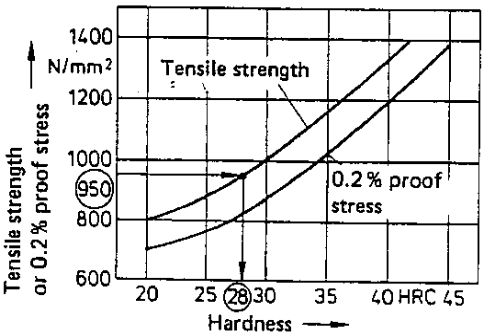

Figure 20. Relationship between tensile strength, 0.2 % proof stress and hardness of steel (mean value curves of the scatter bands shown in Fig. 9)

At the point which is critical for stressing, the hardness characteristic over the cross-section is determined and displayed graphically as shown in Fig. 22. In the same graph the surface and core hardness values required after hardening are entered and joined by a straight line. It is clear from this that the required hardness values were not attained on the test piece.

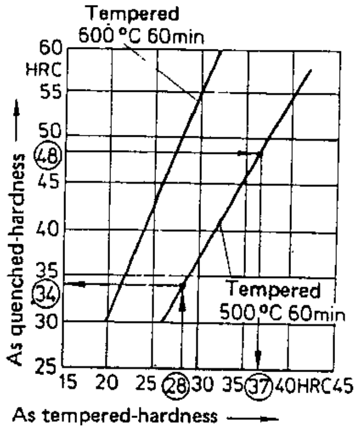

Figure 21. Relationship between hardness before and after tempering steels according to DIN 17 200 (mean value curves of the scatter bands shown in Fig. 5)

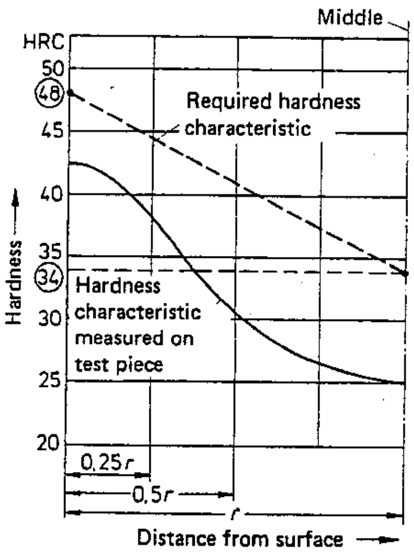

Figure 22. Hardness characteristic curves

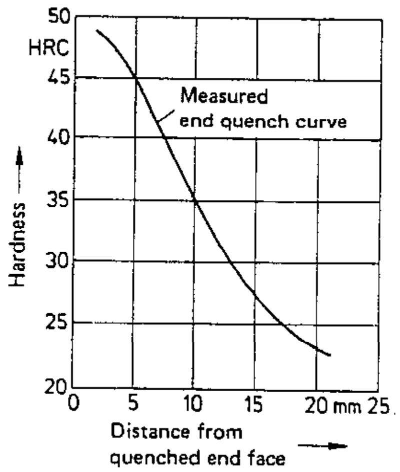

Figure 23. Measured end quench curve for a batch of the 38 Cr 2 grade

In Fig. 23 the end quench curve for the 38 Cr 2 grade is plotted for the batch from which the specimen test pieces were made.

On the basis of the relationship between the component and the end distance hardness curve for points having the same cooling rate resulting in identical hardness values, it is now possible to draw point by point the necessary end distance hardness curve for the required hardness characteristic. The procedure for this is as follows (see Fig. 24):

a) For some optional edge distance of the component the relevant hardness values are found in the two hardness characteristic curves in Fig. 24 (left-hand diagram) and projected horizontally to the right (projection lines c_1, c'_1, c_2, c'_2 until they intersect the edge distance hardness curve of the test piece (intersection points H'_1, H'_2).

b) On the abscissa of the right-hand diagram the end distances having the same cooling rate as the corresponding points on the surface and in the core of the component can be read off from the end distance hardness curve of the test piece.

c) The next step is to extend the verticals passing through these end distances and the intersection points H'_1 and H'_2 until they intercept the projection lines c_1 and c_2 (intersection points H_1 and H_2). These intersections represent two points on the sought end distance hardness curve with which the stipulated conditions are fulfilled.

d) In order to draw the necessary end distance hardness curve more accurately it may be necessary to enter further points which can be located by proceeding according to the stages described above.

Result:

For the purpose required, the hardenability of the 38 Cr 2 grade is not sufficient for meeting the required hardness characteristic. A comparison of the end distance hardness curve thus found with the hardenability scatter bands contained, for example, in DIN 17 200 enables the steel to be found whose lower curve of the scatter band is virtually identical with the curve constructed. For the example chosen here, this would be the case, among other possibilities, with the 41 Cr 4 grade. It should be noted, however, that because of the risk of temper embrittlement (see Section 4.3.2) this steel must not, as in the example, be tempered at 500 °C for applications requiring high toughness values. The remedy here, for example, is to use the 42 CrMo 4 grade or to raise the tempering temperature. The solution procedure is then repeated, starting by tracing the as quenched-hardness values from Fig. 21.

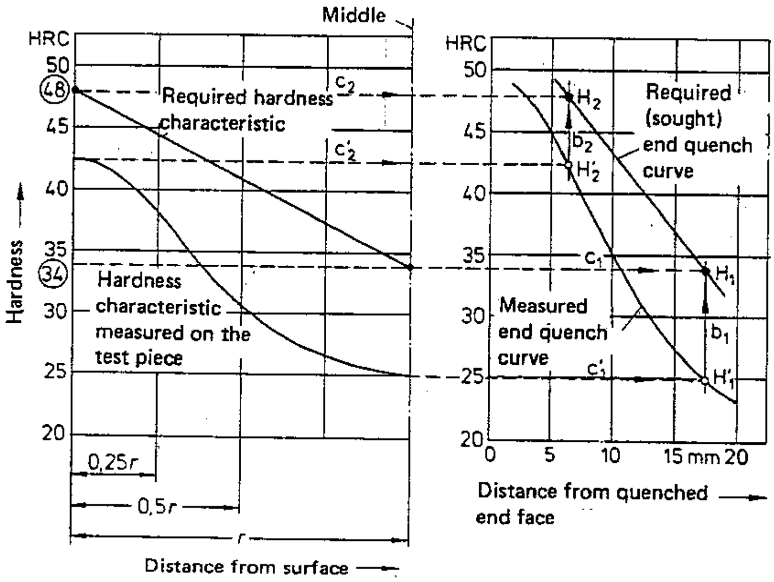

Figure 24. Graphical determination of hardenability sought

Explanations

The service properties required in a workpiece are only attained with certainty by a heat treatment, if the material used is suitable for the proposed treatment. Therefore, apart from economic and production engineering considerations it is specially important when selecting steels for workpieces which are to be hardened or quenched and tempered to pay attention to hardenability.

Various publications have proposed different approaches to the problem of steel selection on the basis of hardenability. In this Standard, the draft of which was drawn up by a special committee of the Arbeitsgemeinschaft Wärmebehandlung und Werkstofftechnik (AWT) (Heat Treatment and Materials Technology Working Group) a method is suggested which is easy to apply.

For this purpose the connection between the basically identical cooling conditions in the end quench specimens according to DIN 50 191 and in round steel specimens is used, as presented, for example, in the Metals Handbook, Vol. 1, 8th edition 1961, pages 189 to 216. (Cf. also Rose, Peter, Strassburg and Rademacher: "Atlas zur Wärmebehandlung der Stähle" (Steel Heat Treatment Atlas), Verlag Stahleisen mbH, Düsseldorf 1961 or Crafts, Lamont: "Hardenability and Steel Selection", translated into German by Rühenbeck, Springer-Verlag 1954, also the report on the work of the AWT special committee "Wärmebehandlungsangaben in Fertigungsunterlagen" (Heat Treatment Data in Production Documents): "Stahlauswahl aufgrund der Härtbarkeit" (Steel Selection on the Basis of Hardenability), Zeitschrift für wirtschaftliche Fertigung, 66 (1971) 4, pages 195 to 207.

The International Organization for Standardization (ISO) has so far not drawn up any recommendation for steel selection on the basis of hardenability.

It is intended to add further to this Standard. In particular it is proposed to widen the coverage of Fig. 5 (Section 4.3.1) so that it can also be used for tempering treatments other than those stated.

Figs 6 and 7 (Section 5.1.2) only deal with the relationship for cooling in oil or water and round specimens. Further work is needed to extend the relationship to other cross-sections, further and more closely identified cooling agents and conditions, and to state suitable correction factors in order thereby to cater for all the conditions arising in actual practice.

In view of the present status of the work, this Standard has also deliberately refrained from including other connections between hardness and further service properties such as fatigue strength, notched bar impact strength, elongation at break, percentage reduction of area etc., since the numerical data available does not yet permit the necessary processing to produce a Standard of general validity.

The selection procedures illustrated in Examples 1 and 2 generally lead in practice to satisfactorily approximated values. If in-plant conditions need to be considered to a greater extent, the method illustrated in Example 3 is recommended. It is a common feature of all the methods, however, that they are directed at the hardenability scatter bands contained in the various quality Standards for steel (e.g. DIN 17 200, DIN 17 210 etc.).

In the context of this Standard, further work is also envisaged, e.g. guidance on process aspects of the various heat treatment methods, also material selection to suit the required service properties by means of decision tables.