INTERNATIONAL STANDARD

ISO 6336-5

Second edition
2003-07-01

Calculation of load capacity of spur and helical gears —

Part 5:
Strength and quality of materials

Calcul de la capacité de charge des engrenages cylindriques à dentures droite et hélicoïdale —

Partie 5: Résistance et qualité des matériaux

Reference number
ISO 6336-5:2003(E)

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO 6336-5 was prepared by Technical Committee ISO/TC 60, *Gears*, Subcommittee SC 2, *Gear capacity calculation*.

This second edition cancels and replaces the first edition (ISO 6336-5:1996), which has been technically revised.

ISO 6336 consists of the following parts, under the general title *Calculation of load capacity of spur and helical gears*:

— *Part 1: Basic principles, introduction and general influence factors*

— *Part 2: Calculation of surface durability (pitting)*

— *Part 3: Calculation of tooth bending strength*

— *Part 5: Strength and quality of materials*

Part 6, *Calculation of service life under variable load*, is under preparation.

Introduction

This part of ISO 6336, together with ISO 6336-1, ISO 6336-2 and ISO 6336-3, provides the principles for a coherent system of procedures for the calculation of the load capacity of cylindrical involute gears with external or internal teeth. ISO 6336 is designed to facilitate the application of future knowledge and developments, as well as the exchange of information gained from experience.

Allowable stress numbers, as covered by this part of ISO 6336, may vary widely. Such variation is attributable to defects and variations of chemical composition (charge), structure, the type and extent of hot working (e.g. bar stock, forging, reduction ratio), heat treatment, residual stress levels, etc.

Tables summarize the most important influencing variables and the requirements for the different materials and quality grades. The effects of these influences on surface durability and tooth bending strength are illustrated by graphs.

This part of ISO 6336 covers the most widely used ferrous gear materials and related heat treatment processes. Recommendations on the choice of specific materials, heat treatment processes or manufacturing processes are not included. Furthermore, no comments are made concerning the suitability or otherwise of any materials for specific manufacturing or heat treatment processes.

Calculation of load capacity of spur and helical gears —

Part 5:
Strength and quality of materials

1 Scope

This part of ISO 6336 describes contact and tooth-root stresses, and gives numerical values for both limit stress numbers. It specifies requirements for material quality and heat treatment and comments on their influences on both limit stress numbers.

Values in accordance with this part of ISO 6336 are suitable for use with the calculation procedures provided in ISO 6336-2 and ISO 6336-3 and in the application standards for industrial, high speed and marine gears. They are applicable to the calculation procedures given in ISO 10300 for rating the load capacity of bevel gears. This part of ISO 6336 is applicable to all gearing, basic rack profiles, profile dimensions, design, etc., covered by those standards. The results are in good agreement with other methods for the range indicated in the scope of ISO 6336-1.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 53: 1998, *Cylindrical gears for general and heavy engineering — Standard basic rack tooth profile*

ISO 642:1999, *Steel — Hardenability test by end quenching (Jominy test)*

ISO 643:—[1], *Steel — Micrographic determination of the ferritic or austenitic grain size*

ISO 683-1:1987, *Heat-treatable steels, alloy steels and free-cutting steels — Part 1: Direct hardening unalloyed and low alloyed wrought steel in form of different black products*

ISO 683-9:1988, *Heat-treatable steels, alloy steels and free-cutting steels — Part 9: Wrought free-cutting steels*

ISO 683-10:1987, *Heat-treatable steels, alloy steels and free-cutting steels — Part 10: Wrought nitriding steels*

ISO 683-11:1987, *Heat-treatable steels, alloy steels and free-cutting steels — Part 11: Wrought case-hardening steels*

ISO 1122-1:1998, *Vocabulary of gear terms — Part 1: Definitions related to geometry*

1) To be published. (Revision of ISO 643:1983)

ISO 1328-1:1995, *Cylindrical gears — ISO system of accuracy — Part 1: Definitions and allowable values of deviations relevant to corresponding flanks of gear teeth*

ISO 2639:2002, *Steel — Determination and verification of the effective depth of carburized and hardened cases*

ISO 3754:1976, *Steel — Determination of effective depth of hardening after flame or induction hardening*

ISO 4948/2:1981, *Steels — Classification — Part 2: Classification of unalloyed and alloy steels according to main quality classes and main property or application characteristics*

ISO 4967:1998, *Steel — Determination of content of non-metallic inclusions — Micrographic method using standard diagrams*

ISO 6336-1:—[2)], *Calculation of load capacity of spur and helical gears — Part 1: Basic principles, introduction and general influence factors*

ISO 6336-2:—[2)], *Calculation of load capacity of spur and helical gears — Part 2: Calculation of surface durability (pitting)*

ISO 6336-3: —[2)], *Calculation of load capacity of spur and helical gears — Part 3: Calculation of tooth bending strength*

ISO 9443:1991, *Heat-treatable and alloy steels — Surface quality classes for hot-rolled round bars and wire rods — Technical delivery conditions*

ISO 10474:1991, *Steel and steel products — Inspection documents*

ISO 14104:1995, *Gears — Surface temper etch inspection after grinding*

ASTM[3)] A388-01, *Standard Practice for Ultrasonic Examination of Heavy Steel Forgings*

ASTM E428-00, *Standard Practice for Fabrication and Control of Steel Reference Blocks Used in Ultrasonic Inspection*

ASTM A609-91, *Standard Practice for Castings, Carbon, Low Alloy and Martensitic Stainless Steel, Ultrasonic Examination Thereof*

ASTM E1444-01, *Standard Practice for Magnetic Particle Examination*

3 Terms, definitions and symbols

For the purposes of this document, the terms and definitions given in ISO 1122-1 and the symbols and units given in ISO 6336-1 apply.

4 Methods for the determination of allowable stress numbers

4.1 General

Allowable stress numbers should be determined for each material and material condition, preferably by means of gear running tests. Test conditions and component dimensions should equate, as nearly as is practicable, to the operating conditions and dimensions of the gears to be rated.

2) Under preparation. (Revisions of ISO 6336-1:1996, ISO 6336-2:1996 and ISO 6336-3:1996, respectively)

3) American Society for Testing and Materials

When evaluating test results or data derived from field service, it is always necessary to ascertain whether or not specific influences on permissible stresses are already included with the evaluated data, e.g. in the case of surface durability, the effects of lubricants, surface roughness and gear geometry; in the case of tooth bending strength, the fillet radius, surface roughness and gear geometry. Where appropriate, 1,0 should be substituted for the relevant influence factor when calculating the permissible stresses.

4.2 Method A

The allowable stress numbers for contact and bending are derived from endurance tests of gears having dimensions closely similar to those of the gears to be rated, under test conditions which are closely similar to the intended operating conditions.

4.3 Method B

The allowable stress numbers for contact and bending were derived from endurance tests of reference test gears under reference test conditions. Tooth-root allowable stress numbers were also derived from pulsator tests. Practical experience should be taken into account. The standard allowable stress numbers specified in 5.2 and 5.3 are based on such tests and experience.

Three different classes, ME, MQ and ML, are given for the allowable stress numbers. The appropriate choice of class will depend, as described in Clause 6, on the type of production and quality control exercised.

4.4 Method B_k

Allowable stress numbers for bending are derived from the results of testing notched test pieces. Preferably, the ratio of the test piece notch radius to thickness should be similar to that of the fillet radius to the tooth-root chord in the critical section and the surface condition should be similar to that of the tooth root. When evaluating test data, it should be understood that test pieces are usually subjected to pure, alternating bending stress, whereas in the case of a gear tooth the fillets of the teeth are subjected to combined bending, shear and compressive stresses. Data on the various materials can be obtained from in-house testing, experience or from the literature.

4.5 Method B_p

Allowable stress numbers for bending are derived from the results of testing un-notched test pieces. See 4.4 for comments on evaluation of test results. In order to take into account the effect of notch sensitivity, it is necessary that actual notch form and notch factors be included in calculations; thus their results will be influenced by the extreme unreliability of these factors. Data on the various materials can be obtained from known test facilities or from the literature (see Bibliography).

5 Standard allowable stress numbers — Method B

5.1 Application

The allowable stress numbers shown in Figures 1 to 16 are based on the assumption that material composition, heat treatment and inspection methods are appropriately chosen for the size of the gear.

If test values for specific materials are available they can be used in replacement of the values in Figures 1 to 16.

The data furnished in this part of ISO 6336 are well substantiated by tests and practical experience.

The values are chosen for 1 % probability of damage. Statistical analysis enables adjustment of these values in order to correspond to other probabilities of damage.

When other probabilities of damage (reliability) are desired, the values of $\sigma_{H\,lim}$, $\sigma_{F\,lim}$, and σ_{FE} are adjusted by an appropriate "reliability factor". When this adjustment is made, a subscript shall to be added to indicate the relevant percentage (e.g. $\sigma_{H\,lim10}$ for 10 % probability of damage).

The allowable stress numbers indicated in Figures 9 and 10 were derived for effective case depths of about $0{,}15m_n$ to $0{,}2m_n$ on finish-machined gears.

The extent to which the level of surface hardness influences the strength of contour-hardened, nitrided, carbo-nitrided and nitro-carburized gears, cannot be reliably specified. Other surface related factors of the material and heat treatment have a much more pronounced influence.

In some cases the full hardness range is not covered. The ranges covered are indicated by the length of the lines in Figures 1 to 16.

For surface-hardened steels (Figures 9 to 16), the HV scale was chosen as the reference axis. The HRC scale is included for comparison. To define the relationship between Vickers and Rockwell hardness numbers conversion tables are included in Annex B.

5.2 Allowable stress number (contact), $\sigma_{H\,lim}$

The allowable stress number, $\sigma_{H\,lim}$, is derived from a contact pressure that may be sustained for a specified number of cycles without the occurrence of progressive pitting. For some materials, 5×10^7 stress cycles are considered to be the beginning of the long-life strength range (see life factor in ISO 6336-2).

Values of $\sigma_{H\,lim}$ indicated in Figures 1, 3, 5, 7, 9, 11, 13 and 15 are appropriate for the reference operating conditions and dimensions of the reference test gears, as follows[4)]:

— Centre distance	a = 100 mm
— Helix angle	$\beta = 0$ (Z_β = 1)
— Module	m = 3 mm to 5 mm (Z_x = 1)
— Mean peak-to-valley roughness of the tooth flanks	Rz = 3 µm (Z_R = 1)
— Tangential velocity	v = 10 m/s (Z_v = 1)
— Lubricant viscosity	ν_{50} = 100 mm²/s (Z_L = 1)
— Mating gears of the same material	(Z_W =1)
— Gearing accuracy grades	4 to 6 according to ISO 1328-1
— Facewidth	b = 10 mm to 20 mm
— Load influence factors	$K_A = K_v = K_{H\beta} = K_{H\alpha} = 1$

Test gears were deemed to have failed by pitting when the following conditions were met: when 2 % of the total working flank area of through hardened gears, or when 0,5 % of the total working flank area of surface hardened gears, or 4 % of the working flank area of a single tooth, is damaged by pitting. The percentages refer to test evaluations; they are not intended as limits for product gears.

4) Data obtained under different conditions of testing were adjusted to be consistent with reference conditions. It is important to note $\sigma_{H\,lim}$ is not the contact pressure under continuous load, but rather the upper limit of the contact pressure derived in accordance with ISO 6336-2, which can be sustained without progressive pitting damage, for a specified number of load cycles.

5.3 Bending stress number values for $\sigma_{F\,lim}$ and σ_{FE}

5.3.1 Nominal stress numbers (bending), $\sigma_{F\,lim}$

The nominal stress number (bending), $\sigma_{F\,lim}$, was determined by testing reference test gears (see ISO 6336-3). It is the bending stress limit value relevant to the influences of the material, the heat treatment and the surface roughness of the test gear root fillets.

5.3.2 Allowable stress number (bending), σ_{FE}

The allowable stress number for bending, σ_{FE} (for definition of σ_{FE}, see ISO 6336-3), is the basic bending strength of the un-notched test piece, under the assumption that the material condition (including heat treatment) is fully elastic:

$$\sigma_{FE} = \sigma_{F\,lim}\, Y_{ST} \tag{1}$$

For the reference test gear, the stress correction factor Y_{ST} = 2,0. For most materials, 3×10^6 stress cycles are considered to be the beginning of the long-life strength range (see life factor in ISO 6336-3).

Values of $\sigma_{F\,lim}$ and σ_{FE} indicated in Figures 2, 4, 6, 8, 10, 12, 14 and 16 are appropriate for the reference operating conditions and dimensions of the reference test gears, as shown below (see 5.2, Footnote 3):

— Helix angle $\beta = 0$ ($Y_\beta = 1$)

— Module m = 3 mm to 5 mm ($Y_X = 1$)

— Stress correction factor Y_{ST} = 2,0

— Notch parameter q_{ST} = 2,5 ($Y_{\delta\,rel\,T} = 1$)

— Mean peak-to-valley roughness of the tooth fillets Rz = 10 μm ($Y_{R\,rel\,T} = 1$)

— Gearing accuracy grades 4 to 7 according to ISO 1328-1

— Basic rack according to ISO 53

— Facewidth b = 10 mm to 50 mm

— Load factors $K_A = K_v = K_{F\beta} = K_{F\alpha} = 1$

5.3.3 Reversed bending

The allowable stress numbers indicated in Figures 2, 4, 6, 8, 10, 12, 14 and 16 are appropriate for repeated, unidirectional, tooth loading. When reversals of full load occur, a reduced value of σ_{FE} is required. In the most severe case (e.g. an idler gear where full load reversal occurs each load cycle), the values $\sigma_{F\,lim}$ and σ_{FE} should be reduced to 0,7 times the unidirectional value. If the number of load reversals is less frequent than this, a different factor, depending on the number of reversals expected during the gear lifetime, can be chosen. For guidance on this, see ISO 6336-3: —[2)], Annex B.

5.4 Graphs for $\sigma_{H\,lim}$ and $\sigma_{F\,lim}$ and σ_{FE}

Allowable stress numbers for hardness values which exceed the minimum and maximum hardness values in Figures 1 to 16 are subject to agreement between manufacturer and purchaser on the basis of previous experience.

5.5 Calculation of $\sigma_{H\,lim}$ and $\sigma_{F\,lim}$

The allowable stress numbers, $\sigma_{H\,lim}$, and the nominal stress numbers, $\sigma_{F\,lim}$, can be calculated by the following equation:

$$\left.\begin{matrix}\sigma_{H\lim}\\ \sigma_{F\lim}\end{matrix}\right\} = A \cdot x + B \qquad (2)$$

where

x is the surface hardness HBW or HV;

A, B are constants (See Table 1).

The hardness ranges are restricted by the minimum and maximum hardness values given in Table 1.

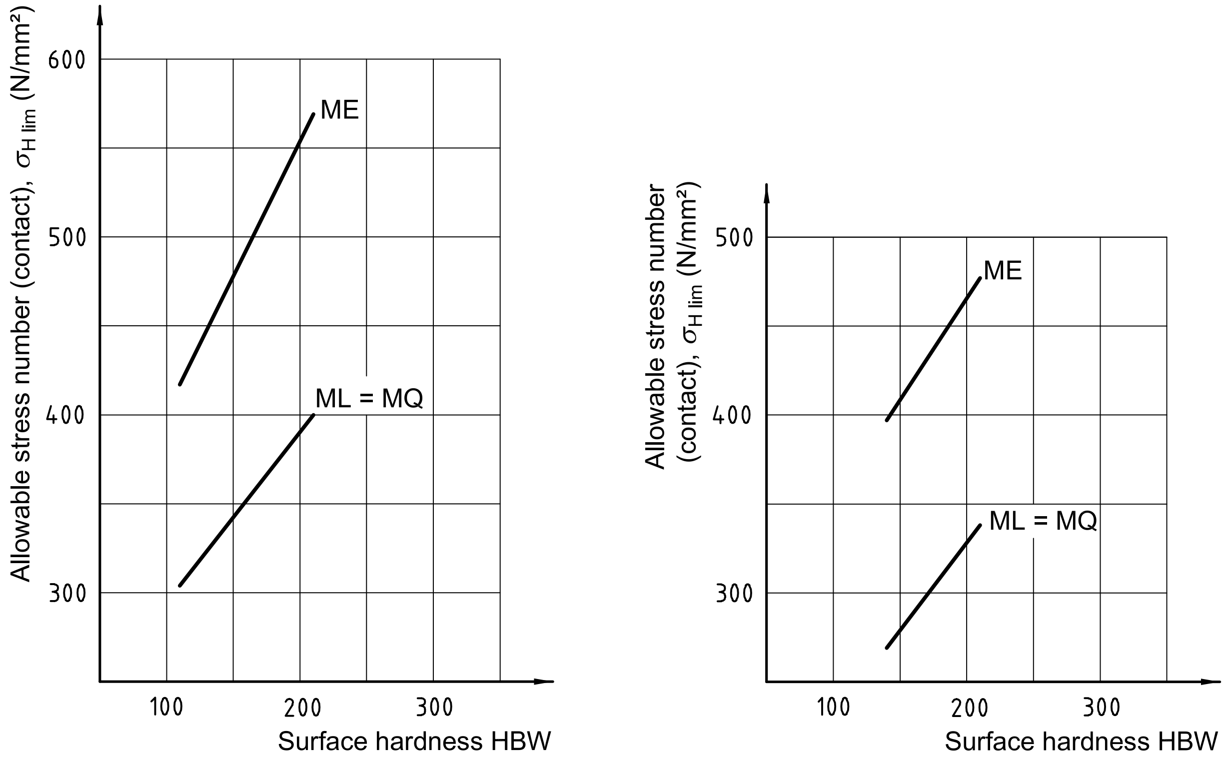
Table 1 — Calculation of $\sigma_{H\,lim}$ and $\sigma_{F\,lim}$

No.	Material	Stress	Type	Abbre-viation	Fig.	Quality	A	B	Hard-ness	Min. hardness	Max. hardness
1	Normalized low carbon steels/cast steels [a]	contact	wrought normalized	St	1 a)	ML/MQ	1,000	190	HBW	110	210
2			low carbon steels			ME	1,520	250		110	210
3			cast steels	St	1 b)	ML/MQ	0,986	131	HBW	140	210
4				(cast)		ME	1,143	237		140	210
5		bending	wrought normalized	St	2 a)	ML/MQ	0,455	69	HBW	110	210
6			low carbon steels			ME	0,386	147		110	210
7			cast steels	St	2 b)	ML/MQ	0,313	62	HBW	140	210
8				(cast)		ME	0,254	137		140	210
9	Cast iron materials	contact	black malleable	GTS	3 a)	ML/MQ	1,371	143	HBW	135	250
10			cast iron	(perl.)		ME	1,333	267		175	250
11			nodular cast iron	GGG	3 b)	ML/MQ	1,434	211	HBW	175	300
12						ME	1,500	250		200	300
13			grey cast iron	GG	3 c)	ML/MQ	1,033	132	HBW	150	240
14						ME	1,465	122		175	275
15		bending	black malleable	GTS	4 a)	ML/MQ	0,345	77	HBW	135	250
16			cast iron	(perl.)		ME	0,403	128		175	250
17			nodular cast iron	GGG	4 b)	ML/MQ	0,350	119	HBW	175	300
18						ME	0,380	134		200	300
19			grey cast iron	GG	4 c)	ML/MQ	0,256	8	HBW	150	240
20						ME	0,200	53		175	275
21	Through hardened wrought steels [b]	contact	carbon steels	V	5	ML	0,963	283	HV	135	210
22						MQ	0,925	360		135	210
23						ME	0,838	432		135	210
24			alloy steels	V	5	ML	1,313	188	HV	200	360
25						MQ	1,313	373		200	360
26						ME	2,213	260		200	390
27		bending	carbon steels	V	6	ML	0,250	108	HV	115	215
28						MQ	0,240	163		115	215
29						ME	0,283	202		115	215
30			alloy steels	V	6	ML	0,423	104	HV	200	360
31						MQ	0,425	187		200	360
32						ME	0,358	231		200	390

Table 1 (*continued*)

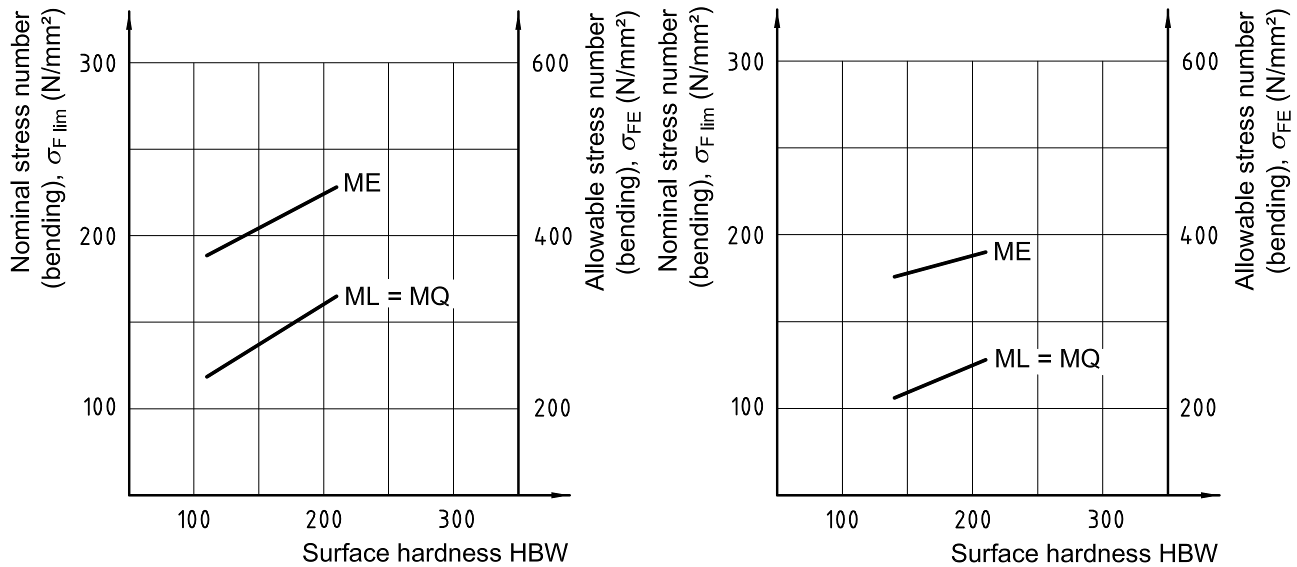
No.	Material	Stress	Type	Abbre-viation	Fig.	Quality	A	B	Hard-ness	Min. hardness	Max. hardness
33	Through hardened cast steels	contact	carbon steels	V	7	ML/MQ	0,831	300	HV	130	215
34				(cast)		ME	0,951	345		130	215
35			alloy steels	V	7	ML/MQ	1,276	298	HV	200	360
36				(cast)		ME	1,350	356		200	360
37		bending	carbon steels	V	8	ML/MQ	0,224	117	HV	130	215
38				(cast)		ME	0,286	167		130	215
39			alloy steels	V	8	ML/MQ	0,364	161	HV	200	360
40				(cast)		ME	0,356	186		200	360
41	Case hardened wrought steels [c]	contact		Eh	9	ML	0,000	1 300	HV	600	800
42						MQ	0,000	1 500		660	800
43						ME	0,000	1 650		660	800
44		bending	core hardness:	Eh	10	ML	0,000	312	HV	600	800
45			⩾ 25 HRC, lower			MQ	0,000	425		660	800
46			⩾ 25 HRC, upper				0,000	461		660	800
47			⩾ 30 HRC				0,000	500		660	800
48						ME	0,000	525		660	800
49	Flame or induction hardened wrought and cast steels	contact		IF	11	ML	0,740	602	HV	485	615
50						MQ	0,541	882		500	615
51						ME	0,505	1 013		500	615
52		bending		IF	12	ML	0,305	76	HV	485	615
53						MQ	0,138	290		500	570
54							0,000	369		570	615
55						ME	0,271	237		500	615
56	Nitrided wrought steels/nitriding steels [d] /through hardening steels [b] nitrided	contact	nitriding steels (a)	NT	13 a)	ML	0,000	1 125	HV	650	900
57				(nitr.)		MQ	0,000	1 250		650	900
58						ME	0,000	1 450		650	900
59			through hardening steels (b)	NV	13 b)	ML	0,000	788	HV	450	650
60				(nitr.)		MQ	0,000	998		450	650
61						ME	0,000	1 217		450	650
62		bending	nitriding steels (a)	NT	14 a)	ML	0,000	270	HV	650	900
63				(nitr.)		MQ	0,000	420		650	900
64						ME	0,000	468		650	900
65			through hardening steels (b)	NV	14 b)	ML	0,000	258	HV	450	650
66				(nitr.)		MQ	0,000	363		450	650
67						ME	0,000	432		450	650
68	wrought steels nitro-carburized [e]	contact	through hardening steels	NV	15	ML	0,000	650	HV	300	650
69				(nitro-		MQ/ME	1,167	425		300	450
70				car.)			0,000	950		450	650
71		bending	through hardening steels	NV	16	ML	0,000	224	HV	300	650
72				(nitro-		MQ/ME	0,653	94		300	450
73				car.)			0,000	388		450	650

[a] In accordance with ISO 4948-2.
[b] In accordance with ISO 683-1.
[c] In accordance with ISO 683-11.
[d] In accordance with ISO 683-10.
[e] In accordance with ISO 683-1, ISO 683-10 or ISO 683-11.



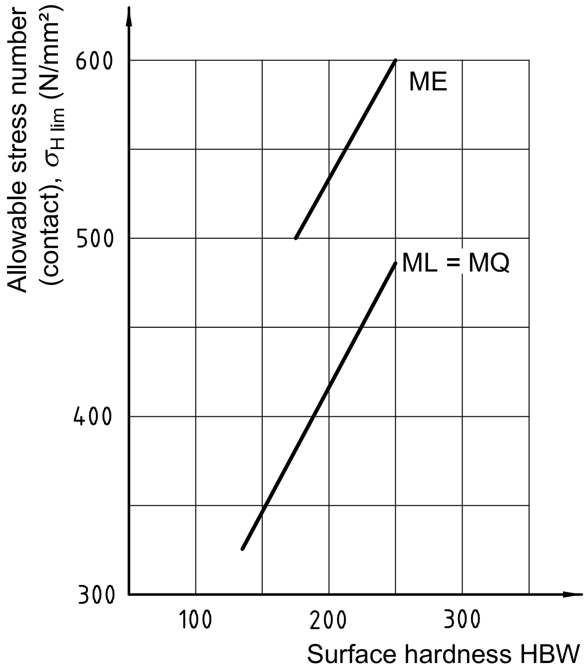
a) Wrought normalized low carbon steels **b) Cast steels**

Figure 1 — Allowable stress numbers (contact) for wrought normalized low carbon steels and cast steels (Attention is drawn to the quality requirements of 6.2)

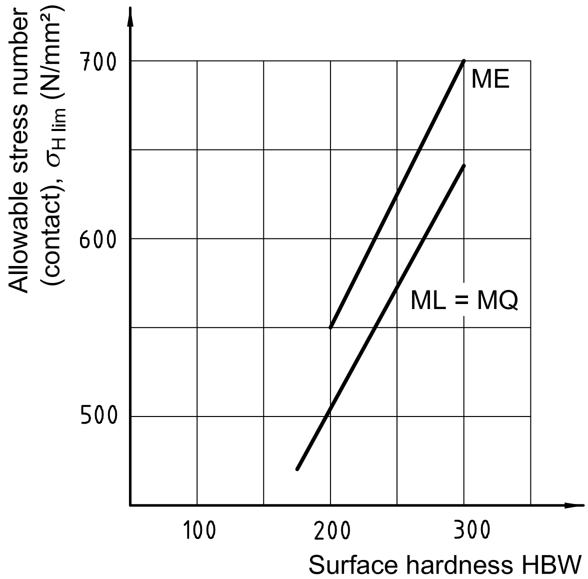


a) Wrought normalized low carbon steels **b) Cast steels**

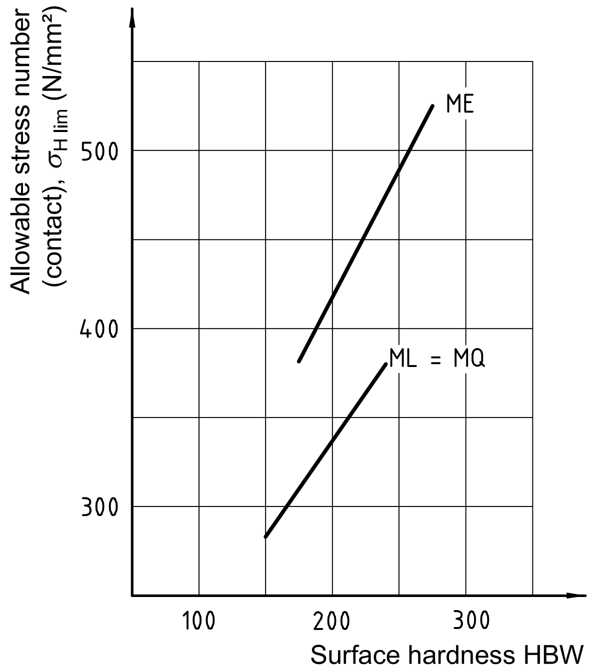
Figure 2 — Nominal and allowable stress numbers (bending) for wrought normalized low carbon steels and cast steels (Attention is drawn to the quality requirements of 6.2)



a) Black malleable cast iron (see 6.3)



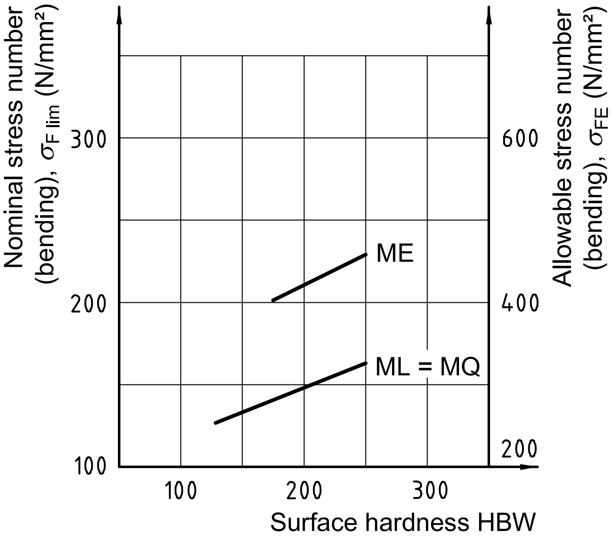
b) Nodular cast iron (see Table 2)



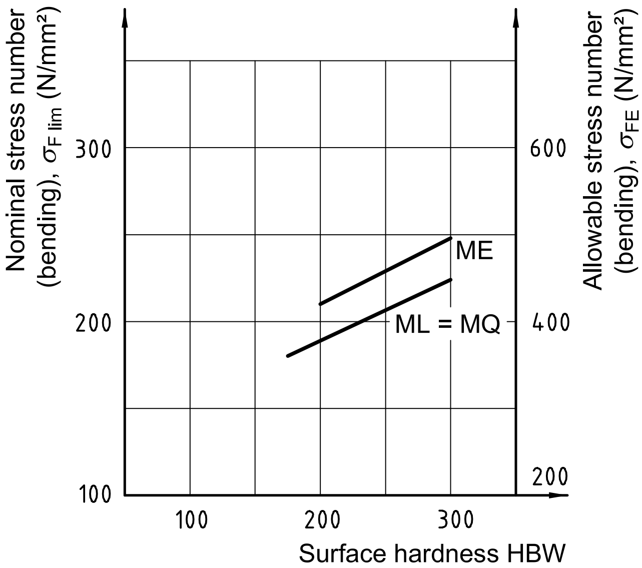
c) Grey cast iron (see Table 2)

NOTE Brinell hardness HBW < 180 indicates the presence of a high proportion of ferrite in the structure. For gears, this condition is not recommended.

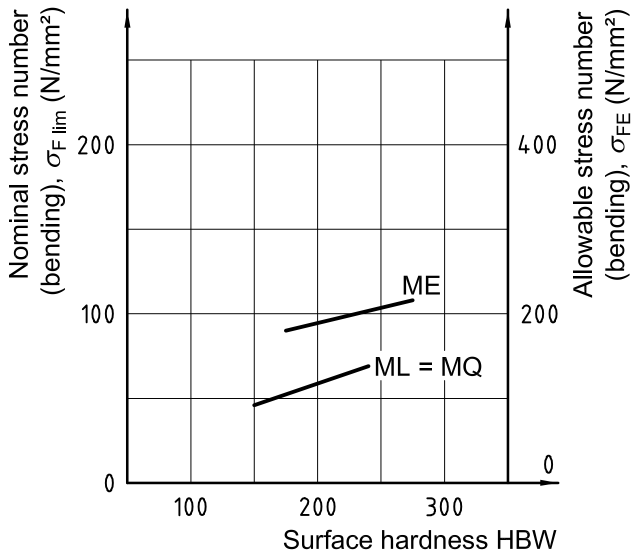
Figure 3 — Cast iron materials — Allowable stress numbers (contact) for cast iron materials
(Attention is drawn to the quality requirements of 6.3 and Table 2)



a) Black malleable cast iron (see 6.3)



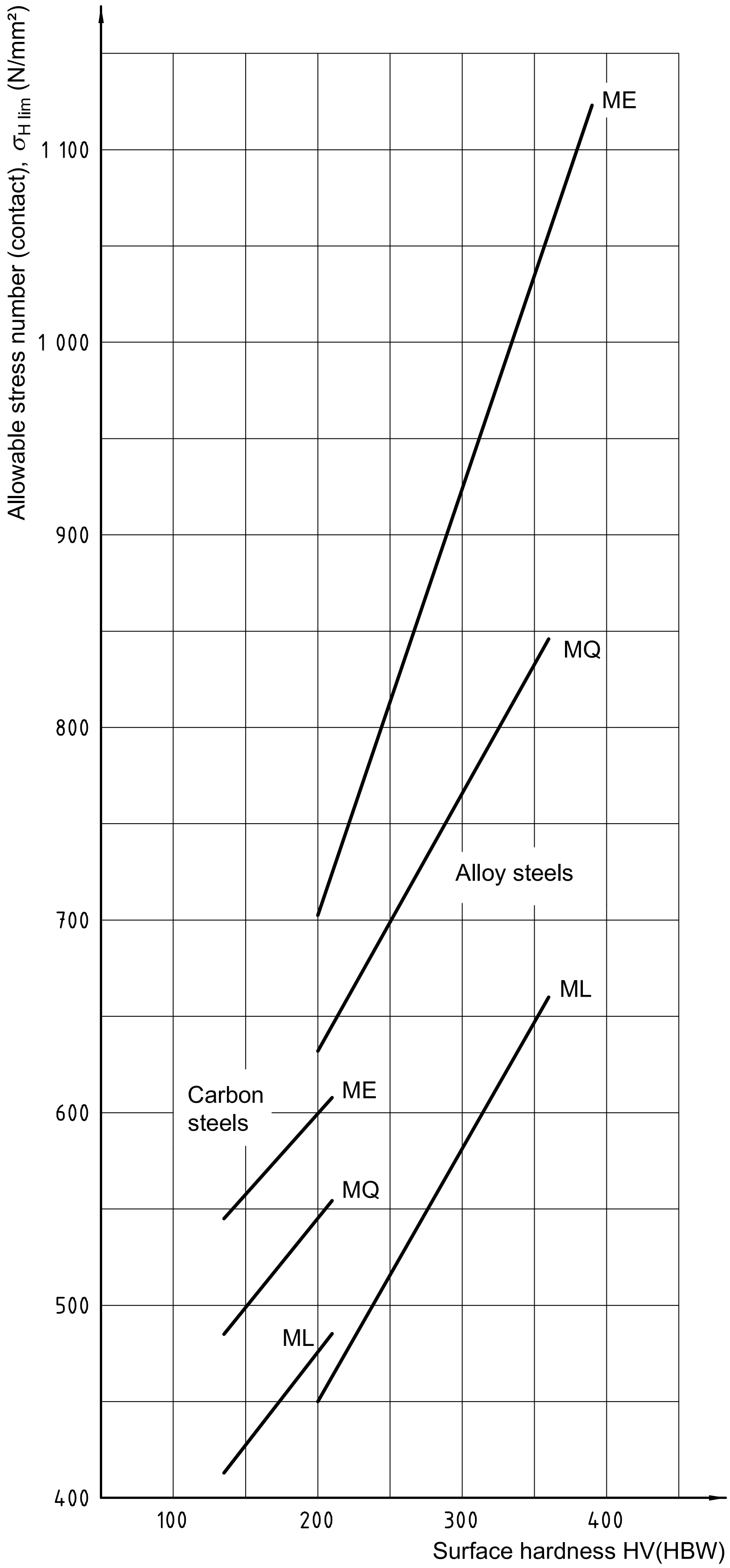
b) Nodular cast iron (see Table 2)



c) Grey cast iron (see Table 2)

NOTE Brinell hardness HBW < 180 indicates the presence of a high proportion of ferrite in the structure. For gears, this condition is not recommended.

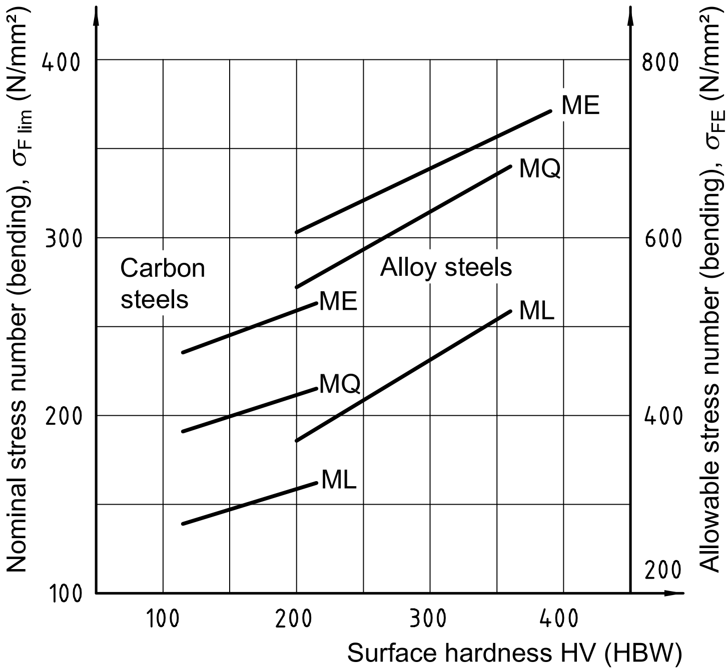
Figure 4 — Cast iron materials — Nominal and allowable stress numbers (bending) for cast iron materials (Attention is drawn to the quality requirements of 6.3 and Table 2)



NOTE 1 Nominal carbon content ⩾ 0,20 %.

NOTE 2 The alloy steel MX line from the first edition of ISO 6336-5 was replaced by the ME line.

Figure 5 — Allowable stress numbers (contact) for through hardened wrought steels
(Attention is drawn to the quality requirements of Table 3)



NOTE Nominal carbon content ⩾ 0,20 %.

Figure 6 — Nominal and allowable stress numbers (bending) for through hardened wrought steels
(Attention is drawn to the quality requirements of Table 3)

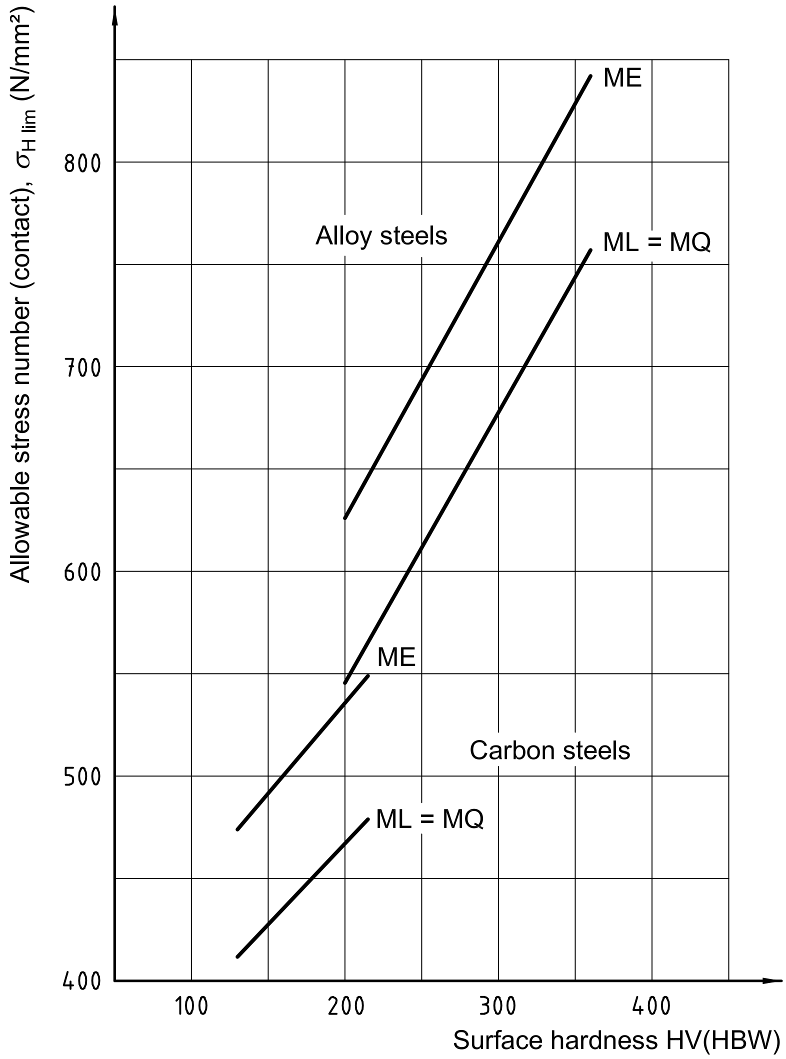


Figure 7 — Allowable stress numbers (contact) for through hardened cast steels
(Attention is drawn to the quality requirements of Table 4)

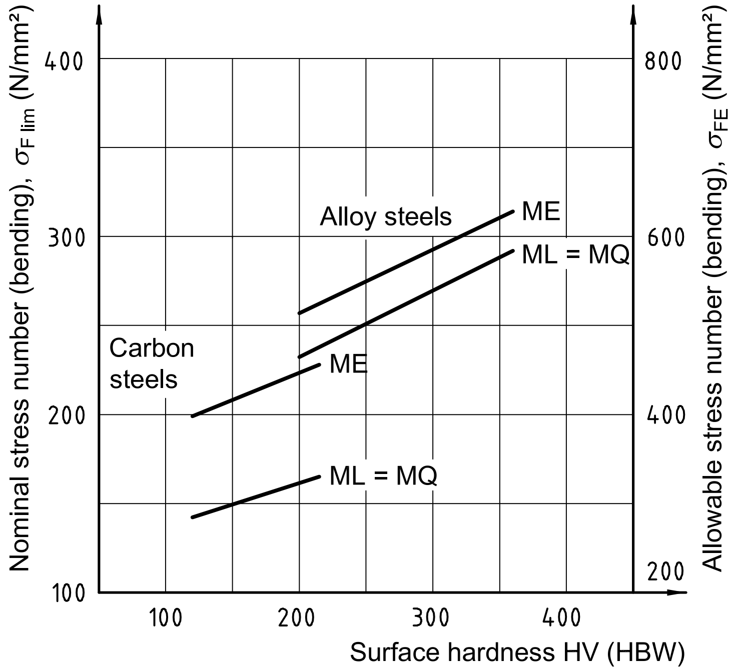
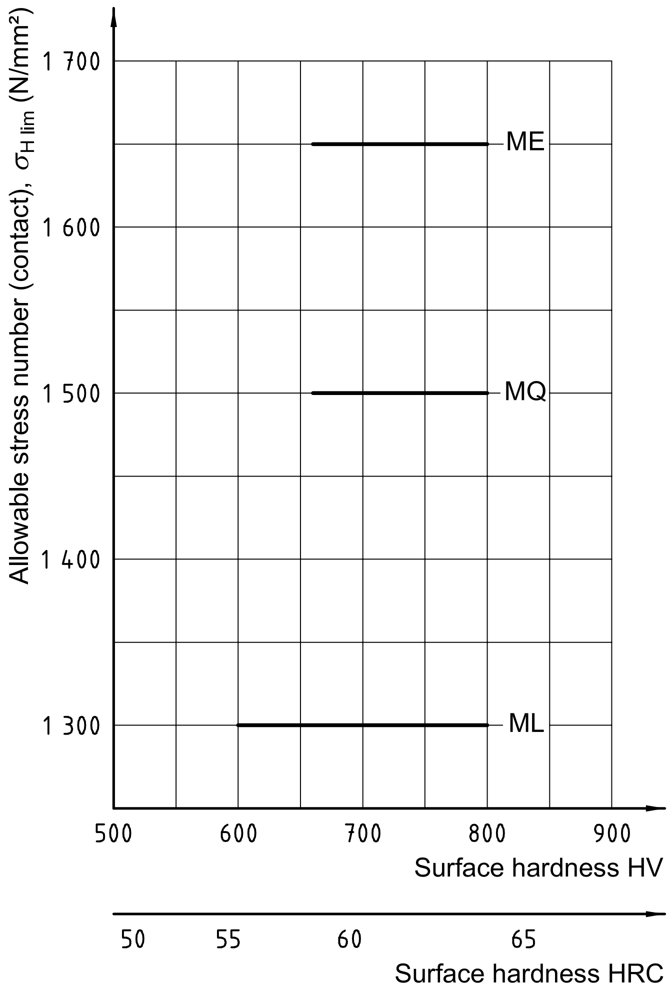
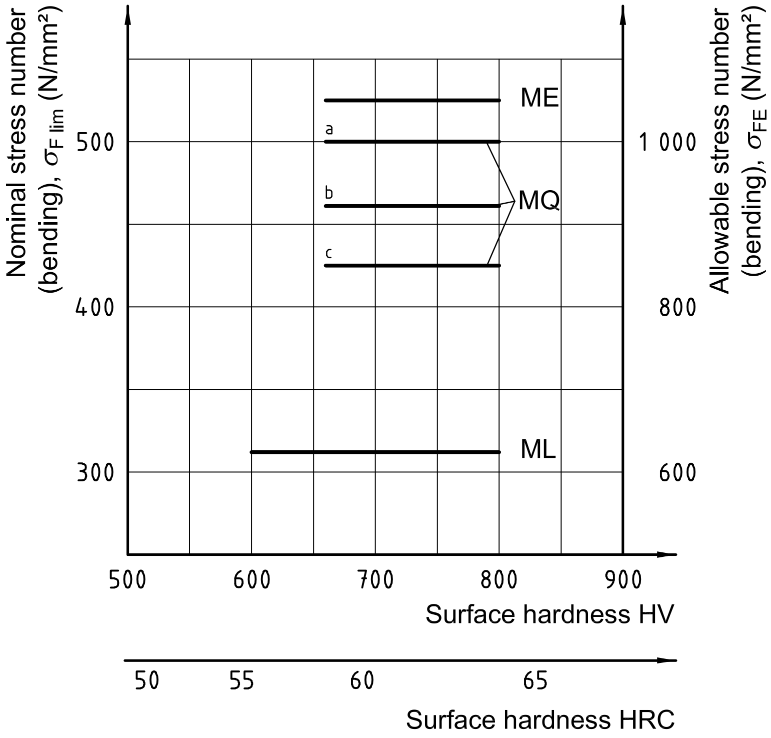


Figure 8 — Nominal and allowable stress numbers (bending) for through hardened cast steels
(Attention is drawn to the quality requirements of Table 4)



NOTE Adequate case depth required, see 5.6.1.

Figure 9 — Allowable stress numbers (contact) for case hardened wrought steels
(Attention is drawn to the quality requirements of Table 5)



a Core hardness ⩾ 30 HRC.

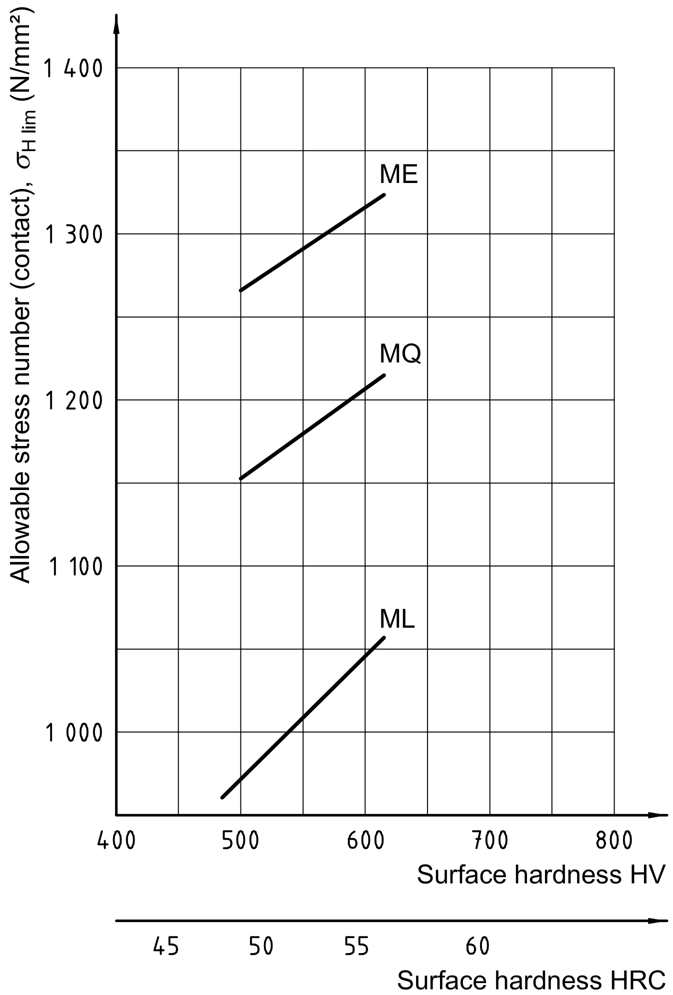
b Core hardness ⩾ 25 HRC Jominy hardenability at J = 12 mm ⩾ HRC 28.

c Core hardness ⩾ 25 HRC Jominy hardenability at J = 12 mm < HRC 28.

NOTE 1 Adequate case depth required, see 5.6.2.

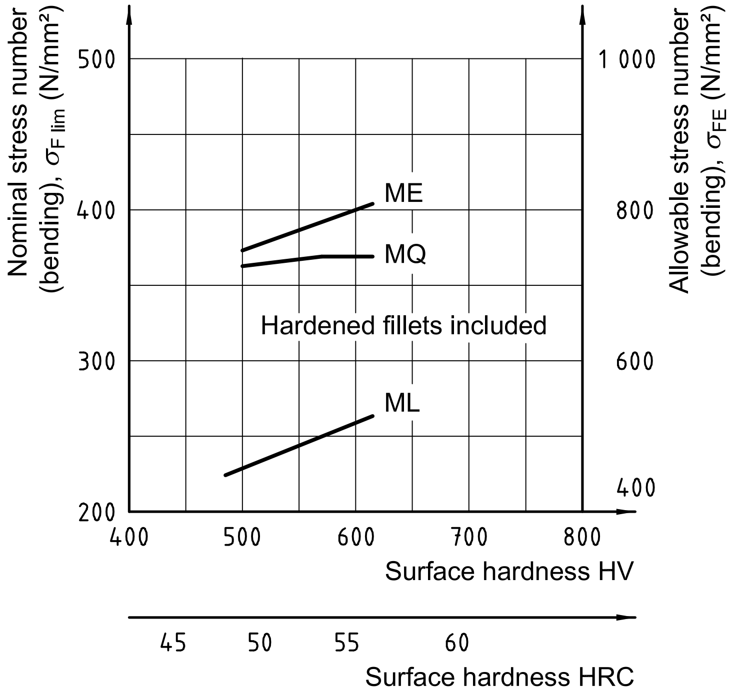
NOTE 2 See 6.6.

Figure 10 — Nominal and allowable stress numbers (bending) for case hardened wrought steels
(Attention is drawn to the quality requirements of Table 5)



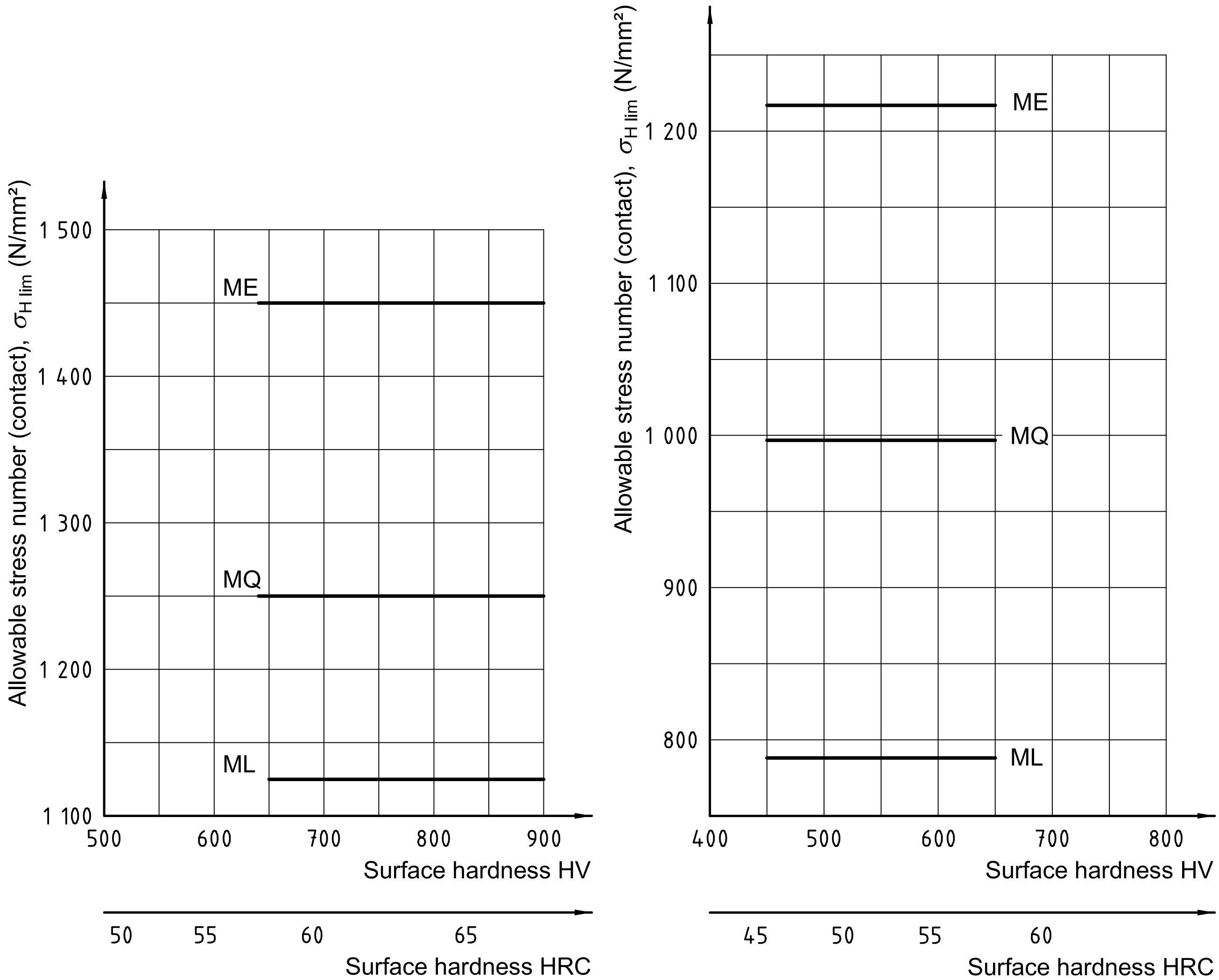
NOTE Adequate case depth required.

Figure 11 — Allowable stress numbers (contact) for flame or induction hardened wrought and cast steels (Attention is drawn to the quality requirements of Table 6)



NOTE Hardened fillets only. Values for unhardened fillets are not provided. Adequate case depth required.

Figure 12 — Nominal and allowable stress numbers (bending) for flame or induction hardened wrought and cast steels (Attention is drawn to the quality requirements of Table 6)

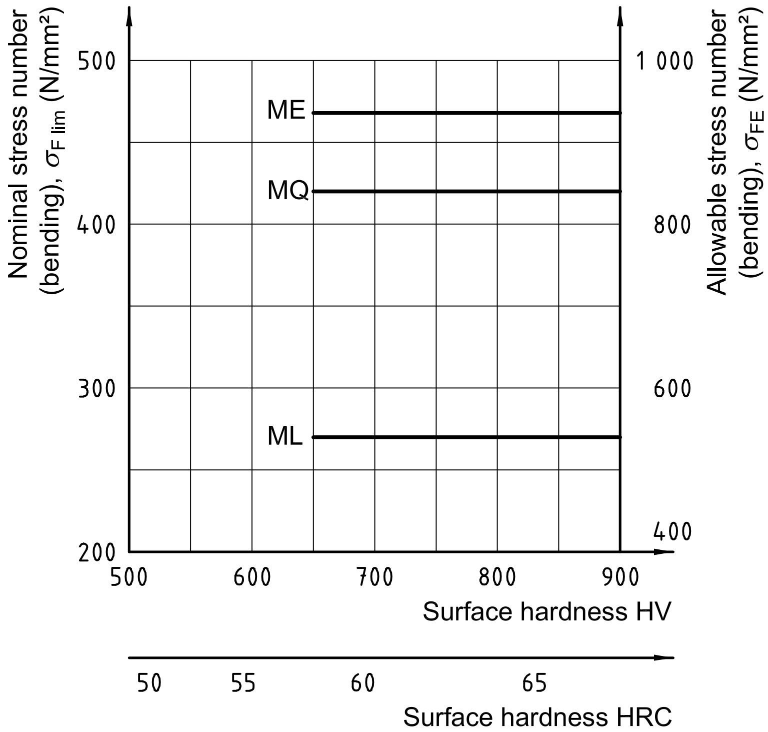


a) Nitriding steels: hardened, tempered and gas nitrided

b) Through hardening steels: hardened, tempered and gas nitrided

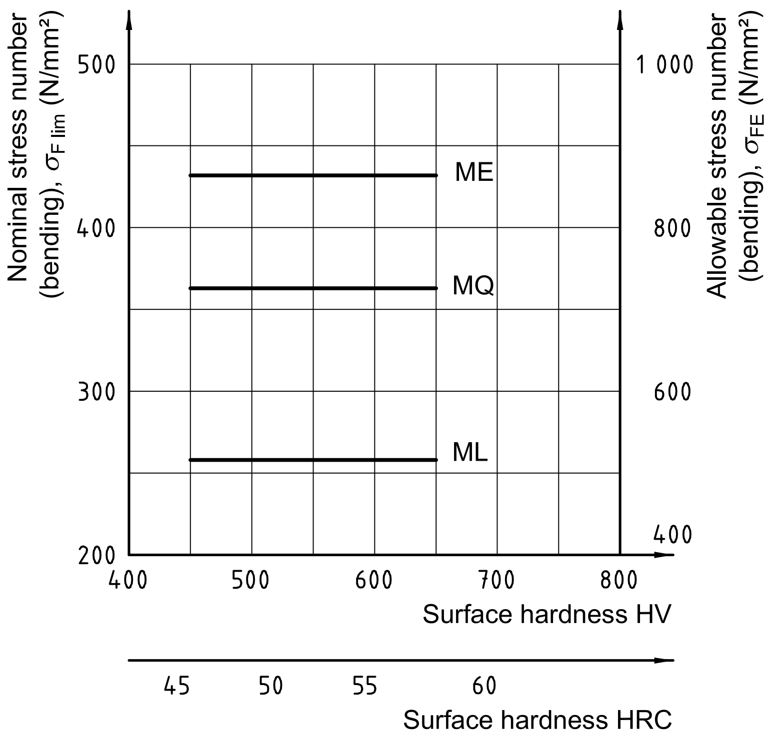
NOTE Working trials for reliability of process are recommended. Adequate case depth required, see 5.6.3.

Figure 13 — Allowable stress numbers (contact) for nitrided wrought steels/nitriding steels/through hardening steels nitrided (Attention is drawn to the quality requirements of Table 7)



NOTE Working trials for reliability of process are recommended. For flank hardness HV1 > 750, the allowable stress numbers can be reduced by embrittlement when the white layer thickness exceeds 10 µm. Adequate case depth required, see 5.6.3.

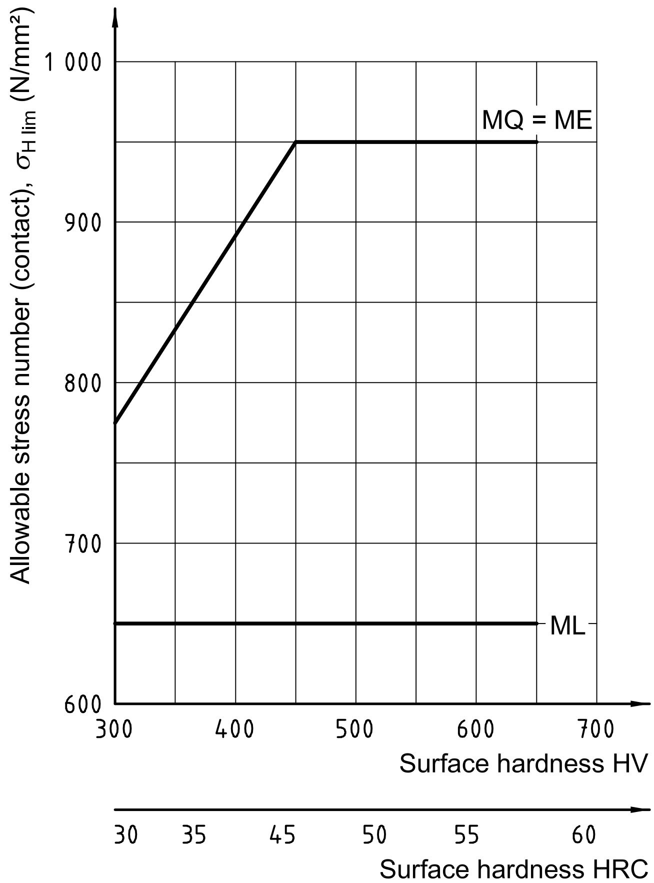
a) Nitriding steels: hardened, tempered and gas nitrided



NOTE Working trials for reliability of process are recommended. Adequate case depth required, see 5.6.3.

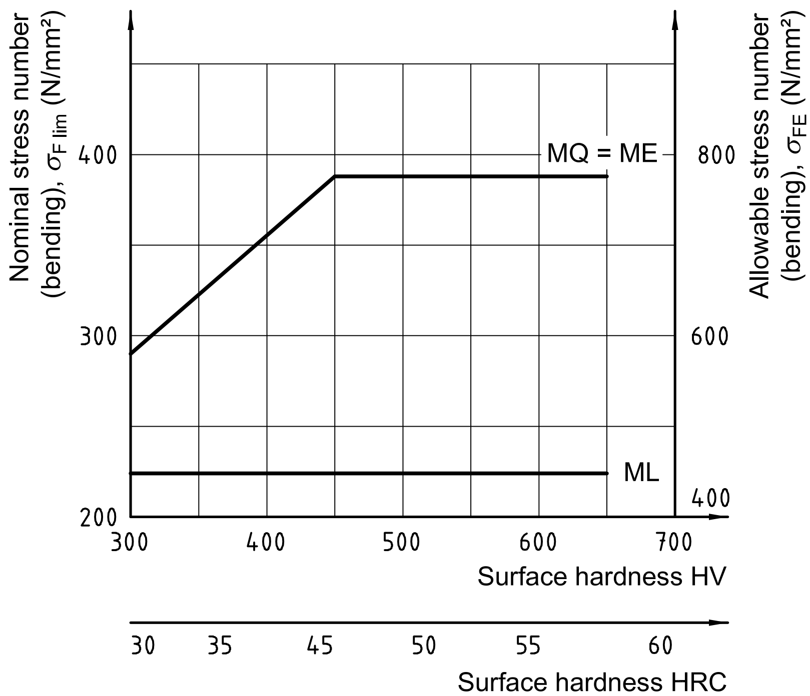
b) Through hardening steels: hardened, tempered and gas nitrided

Figure 14 — Nominal and allowable stress numbers (bending) for nitrided wrought steels/nitriding steels/through hardening steels nitrided (Attention is drawn to the quality requirements of Table 7)



NOTE Working trials for reliability of process are recommended. Adequate case depth required, see 5.6.3.

Figure 15 — Allowable stress numbers (contact) for wrought steels nitrocarburized
(Attention is drawn to the quality requirements of Table 8)



NOTE Working trials for reliability of process are recommended. Adequate case depth required, see 5.6.3.

Figure 16 — Nominal and allowable stress numbers (bending) for wrought steels nitrocarburized
(Attention is drawn to the quality requirements of Table 8)

5.6 Case depth of surface hardened gears

5.6.1 General

Surface hardened gear teeth require adequate case depth to resist the stress condition in the loaded tooth. Minimum and maximum values of case depth shall be shown on the drawing. When specifying minimum case depth, note that the “optimum” values for bending and surface load capacity are not the same. A specified maximum case thickness should not be exceeded, because to do so would increase risk of embrittlement of the tooth tips.[5)]

5.6.2 Case depth of carburized and hardened gears[6)]

See a) to d).

a) **Recommended values of case depth to avoid pittings ($Eht_{H\ opt}$):** Are shown in Figure 17. $Eht_{H\ opt}$ is the optimum effective case depth relating to permissible contact stress for long life at the reference circle after tooth finishing:

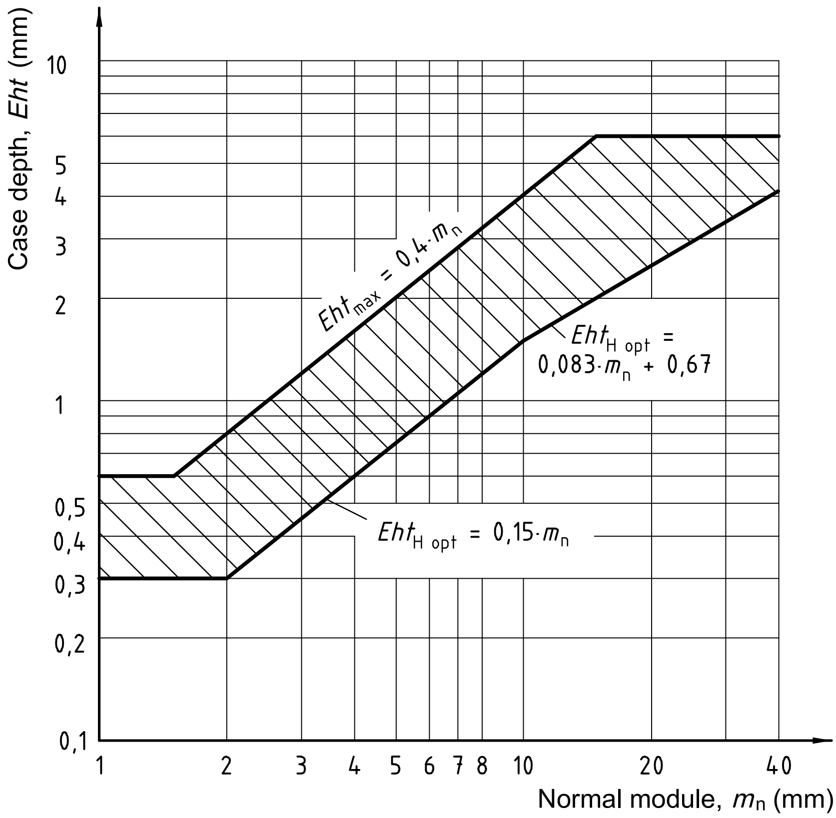


Figure 17 — Recommended values of optimum case depth $Eht_{H\ opt}$ regarding surface load capacity and maximum case depth Eht_{max} regarding bending and surface load capacity

b) **Recommended values of case depth to avoid tooth breakage ($Eht_{F\ opt}$):** $Eht_{F\ opt}$ is the optimum effective case depth relating to permissible bending stress for long life at the root fillet at mid face width and on a normal to the 30° tangent (external gears), 60° tangent (internal gears) after tooth finishing:

$$Eht_{F\ opt} = 0{,}1 \ldots 0{,}2\ m_n$$

5) The data of 5.6 may not apply to bevel gears.

6) Definition of case depth according to Table 5, Item 9.

c) **Recommended values of case depth to avoid case-crushing (Eht_c):** Eht_c is the minimum effective case depth at the reference circle after tooth finishing based on the depth of maximum shear stress from contact load.

NOTE Regarding case-crushing, at present there is no standardized calculation method available.

$$Eht_c = \frac{\sigma_H \cdot d_{w1} \cdot \sin\alpha_{wt}}{U_H \cdot \cos\beta_b} \frac{z_2}{z_1 + z_2}$$

with

U_H = 66 000 N/mm^2 for quality grades MQ/ME;

U_H = 44 000 N/mm^2 for quality grades ML.

d) **Recommended limits of minimum and maximum effective case depth:** $Eht_{min/max}$ is the effective case depth at the reference circle after tooth finishing (values also shown in Figure 17): $Eht_{min} \geqslant 0{,}3$ mm and $Eht_{max} \leqslant 0{,}4 \cdot m_n$ ($\leqslant$ 6 mm).

5.6.3 Case depth of nitrided gears[7)]

See a) and b).

a) **Recommended values of effective nitride case depth (Nht):** See in Figure 18.

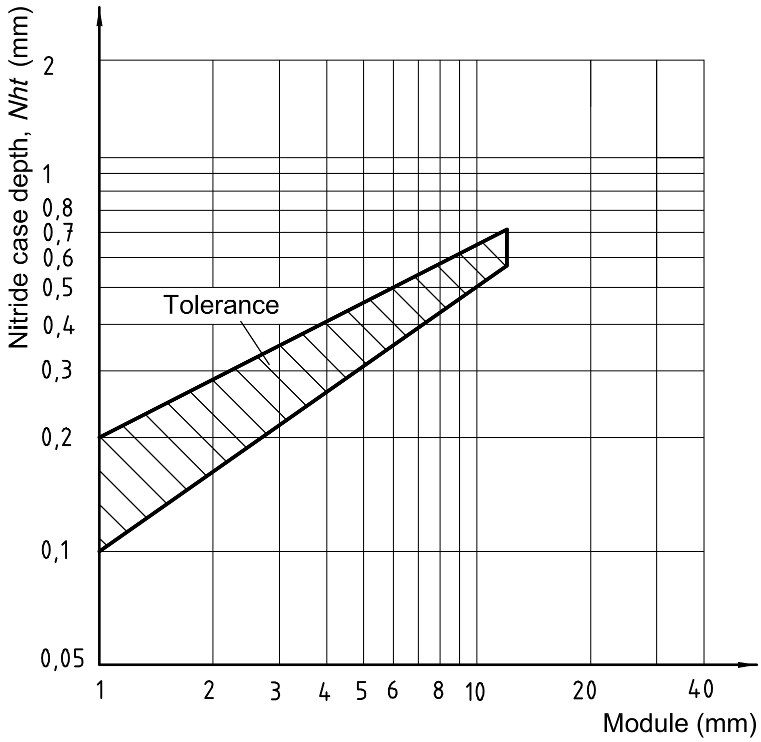


Figure 18 — Recommended values of nitride case depth, *Nht*

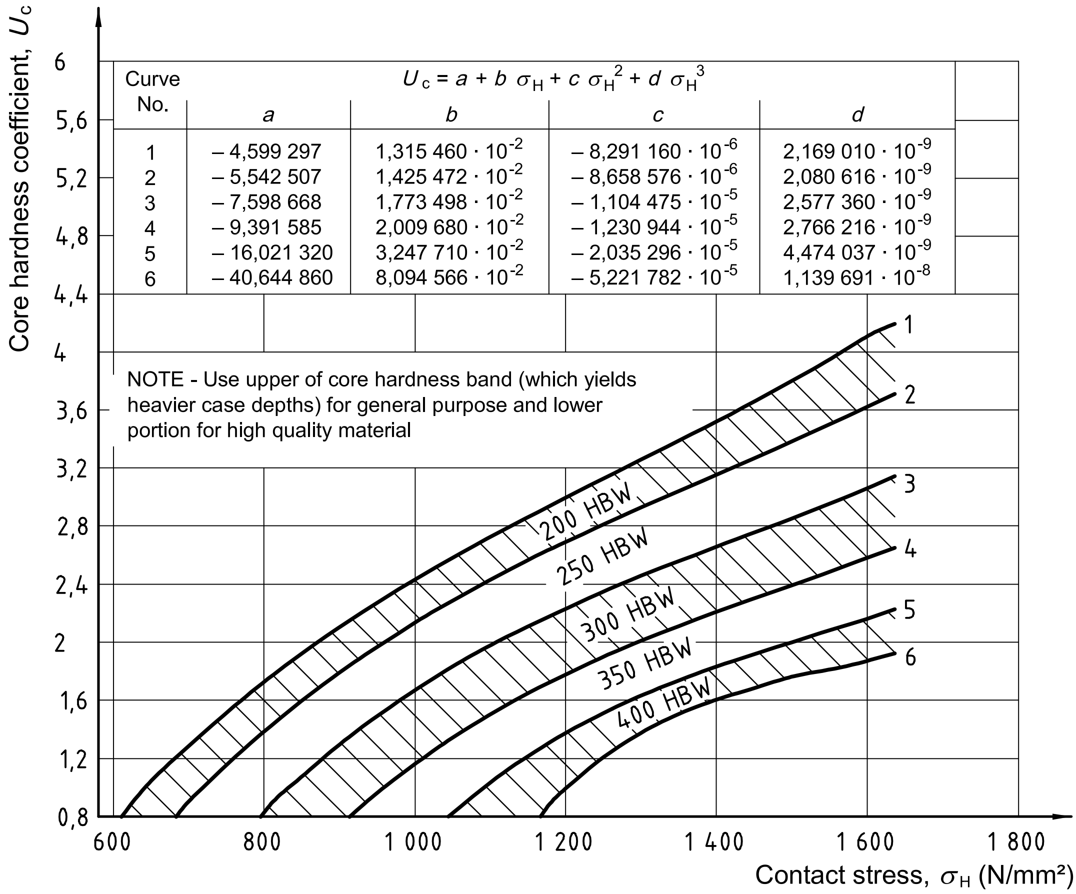
7) Definition of nitride case depth according to Table 7, Item 7.

b) **Recommended values of nitride case depth to avoid case-crushing (Nht_c):** Nht_c is the minimum total case depth for nitrided gears, and is based on the depth of maximum shear stress from contact load. If the value of Nht_c is less than the value for nitride case depth Nht from Figure 18, then the minimum value from Figure 18 should be used.

NOTE Regarding case-crushing, at present there is no standardized calculation method available.

$$Nht_c = \frac{U_c \cdot \sigma_H \cdot d_{w1} \cdot \sin \alpha_{wt}}{1{,}14 \cdot 10^5 \cdot \cos \beta_b} \frac{z_2}{z_1 + z_2}$$

where U_c is the core hardness coefficient, see Figure 19.



Curve No.	$U_c = a + b\,\sigma_H + c\,\sigma_H^2 + d\,\sigma_H^3$			
	a	b	c	d
1	– 4,599 297	$1{,}315\,460 \cdot 10^{-2}$	$-8{,}291\,160 \cdot 10^{-6}$	$2{,}169\,010 \cdot 10^{-9}$
2	– 5,542 507	$1{,}425\,472 \cdot 10^{-2}$	$-8{,}658\,576 \cdot 10^{-6}$	$2{,}080\,616 \cdot 10^{-9}$
3	– 7,598 668	$1{,}773\,498 \cdot 10^{-2}$	$-1{,}104\,475 \cdot 10^{-5}$	$2{,}577\,360 \cdot 10^{-9}$
4	– 9,391 585	$2{,}009\,680 \cdot 10^{-2}$	$-1{,}230\,944 \cdot 10^{-5}$	$2{,}766\,216 \cdot 10^{-9}$
5	– 16,021 320	$3{,}247\,710 \cdot 10^{-2}$	$-2{,}035\,296 \cdot 10^{-5}$	$4{,}474\,037 \cdot 10^{-9}$
6	– 40,644 860	$8{,}094\,566 \cdot 10^{-2}$	$-5{,}221\,782 \cdot 10^{-5}$	$1{,}139\,691 \cdot 10^{-8}$

Figure 19 — Core hardness coefficient for nitrided gearing, U_c

6 Requirements for material quality and heat treatment

6.1 General aspects

The three material quality grades ML, MQ and ME, stand in relationship to Figures 1 to 16, which means that they refer to the allowable stress numbers determined using Method B[8]. See 4.2, 5.2 and 5.3.

— ML stands for modest demands on the material quality and on the material heat treatment process during gear manufacture.

— MQ stands for requirements that can be met by experienced manufacturers at moderate cost.

— ME represents requirements that must be realized when a high degree of operating reliability is required.

NOTE This standard does not allow extrapolation of the allowable stress lines.

Frequently, special quality material such as VIM/VAR is used to achieve high reliability or load-bearing capability.

Gear wheels which are manufactured by fabricating rims to centres using conventional welding procedures should be stress relieved following the fabrication process.

The provisions given in 6.2 to 6.4 have been confirmed by practical experience and may be used as guidelines. All requirements for a material grade shall be met when the allowable stress numbers are to be applied[9]. However, depending on their experience, manufacturers may adopt methods or values other than those listed here. The manufacturer and the customer should agree on the details, particularly for large gears.

6.2 Normalized low carbon or cast steel, plain carbon, unalloyed steels (see Figures 1 and 2)

Since the composition of these is not specified and the melting method is often unknown, the MQ line was positioned at the lower limit (ML). Normalized low carbon steels are used only for lightly loaded gears and secondary applications. If high quality of steel production is achieved and when justified by experience the levels of ME may be used.

6.3 Black malleable cast iron (see Figures 3 and 4)

High quality can be achieved through controlled heat treatment. However, since it is ordinarily used for small, lightly loaded gears, the MQ line was positioned at the lower limit (ML) to be on the safe side. When justified by experience the levels of ME may be used.

6.4 Other materials (see Figures 5 to 16)

Material quality and heat treatment for other materials shall be in accordance with Tables 2 to 8.

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8) The levels of the allowable stresses have been modified in respect of the through hardened wrought steels. The material quality grade MX, which existed in the previous edition of this part of ISO 6336, was replaced by the ME line.

9) The material chosen is either that quoted in the relevant grade according to ISO 683-1, -9, -10 or -11 (recommended) or an appropriate National Standard.

Table 2 — Cast iron materials (grey and nodular — spheroidal — graphite cast iron)

Item	Requirement	**Grey cast iron** (see Figures 3 and 4)		**Nodular cast iron** (see Figures 3 and 4)	
		ML MQ	**ME**	**ML MQ**	**ME**
1	Chemical analysis	Not verified	100 % verified. Foundry certificate	Not verified	100 % verified. Foundry certificate
2	Melting practice	No specification	Electric furnace or equivalent	No specification	Electric furnace or equivalent
3	Mechanical properties evaluation	Only HBW	R_m Specific test report on a separate test piece from the same cast	Only HBW	σ_s ($\sigma_{0,2}$) σ_b $\delta_s \psi$ Specific test report per ISO 10474 of physical testing on a representative sample which is an integral part on each test piece, heat treated with the parts before being cut. Verification of HBW on gear teeth or as near as practicable.
4	Structure: graphite form	Specified but not verified	Limited	Not verified	Limited
	Basic structure	No specification (alloyed grey cast iron, maximum ferrite: 5 %)	Maximum ferrite: 5 %	No specification	
5	Tests for inner separations (cracks). Acceptability agreed between customer and supplier.	Not tested	Tested (pores, cracks, blow-holes), limited defects	Not tested	Tested (pores, cracks, blow-holes), limited defects
6	Stress relief	Not required	Recommended: 2 h at 500 °C to 530 °C. Alloyed, grey cast iron 2 h at 530 °C to 560 °C	Not required	Recommended: 2 h at 500 °C to 560 °C
7	Repair welding	Not permitted near tooth region; elsewhere, permissible only with approved processes		Not permitted near tooth region, elsewhere, permissible only with approved processes	
8	Surface crack detection	Not tested	Dye penetrant test by agreement between customer and supplier	Not tested	Cracks not permitted. 100 % magnetic particle, fluorescent magnetic particle penetrant or dye penetrant inspection. Statistical sampling permitted for large production lots.

Table 3 — Through hardened wrought steels, not surface hardened (forged or rolled steels)
(see Figures 5 and 6)

<table>
<tr><th>Item</th><th>Requirement</th><th>ML</th><th>MQ</th><th>ME</th></tr>
<tr><td>1</td><td>Chemical analysis [a, b]</td><td>Not verified</td><td colspan="2">Specific test report per ISO 10474 with 100 % traceability to the original cast.</td></tr>
<tr><td>2</td><td>Mechanical properties after heat treatment</td><td>HBW</td><td>Recommended: HBW and either mechanical tests or hardenability test.</td><td>σ_s ($\sigma_{0,2}$) σ_b δ_s ψ

Specific test report per ISO 10474 of physical testing on a representative sample from the same cast, heat treated with the parts, for forgings or rolled bars larger than 250 mm diameter and verification of surface hardness (HBW) for all parts. Optional per customer/ supplier agreement. Controlling section examples are presented in Annex A.</td></tr>
<tr><td>3</td><td>Cleanness in accordance with ISO 4967 [c]</td><td>No specification</td><td colspan="2">The steel shall be deoxidized and refined in the ladle. Steel shall be vacuum degassed. The steel shall be protected from reoxidation during the teeming or casting. Adding calcium when melting the steel — maximum 15 ppm (=15 µg/g) — is permissible for castability subject to agreement by the end-user. Oxygen content 25 ppm (= 25 µg/g) maximum. Cleanness in accordance with ISO 4967, procedure in accordance with Method B, Plate II, inspected area approximately 200 mm^2 and the following acceptance table. Other specifications, which ensure the equivalent cleanliness are permitted. Test report in accordance with ISO 10474
<table>
<tr><th></th><th colspan="2">A</th><th colspan="2">B</th><th colspan="2">C</th><th colspan="2">D</th></tr>
<tr><th></th><th>Fine</th><th>Thick</th><th>Fine</th><th>Thick</th><th>Fine</th><th>Thick</th><th>Fine</th><th>Thick</th></tr>
<tr><td>MQ</td><td>3,0</td><td>3,0</td><td>2,5</td><td>1,5</td><td>2,5</td><td>1,5</td><td>2,0</td><td>1,5</td></tr>
<tr><td>ME</td><td>3,0</td><td>2,0</td><td>2,5</td><td>1,5</td><td>1,0</td><td>1,0</td><td>1,5</td><td>1,0</td></tr>
</table></td></tr>
<tr><td>4</td><td>Grain size in accordance with ISO 643</td><td>No specification</td><td colspan="2">Fine grain, predominantly 5 and finer. Test report in accordance with ISO 10474</td></tr>
<tr><td>5</td><td colspan="4">Non destructive testing</td></tr>
<tr><td>5.1</td><td>Ultrasonic test (in rough machined condition)</td><td>No specification</td><td colspan="2">Checked after forging. Specific test report in accordance with ISO 10474: recommended. Suggested for large diameter parts to detect flaws before the expense of tooth cutting. Inspection per ASTM A388, using either the back reflection or reference block 8-0400, 3,2 mm flat bottom hole per ASTM E428 technique. Inspection is from the outside diameter to the mid-radius and a 360° scan is required. A distance amplitude correction curve (single point DAC) is not intended. Other UT specifications which ensure the same quality level are permitted.</td></tr>
<tr><td>5.2</td><td>Surface cracks detection (in finished condition, before any shot peening treatment)</td><td colspan="2">Cracks are not permitted. Inspection by ASTM E1444 including fluorescent, magnetic particle or dye penetrant inspection.</td><td>Cracks are not permitted. Ground gears shall be inspected for surface cracks. Inspection by ASTM E1444, including fluorescent, magnetic particle or dye penetrant inspection. Method to be agreed between buyer and seller.</td></tr>
<tr><td>6</td><td>Area reduction ratio [d]</td><td>No specification</td><td colspan="2">At least 3 : 1</td></tr>
</table>

Table 3 (*continued*)

Item	Requirement	ML	MQ	ME
7	Microstructure	No specification	No specification. For material strengths greater than 800 N/mm^2 (240 HBW) the gear should be quenched and tempered.	Minimum temper temperature 480 °C. Root hardness shall meet drawing requirements. Microstructure in gear rim predominantly tempered martensite. [e]

To use the values in the tables a hardness difference of 40 HV minimum is recommended between the pinion and the wheel.

[a] See Clause 6, footnote 8.

[b] **CAUTION: For cold service, below 0 °C:**
- **consider low temperature Charpy specification;**
- **consider fracture appearance transition or nil ductility temperature specification;**
- **consider using higher nickel alloy steels;**
- **consider reduced carbon content to less than 0,4 % carbon;**
- **consider using heating elements to increase lubricant temperature.**

[c] The grade cleanness requirements apply only to those portions of the gear material where the teeth will be located at a distance below the finished tip diameter of at least two times the tooth depth. On external gears, this portion of the gear blank normally will be less than 25 % of the radius.

[d] The area reduction is a total reduction irrespective of the method. Applies to forgings from ingot cast material. For continuous cast material the minimum reduction is 5 : 1.

[e] The microstructure of the gear section to a depth of 1,2 times the tooth height to consist primarily of tempered martensite with limited upper transformation products (proeutectoid ferrite, upper bainite and fine pearlite). No blocky ferrite, due to incomplete austenitization, is permitted. The maximum limit for upper transformation products is 10 % for gear controlling sections $\leqslant$ 250 mm, and 20 % for gear controlling sections > 250 mm.

Table 4 — Through hardened cast steels, not surface hardened (see Figures 7 and 8)

Item	Requirement	ML-MQ	ME
1	Chemical analysis	Not verified	Specific test report in accordance with ISO 10474 with 100 % traceability to the original cast.
2	Mechanical properties after heat treatment	HBW	σ_S ($\sigma_{0,2}$) σ_B δ_S ψ HBw Specific test report in accordance with ISO 10474 with 100 % traceability to the original cast. Verification of HBW. Optional per customer/supplier agreement. Statistical inspection required.
3	Grain size in accordance with ISO 643	No specification	Fine grain, size 5 or finer. Test report per ISO 10474. Optional per customer/supplier agreement.
4	Non destructive testing		
4.1	Ultrasonic test (in rough machined condition) in accordance with ISO 9443	No specification	Check tooth and tooth root areas only. Specific test report in accordance with ISO 10474. Recommended but not required. Suggested for large diameter parts to detect flaws before the expense of tooth cutting. Acceptance criteria per ASTM A609 level 1 in Zone 1 (Outside diameter to 25 mm below roots) and level 2 in Zone 2 (remainder of rim) using 3,2 mm flat bottom hole; or approved equivalent using back reflection technique.
4.2	Surface cracks detection (in finished condition but before any shot peening treatment)	Cracks not permitted. 100 % inspection by ASTM E1444 including fluorescent, magnetic particle or dye penetrant inspection. Statistical sampling permitted for large production lots.	
5	Repair welding	Allowed with approved procedure.	Allowed only in rough condition if performed before heat treatment. Not allowed after tooth cutting.

When the casting quality meets the quality criteria for wrought (forged or rolled) steels, wrought steel allowable stress numbers may be used in gear rating calculations for cast steel gears operating with wrought steel pinions. Suitability of using wrought steel allowable stress numbers for casting rating calculations shall be supported by test and operating experience.

For castings, wrought steel cleanness and forging reduction ratio criteria are excluded. Inclusion content and shape control are required to produce predominantly round manganese sulfide inclusions (Type I). No grain boundary (Type II) manganese sulfide inclusions permitted.

Table 5 — Case hardened wrought steels (forged or rolled steels) (see Figures 9 and 10)

<table>
<tr><th>Item</th><th>Requirement</th><th>ML</th><th colspan="4">MQ</th><th colspan="5">ME</th></tr>
<tr><td>1</td><td>Chemical analysis [a]</td><td>Not verified</td><td colspan="4">Specific test report in accordance with ISO 10474 with 100 % traceability to the original cast.</td><td colspan="5">Specific test report in accordance with ISO 10474 of testing on a representative sample from the same cast.</td></tr>
<tr><td>2</td><td>Hardenability by end quench test (see ISO 642)</td><td>Not verified</td><td colspan="4">Specific test report in accordance with ISO 10474 with 100 % traceability to the original cast.</td><td colspan="5">Specific test report in accordance with ISO 10474 of testing on a representative sample from the same cast</td></tr>
<tr><td rowspan="5">3</td><td rowspan="5">Cleanness, steelmaking [b]</td><td rowspan="5">No specification</td><td colspan="9">The steel shall be deoxidized and refined in the ladle. Steel shall be vacuum degassed. The steel shall be protected from reoxidation during the teeming or casting. Adding calcium when melting the steel — maximum 15 ppm (= 15 μg/g) — is permissable for castability subject to agreement by the end-user. Oxygen content 25 ppm (= 25 μg/g) maximum. Cleanness in accordance with ISO 4967, procedure in accordance with Method B, Plate II, inspected area approximately 200 mm^2 and the following acceptance table. Other specifications, which ensure the equivalent cleanliness are permitted. Test report in accordance with ISO 10474</td></tr>
<tr><td></td><td colspan="2">A</td><td colspan="2">B</td><td colspan="2">C</td><td colspan="2">D</td></tr>
<tr><td></td><td>Fine</td><td>Thick</td><td>Fine</td><td>Thick</td><td>Fine</td><td>Thick</td><td>Fine</td><td>Thick</td></tr>
<tr><td>MQ</td><td>3,0</td><td>3,0</td><td>2,5</td><td>1,5</td><td>2,5</td><td>1,5</td><td>2,0</td><td>1,5</td></tr>
<tr><td>ME</td><td>3,0</td><td>2,0</td><td>2,5</td><td>1,5</td><td>1,0</td><td>1,0</td><td>1,5</td><td>1,0</td></tr>
<tr><td>4</td><td>Area reduction ratio [c]</td><td>No specification</td><td colspan="9">At least 3 : 1</td></tr>
<tr><td>5</td><td>Grain size in accordance with ISO 643</td><td>No specification</td><td colspan="9">Fine grain, predominantly 5 and finer. Test report in accordance with ISO 10474</td></tr>
<tr><td rowspan="2">6</td><td rowspan="2">Ultrasonic test in rough machined condition.
ASTM A388</td><td rowspan="2">No specification</td><td colspan="4">Recommended. Suggested for large diameter parts to detect flaws before the expense of tooth cutting.</td><td colspan="5">Required. Statistical samples permitted when lot size is ≥ 5.</td></tr>
<tr><td colspan="9">Inspection per ASTM A388, using either the back reflection or reference block 8-0400; 3,2 mm flat bottom hole per ASTM E428 technique. Inspection is from the outside diameter to the mid-radius and a 360° scan is required. A distance amplitude correction curve (single point DAC) is not intended. Other UT specifications which ensure the same quality level are permitted.</td></tr>
<tr><td>7</td><td colspan="11">Surface hardness</td></tr>
<tr><td>7.1</td><td>Surface hardness on a representative surface of workpiece[d]. (See Vickers-Rockwell hardness conversion table in Annex B)</td><td>600 HV or 55 HRC minimum. Statistical sample testing</td><td colspan="4">660 HV to 800 HV or 58 HRC to 64 HRC. Statistical sample testing.</td><td colspan="5">660 HV to 800 HV or 58 HRC to 64 HRC. 100 % testing if heat treatment lot size ≤ 5, else statistical samples permitted. Test method as appropriate for the size of the part.</td></tr>
<tr><td>7.2</td><td>Surface hardness in root space, mid-face width, for modules ≥ 12 [d].</td><td>No specification</td><td colspan="4">Meets drawing specification. Statistical sampling or on representative test piece in agrreement between supplier and purchaser.</td><td colspan="5">Meets drawing specification. 100 % testing of every pinion and gear wheel or on representative test piece in agreement between supplier and purchaser.</td></tr>
<tr><td>8</td><td>Core hardness at mid-face width on a normal to the 30° tangent at distance 5 × case depth but not less than 1 × module or measured on a representative test bar in accordance with 6.5.</td><td>21 HRC or more. Specified but not verified.</td><td colspan="4">25 HRC or more, measured on a representative test bar per 6.5 b) or calculated based on knowledge of quench rate and hardenability curve.</td><td colspan="5">30 HRC or more, measured on sample part or representative test bar in accordance with 6.5.</td></tr>
</table>

Table 5 (*continued*)

<table>
<tr><th>Item</th><th>Requirement</th><th>ML</th><th colspan="2">MQ</th><th colspan="2">ME</th></tr>
<tr><td>9</td><td>Case depth in finished condition in accordance with ISO 2639. Measured on representative test bar per 6.5 or measured at mid-face width one addendum below the tip circle.</td><td colspan="5">Case depth is defined as the distance from the surface to a point at which the hardness number is 550 HV or 52 HRC.

Minimum and maximum limits shall be shown on the drawing. When specifying case depth, note that the “optimum” values for bending and surface load capacity are not the same. Recommended values of case depth are shown in 5.6 [e].</td></tr>
<tr><td>10</td><td colspan="6">Inspection of all microstructure requirements can be made on one representative test bar in accordance with 6.5. This inspection is optional for MQ but required for ME. (Not required for ML)</td></tr>
<tr><td>10.1</td><td>Limits on surface carbon content.</td><td>No specification</td><td colspan="4">Low nominal alloy steels with total alloy content ⩽ 1,5 %: 0,70 % to 1,0 %.
High nominal alloy steels with total alloy content > 1,5 %: 0,65 % to 0,90 %.
Recommended.</td></tr>
<tr><td>10.2</td><td>Surface structure: The desired structure has less than 10 % bainite.</td><td>No specification</td><td colspan="2">Recommended.
Martensite, essentially fine acicular, as shown by a representative test bar.</td><td colspan="2">Required.
Martensite, fine acicular, as shown by a representative test bar.</td></tr>
<tr><td>10.3</td><td>Reduction of surface hardness in the outer 0,1 mm of the case, except in the root, due to decarburization, retained austenite or non-martensitic components [f].</td><td>No specification</td><td colspan="4">Maximum 40 HV on the part or on a representative test bar.</td></tr>
<tr><td>10.4</td><td>Carbide precipitation</td><td>Semi-continuous carbide network permitted in accordance with Figure 20 a). On representative test bar, if used.</td><td colspan="2">Discontinuous carbides permitted in accordance with Figure 20 b). Maximum length of any carbide is 0,02 mm. (On representative test bar, if used.)</td><td colspan="2">Dispersed carbides permitted in accordance witrh Figure 20 c). Inspection of representative test bar in accordance with 6.5.</td></tr>
<tr><td rowspan="2">10.5</td><td rowspan="2">Residual austenite. Determined by metallographic inspection.</td><td rowspan="2">No specification</td><td colspan="2">Up to 25 % on inspection of companion heat treatment batch test piece.</td><td colspan="2">Up to 25 %, finely dispersed. Inspection of representative test bar in accordance with 6.5.</td></tr>
<tr><td colspan="4">If outside specification, salvage may be passable by controlled shot-peening, or other appropriate procedures, with the agreement of the customer.</td></tr>
<tr><td rowspan="7">10.6</td><td rowspan="7">Intergranular oxidation (IGO), applicable to unground surface. Determined by metallographic inspection of unetched coupon, if used. Limits in micrometers shall be based on case depth as given.</td><td rowspan="7">No specification</td><td>Case depth e [mm]</td><td>IGO [µm]</td><td>Case depth e [mm]</td><td>IGO [µm]</td></tr>
<tr><td>e < 0,75</td><td>17</td><td>e < 0,75</td><td>12</td></tr>
<tr><td>0,75 < e < 1,50</td><td>25</td><td>0,75 < e < 1,50</td><td>20</td></tr>
<tr><td>1,50 < e < 2,25</td><td>38</td><td>1,50 < e < 2,25</td><td>20</td></tr>
<tr><td>2,25 < e < 3,00</td><td>50</td><td>2,25 < e < 3,00</td><td>25</td></tr>
<tr><td>e > 3,00</td><td>60</td><td>e > 3,00</td><td>30</td></tr>
<tr><td colspan="4">If outside specification, salvage may be possible by controlled shot-peening, or other appropriate procedures, with the agreement of the customer.</td></tr>
</table>

Table 5 (*continued*)

<table>
<tr><th>Item</th><th>Requirement</th><th>ML</th><th colspan="2">MQ</th><th colspan="2">ME</th></tr>
<tr><td>11</td><td>Surface cracks. Removal of defects is acceptable, with customer approval, provided that the integrity of the gear is not compromised [g].</td><td>Cracks not permissible. Statistical sample inspection by magnetic particle inspection, fluorescent magnetic particle penetrant or dye penetrant method.</td><td colspan="2">Cracks not permissible. 50 % inspection by ASTM E1444 (magnetic particle inspection method).

Statistical inspection depending on lot size permitted</td><td colspan="2">Cracks not permissible. 100 % inspection by ASTM E1444 (magnetic particle inspection method).

Statistical inspection permitted if lot size ⩾ 5</td></tr>
<tr><td rowspan="4">12</td><td rowspan="4">Magnetic particle inspection (teeth area only)
ASTM E1444 [g]</td><td rowspan="4">No specification</td><td>Module</td><td>Max. indication mm</td><td>Module</td><td>Max. indication mm</td></tr>
<tr><td>⩽ 2,5</td><td>1,6</td><td>⩽ 2,5</td><td>0,8</td></tr>
<tr><td>> 2,5 to 8</td><td>2,4</td><td>> 2,5 to 8</td><td>1,6</td></tr>
<tr><td>> 8</td><td>3,0</td><td>> 8</td><td>2,4</td></tr>
<tr><td rowspan="2">13</td><td rowspan="2">Grinding temper control using nital etch in accordance with ISO 14104 [h]</td><td rowspan="2">Grade B temper permitted on 100 % of functional area (FB3), statistical inspection recommended but not required.</td><td colspan="2">Grade B temper permitted on 25 % of functional area (FB2), statistical inspection required.</td><td colspan="2">Grade B temper permitted on 10 % of functional area (FB1), 100 % inspection by ISO 14104.

Statistical inspection depending on lot size acceptable.</td></tr>
<tr><td colspan="4">If outside specification, salvage may be possible by controlled shot-peening, with the agreement of the customer.</td></tr>
<tr><td>14</td><td>Core structure at the same location as item 8.</td><td>No specification</td><td colspan="2">Martensite, acicular ferrite and bainite. No blocky ferrite (see item 8)</td><td colspan="2">Martensite, acicular ferrite and bainite. No blocky ferrite. Applies to representative test bar in accordance with 6.5</td></tr>
<tr><td colspan="7">NOTE See also 6.6 and 6.7. Requirements for carbo-nitrided steels are presently not given in the standard.</td></tr>
</table>

[a] See Clause 6, Footnote 9.

[b] The grade cleanness requirements apply only to those portions of the gear material where the teeth will be located at a distance below the finished tip diameter of at least two times the tooth depth. On external gears, this portion of the gear blank normally will be less than 25 % of the radius.

[c] The area reduction is a total reduction irrespective of the method. Applies to forgings from ingot cast material. For continuous cast material the minimum reduction is 5 : 1.

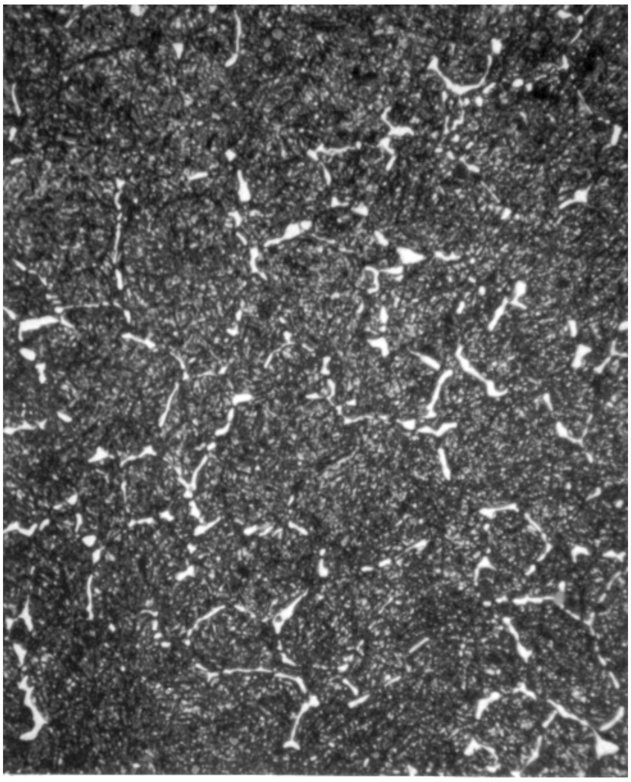
[d] Root hardness may be somewhat less than flank hardness, depending on the size of the gear and the process. Allowable values may be agreed between manufacturer and purchaser.

[e] For other values of case depth see, for example, [10].

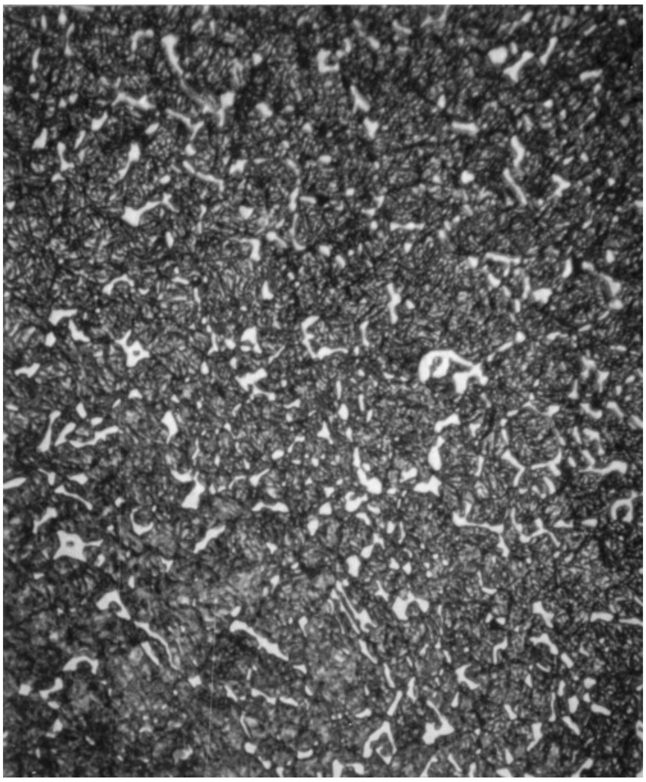
[f] File testing is an accepted method to inspect surface hardness, see Annex E.

[g] No cracks, bursts, seams or laps are permitted in the tooth areas of finished gears, regardless of grade. Limits: maximum of one indication per 25 mm of face width and maximum of five in one tooth flank. No indications allowed below 1/2 of working depth of tooth. Removal of defects which exceed the stated limits is acceptable, with customer approval, provided the integrity of the gear is not compromised.

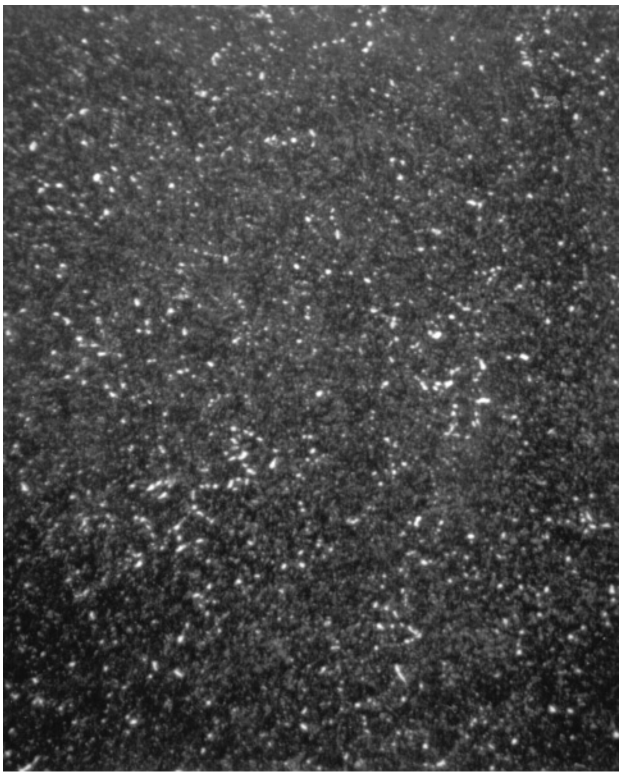
[h] Other methods are available for grinding temper control and can be used by agreement between purchaser and supplier.



a) Semi-continuous carbide network:
Permissible for Grade ML



b) Discontinuous carbides:
Permissible for ML and MQ



c) Dispersed carbides:
Permissible for ML, MQ and ME

Figure 20 — Photo micrographs of permissible carbide structures for case of carburized gears (5 % nital etch. × 400 magnification)

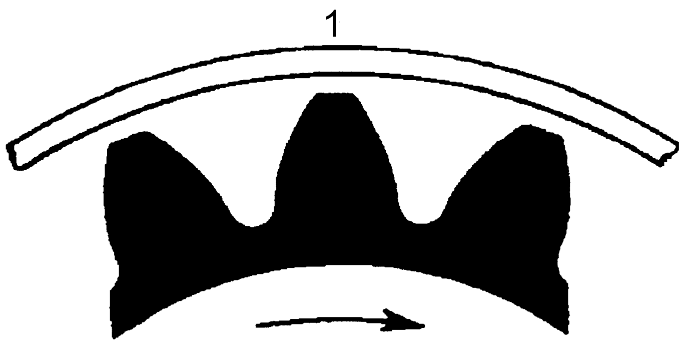
Table 6 — Induction or flame hardened wrought and cast steels (see Figures 11 and 12)

Item	Requirement	ML	MQ	ME	
1	Chemical analysis	No specification	As in Table 3 (through hardened wrought steels: items 1 to 6) or as in Table 4 (through hardened cast steels: items 1 to 3)		
2	Mechanical properties — after heat treatment				
3	Cleanness				
4	Grain size				
5	Ultrasonic test				
6	Extent of forging reduction				
7	Surface hardness. All induction hardened gears shall be furnace tempered.	485 HV to 615 HV or 48 HRC to 56 HRC	500 HV to 615 HV or 50 HRC to 56 HRC		
8	Hardening depth [a], in accordance with ISO 3754	The hardening depth is defined as the distance to the surface from a point where the hardness is equal to 80 % of the required surface hardness. Depth of case to be determined for each part by experience.			
9	Surface structure	No specification	Inspection of statistical samples, mainly fine acicular martensite.	Stricter inspection of statistical samples, fine acicular martensite, ⩽ 10 % non-martensitic structure; no free ferrite permitted.	
10	Non-destructive testing				
10.1	Surface cracks — not permitted (ASTM E1444).	Inspection of first batch (magnetic particle, fluorescent magnetic particle penetrant or dye penetrant method)	Inspection of first batch (magnetic particle, fluorescent magnetic particle penetrant or dye penetrant method)	100 % inspection (magnetic particle, fluorescent magnetic particle penetrant or dye penetrant method).	
10.2	Magnetic particle inspection (teeth area only) ASTM E1444 [b]	No specification		Module	Max. indication mm
				⩽ 2,5	1,6
				> 2,5 to 8	2,4
				> 8	3,0
11	Prior structure	Quenched and tempered			
12	Overheating, especially at the tooth tips	To be avoided	Strict avoidance (< 1 000 °C)		

NOTE This table applies to spin type flame hardening or spin and tooth-to-tooth type induction hardening with hardened roots, hardness patterns similar to Figures 21 and 22.

[a] The hardness pattern, depth, facilities and process method shall be established, documented and checked to be repeatable. A representative sample, with the same geometry and material as the work piece, shall be used to qualify the process. The process equipment and methods shall be sufficiently accurate to reproduce the specified results. The hardness pattern shall extend the full length of the teeth and over the full profile, both flanks, both roots and both root fillets.

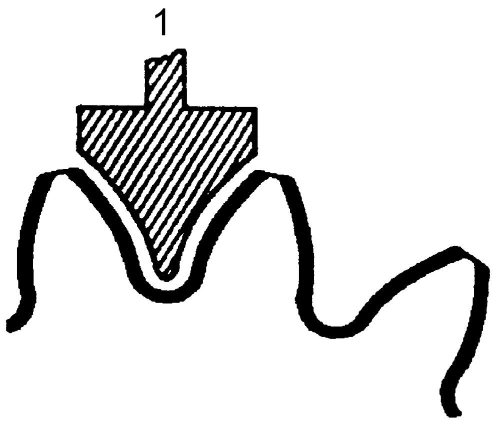
[b] No cracks, bursts, seams or laps are permitted in the tooth areas of finished gears, regardless of grade. Limits: maximum of one indication per 25 mm of face width and maximum of five in one tooth flank. No indications allowed below 1/2 of working depth of tooth. Removal of defects which exceed the stated limits is acceptable, with customer approval, provided the integrity of the gear is not compromised.



Key

1 induction coil or flame head

Figure 21 — Example for non-contour hardening



Key

1 inductor or flame head

Figure 22 — Example for contour hardening

Table 7 — Nitrided wrought steel, nitriding and through hardening steels, nitrided
(see Figures 13 and 14)

Item	Requirement	ML	MQ	ME
1	Chemical analysis	As in Table 3 (through hardened wrought steels: items 1 to 6)		
2	Mechanical properties — after heat treatment			
3	Cleanness			
4	Grain size			
5	Ultrasonic test			
6	Extent of forging reduction			
7	Nitride case depth	**Minimum value specified** The effective nitride case depth is defined as the distance from the surface to a point at which the hardness number is 400 HV or 40,8 HRC. If the core hardness exceeds 380 HV, core hardness + 50 HV may be applied. Recommended values of the nitride case depth Nht are shown in 5.6.		
8	Surface hardness			
8.1	Nitriding steels [a,b,c]	650 HV minimum 900 HV maximum [d]		
8.2	Through hardening steels [a]	450 HV minimum		
9	Pretreatment	Hardened and tempered without decarburization of finished surfaces. Tempering temperature is to exceed nitriding temperature by a margin sufficient to avoid softening during the nitriding cycle.		
10	Surface zone: (white layer)	$\leqslant$ 25 µm	White layer $\leqslant$ 25 µm mostly ε with little of γ' nitrides	White layer $\leqslant$ 25 µm thick; proportion of ε/γ' nitrides > 8; if ground after nitriding, check pitting load capacity.
11	Core	σ_B not verified	σ_B > 900 N/mm^2 (in general, percentage of ferrite less than 5 %)	
12	Finished condition after nitriding.	—	Ground only in special cases; be cautious of possible reduction of surface load capacity. If tooth grinding is provided, magnetic particle inspection by ASTM E1444 recommended.	Ground only in special cases; be cautious of possible reduction of surface load capacity. If tooth grinding is provided, magnetic particle inspection by ASTM E1444 required.

NOTE The overload capacity of many nitrided gears is low.

[a] Surface hardness is measured perpendicular to the surface; values measured on a section may be higher. The test load should be appropriate for the case depth and the hardness.

[b] The overload capacity of nitrided gears is low. Since the shape of the S-N curve is flat, the sensitivity to shock should be investigated before proceeding with the design. There is a risk of the formation of a continuous grain boundary nitride network in aluminum alloy steels, as a result of a prolonged nitriding cycle. The use of these steels requires special precautions in heat treatment.

[c] Aluminum containing nitriding steels Nitralloy N, Nitralloy 135 and similar are limited to grades ML and MQ. Tooth root stress numbers $\sigma_{F\ lim}$ for these materials are limited to 250 N/mm^2 for ML and 340 N/mm^2 for MQ.

[d] When values are higher, due to white layer thickness (> 10 µm), the endurance values decrease because of embrittlement.

Table 8 — Wrought steels, nitro-carburized (see Figures 15 and 16)

Item	Requirement	ML	MQ	ME
1	Chemical analysis	As in Table 3 (through hardened wrought steels: items 1 to 6)		
2	Mechanical properties — after heat treatment			
3	Cleanness			
4	Grain size			
5	Ultrasonic test			
6	Extent of forging reduction			
7	Nitro-carburized dwell time	From 1 h to 8 h		
8	Surface hardness			
8.1	Alloyed steels [a]	> 500 HV		
8.2	Unalloyed steels [a]	> 300 HV		
9	Pretreatment	Hardened and tempered without surface decarburization. Tempering temperature is to exceed nitriding temperature.		
10	Surface zone: (white layer)	Detailed inspection not mandatory	White layer, 5 µm to 30 µm thick. Mostly ε- nitrides	
11	Nitro-carburized equipment: as bath nitro-carburized	Ventilated titanium heat-resisting alloy (inconel) pot or an inert liner. Iron dissolves in the molten salt inhibiting the nitriding process.		

a Surface hardness is measured perpendicular to the surface; values measured on a section may be higher. The test load should be appropriate for the case depth and the hardness.

6.5 Coupon

A coupon is a test piece made from a representative grade of material. The selection of a wrought or cast test piece is based on the gear or process being represented. It shall accompany the gear product through all heat treatment stages represented in Tables 2, 3, 4, 5, 6 or 7. The coupon should be chosen to monitor the interactions of the heat treatment process. Options can also be taken to use a representative coupon, which is intended to represent the properties of the work piece. The properties of the standardized coupon may be extrapolated by experience to estimate the properties of the work piece with regard to finished microstructure and properties.

Details of the manufacture of the coupon may be subject to agreement between the supplier and the customer.

Two types of coupons are recognized.

a) **Process control test bars:** may be of any alloy and shape. They are used to verify the consistency of the heat treatment process. Their microstructure does not represent the microstructure of the finished gear, but it may be extrapolated to estimate the condition of the finished gear. Such extrapolation shall be documented.

b) **Representative test bars:** designed to represent the quenching rate of the finished part. The hardness and microstructure at the centre of the coupon approximates that of the core as designated in Table 5, Lines 8 and 14. Recommended proportions are:

   1) Minimum diameter: 6 × module,

   2) Minimum length: 12 × module.

   With the agreement of the customer a smaller test piece can be used. Recommended proportions are

   1) Minimum diameter: 3 × module,

   2) Minimum length: 6 × module.

The coupon material shall be equivalent to the part in chemical composition and hardenability, but not necessarily from the same cast.

6.6 Mechanical cleaning

Mechanical cleaning is a technique used to remove scale debris or coatings after the heat treatment operation. Industrial practice includes the use of aluminium oxide, grit, shot, cut wire and glass beads. These, in addition to cleaning a surface, will influence the residual stress — some more significantly than others. This change in residual stress will influence bending strength and the influence of subsequent operations. In Figure 10, values of MQ bending stress were achieved with adequate industrial cleaning techniques applied and therefore cannot necessarily be achieved after heat treatment alone.

6.7 Shot peening

Shot peening is a cold working process performed by bombarding the surface of a part with small spherical media which results in a thin layer of high magnitude residual compressive stress at the surface. Shot peening increases residual compressive stresses and improves bending strength in the roots of gear teeth. Shot peening should not be confused with the mechanical cleaning operations discussed in 6.6.

Post-shot peening processes such as metal removal, heat treatment and shrink fitting are allowed, however, they can alter the residual compressive stress and the bending strength. The shot peening process shall be controlled. The recommended minimum control should be based on AMS-S-13165:1997 [8]. Other control systems may be used, provided there is agreement between manufacturer and purchaser.

The benefit values attributed to shot peening are

a) ML — 0 %

b) MQ — 10 %

c) ME — 5 %

The shot peening benefits shall be applied to bending stresses on carburized case hardened gears only.

Annex A
(normative)

Considerations of size of controlling section for through hardened gearing

This annex presents approximate maximum controlling section size considerations for through hardened (quench and tempered) gearing. Also presented are factors which affect maximum controlling size, illustrations of how maximum controlling section size is determined for gearing, and recommended maximum controlling section sizes for some low alloy steels.

The controlling section of a part is defined as that section which has the greatest effect in determining the rate of cooling during quenching at the location (section) where the specified mechanical properties (hardness) are required. The maximum controlling section size for a steel is based principally on hardenability, specified hardness, depth of desired hardness, quenching and tempering temperature considerations.

Figure A.1 shows controlling sections for quenched gear configurations whose teeth are machined after heat treatment.

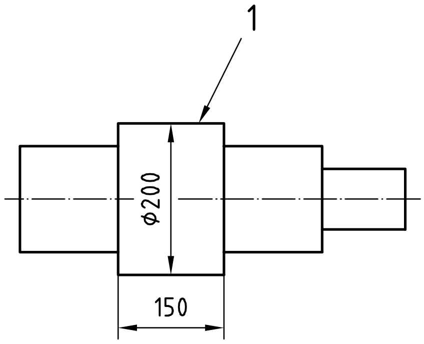
Evaluation of the controlling section size for the selection of an appropriate type of steel and/or specified hardness need not include consideration of standard rough stock machining allowances. Other special stock allowances such as those used to minimize distortion during heat treatment shall be considered.

Figure A.2 provides approximate recommended maximum controlling section sizes for oil quenched and tempered gearing (H = 0,5) of low alloy steels, based on specified hardness range, normal stock allowance before hardening, and minimum tempering temperature of 480 °C, to obtain minimum hardness at the roots of teeth.

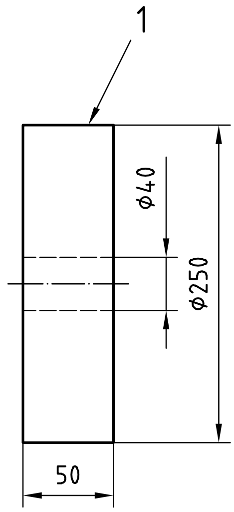
Maximum controlling section sizes versus specified hardness for section sizes to 200 mm diameter rounds can also be approximated by use of the “Chart predicting approximate cross section hardness of quenched round bars” [7], and published tempering response/hardenability data.

Maximum controlling section sizes for rounds greater than 200 mm OD generally require in-house heat treatment experiments on larger sections, followed by sectioning and transverse hardness testing.

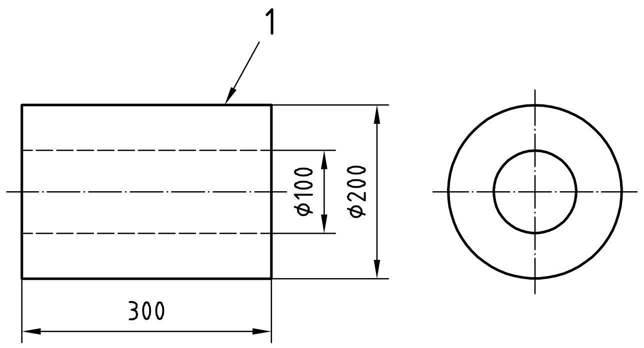
Normalized and tempered heavy section gearing may also require maximum controlling section size considerations if the design does not permit liquid quenching. Specified hardness able to be obtained with the same type steel (hardenability) is considerably lower, however, and higher hardenability steel may be required. In-house normalized and tempered/hardness testing experiments are required.



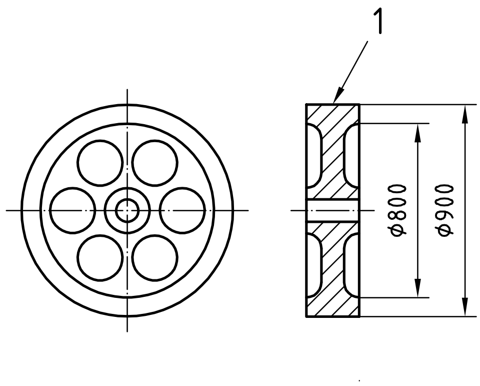
a) Controlling section: 200 mm diameter



b) Controlling section: 50 mm facewidth



c) Controlling section: 50 mm wall thickness (if the bore diameter is less than 20 % of the length of the bore, then the outside diameter is the controling section)

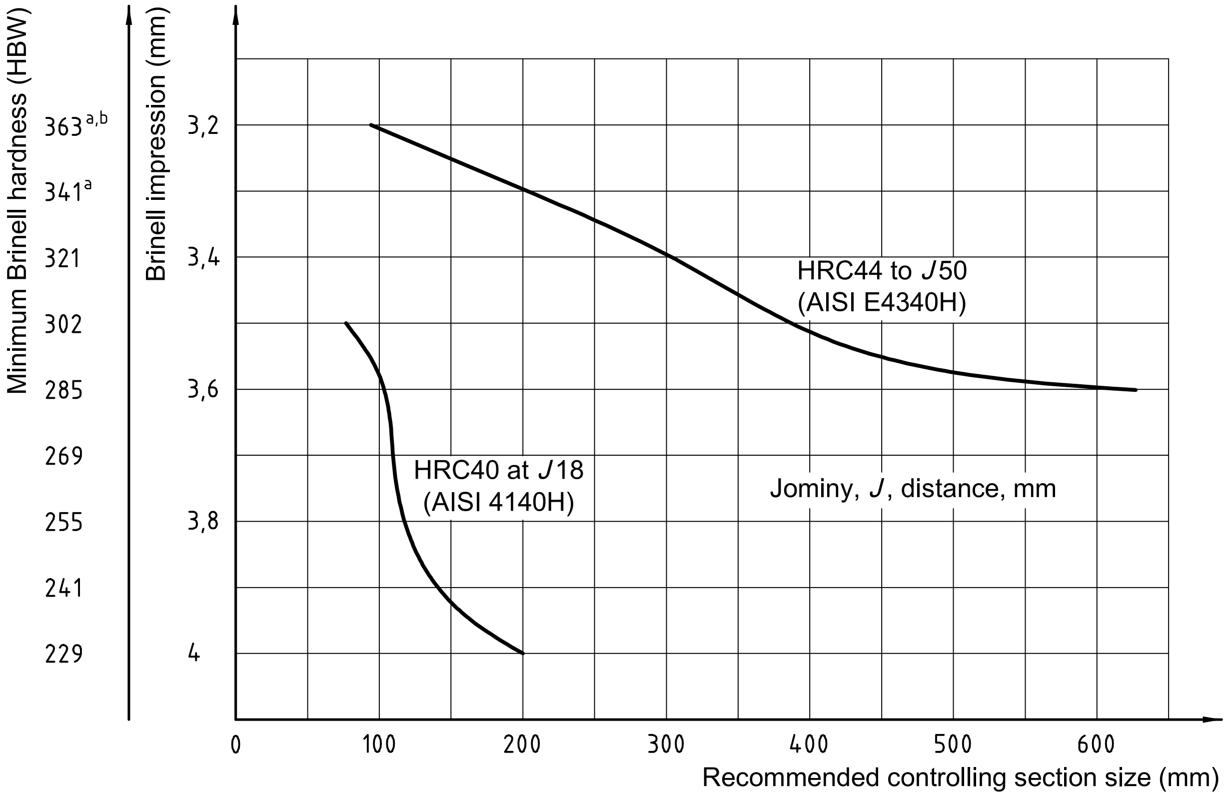


d) Controlling section 50 mm rim thickness

Key

1 teeth

Figure A.1 — Examples of size of controlling section



NOTE Maximum controlling section sizes higher than those above can be recommended when substantiated by test data (heat treat practice).

[a] 480 °C minimum temper temperature may be required to meet these hardness specifications.

[b] Higher specified hardnesses (e.g. 375 HBW to 415 HBW, 388 HBW to 421 HBW and 401 HBW to 444 HBW) are used for special gearing, but costs should be evaluated due to reduced machinability.

Figure A.2 — Size of controlling section for two 0,40 % carbon alloy steels

Annex B
(informative)

Table of hardness conversions [9]

See Table B.1.

Table B.1 — Table of hardness conversions

Tensile strength	Vickers hardness	Brinell hardness	Rockwell hardness	
(N/mm^2)	($F \geqslant 98$ N)	HBW	HRC	HR 30N
770	240	228	20,3	41,7
785	245	233	21,3	42,5
800	250	238	22,2	43,4
820	255	242	23,1	44,2
835	260	247	24,0	45,0
850	265	252	24,8	45,7
865	270	257	25,6	46,4
880	275	261	26,4	47,2
900	280	266	27,1	47,8
915	285	271	27,8	48,4
930	290	276	28,5	49,0
950	295	280	29,2	49,7
965	300	285	29,8	50,2
995	310	295	31,0	51,3
1 030	320	304	32,2	52,3
1 060	330	314	33,3	53,6
1 095	340	323	34,4	54,4
1 125	350	333	35,5	55,4
1 155	360	342	36,6	56,4
1 190	370	352	37,7	57,4
1 220	380	361	38,8	58,4
1 255	390	371	39,8	59,3
1 290	400	380	40,8	60,2
1 320	410	390	41,8	61,1
1 350	420	399	42,7	61,9
1 385	430	409	43,6	62,7
1 420	440	418	44,5	63,5
1 455	450	428	45,3	64,3
1 485	460	437	46,1	64,9
1 520	470	447	46,9	65,7
1 555	480	(456)	47,7	66,4
1 595	490	(466)	48,4	67,1
1 630	500	(475)	49,1	67,7
1 665	510	(485)	49,8	68,3
1 700	520	(494)	50,5	69,0
1 740	530	(504)	51,1	69,5
1 775	540	(513)	51,7	70,0
1 810	550	(523)	52,3	70,5
1 845	560	(532)	53,0	71,2
1 880	570	(542)	53,6	71,7
1 920	580	(551)	54,1	72,1
1 955	590	(561)	54,7	72,7
1 995	600	(570)	55,2	73,2
2 030	610	(580)	55,7	73,7
2 070	620	(589)	56,3	74,2
2 105	630	(599)	56,8	74,6
2 145	640	(608)	57,3	75,1
2 180	650	(618)	57,8	75,5
	660		58,3	75,9
	670		58,8	76,4
	680		59,2	76,8
	690		59,7	77,2
	700		60,1	77,6
	720		61,0	78,4
	740		61,8	79,1
	760		62,5	79,7
	780		63,3	80,4
	800		64,0	81,1
	820		64,7	81,7
	840		65,3	82,2
	860		65,9	82,7
	880		66,4	83,1
	900		67,0	83,6
	920		67,5	84,0
	940		68,0	84,4

Annex C
(informative)

Testing surface hardness with a file

C.1 Application

The file hardness test is used as a qualitative measure of surface hardness. It is most useful on fully hardened parts. Its advantages are

- portability of the test equipment,
- ability to test surfaces which cannot be tested by other equipment,
- speed of application,
- sensitivity to surface conditions, such as decarburization and microstructural defects, and
- that it does not damage the surface being tested.

Specific examples of the use of the file hardness test are

- surface hardness of active profile and roots of gear teeth, and
- decarburization checks on hardened parts.

C.2 Principle

File hardness testing compares the "feel" of a new file biting the surface of the test part to the feel of the same file biting the surface of a calibrated sample or "prover". The term *file hard* means that sharp testing files will not cut the surface more easily than they cut a prover of the minimum specified hardness. Such a comparison can only be done by comparing the feel of cutting the workpiece with the feel of cutting the prover.

C.3 Equipment

C.3.1 Files

First quality files are hardened to Rockwell C 66 HRC to 68 HRC and will generally start to take a slight bite at 65 HRC. File tooth shape and sharpness also influence cutting ability. Standardization of files is necessary for hardness checking.

a) File size should be appropriate for the size of part. Sizes from 100 mm to 200 mm in length are commonly used.

b) The sharpness of the file is important. Experienced testers can judge when a file becomes dull enough to be misleading. A more accurate method is to check periodically the file against a prover.

C.3.2 Provers

A calibrated test block 50 mm in diameter and 6 mm thick, which has been carburized, hardened and drawn to the minimum acceptable hardness, or a sample part of known hardness can be used as a prover. A set of test blocks in 2 HRC steps is a very useful standard. The surface finish of the prover should be similar to the test part.

C.4 Procedure

Scale or rust on the surface of the test parts will load the file, resulting in an inaccurate determination of hardness.

When testing high hardness parts, ground surfaces do not cut as readily as regular machined surfaces.

Grasp the handle or tang of the file by the hand with the index finger extended along the flat face of the file to apply light pressure and steady the stroke. Alternatively hold the file against the part with the ball of the thumb. Move the file slowly until it is apparent whether or not the file will bite. At the first sign of cutting, stop the filing. Use short strokes to prolong file life. Pressure and contact area should remain constant because they affect the cutting action.

The part is file hard if a file will not cut the surface more easily than it cuts a prover of the minimum specified hardness.

Bibliography

[1] ISO 54:1996, *Cylindrical gears for general engineering and heavy engineering — Modules*

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