INTERNATIONAL STANDARD

ISO 6336-5

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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 6336-5:1996(E)

Contents

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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.

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.

International standard ISO 6336-1 was prepared by Technical Committee ISO/TC 60, *Gears*, Subcommittee SC 2, *Gear capacity calculation*.

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*

Annex A forms an integral part of this part of ISO 6336. Annexes B to E are for information only.

Introduction

This part of ISO 6336 and parts 1, 2 and 3 provide 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, also 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 the graphs in figures 1 to 14.

This part of ISO 6336 covers the most widely used gear steels 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.

Requirements for material quality and heat treatment are specified, together with 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 also suited to the calculation procedures in ISO 10300 for rating the load capacity of bevel gears.

The information in this part of ISO 6336 is applicable to all gearing, basic rack profiles, profile dimensions, design, etc., covered by the above mentioned standards. The results are in good agreement with other methods for the range as indicated in the scope of ISO 6336-1.

2 Normative references

The following standards contain provisions which, through reference in this text, constitute provisions of this part of ISO 6336. At the time of publication, the editions indicated were valid. All standards are subject to revision, and parties to arrangements based on this part of ISO 6336 are encouraged to investigate the possibility of applying the most recent edition of the standards indicated below. Members of IEC and ISO maintain registers of currently valid International Standards.

ISO 53: 1974, *Cylindrical gears for general and heavy engineering - Basic rack*

ISO 642: 1979, *Steel - Hardenability test by end quenching (Jominy test)*

ISO 643: 1983, *Steel - Micrographic determination of the ferritic or austenitic grain size*

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

ISO 1122-1: 1983, *Glossary of gear terms - Part 1: Geometrical definitions*

ISO 2639: 1982, *Steel - Determination and verification of the effective depth of carburized and hardened cases*

ISO 3452: 1984, *Non-destructive testing - Penetrant inspection - General principles*

ISO 3754: 1979, *Steel - Determination of effective depth of hardening after flame or induction hardening*

ISO 4967: 1979, *Steel - Determination of content of non-metallic inclusions - Micrographic method using standard diagrams*

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 6336-1: 1996, *Calculation of load capacity of spur and helical gears - Part 1: Basic principles, introduction and general influence factors*

ISO 6336-2: 1996, *Calculation of load capacity of spur and helical gears - Part 2: Calculation of surface durability (pitting)*

ISO 6336-3: 1996, *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*

EN 10204: 1991, *Metallic products - Types of inspection documents*

DIN 3990: 1987, *Tragfähigkeitsberechnung von Stirnrädern*

ANSI/AGMA 2007-B92 *Surface Temper Etch Inspection After Grinding*

ASTM A388-91, *Practice for Ultrasonic Examination of Heavy Steel Forgings*

ASTM E428-92, *Practice for Fabrication and Control of Steel Reference Blocks Used in Ultrasonic Inspection*

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

ASTM E709-91, *Practice for Magnetic Particle Examination*

3 Definitions and symbols

For the purposes of this part of ISO 6336, the definitions given in ISO 1122-1 apply. Symbols and units are given in ISO 6336-1.

4 Methods for the determination of allowable stress numbers

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.

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 and surface roughness; in the case of tooth bending strength, the fillet radius and surface roughness. Where appropriate, 1,0 should be substituted for the relevant influence factor when calculating the permissible stresses.

4.1 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.

4.2 Method B

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

Four different classes, MX, 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.

4.3 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. When evaluating test data, one should understand 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.

4.4 Method B_p

Allowable stress numbers for bending are derived from the results of testing un-notched test pieces. See 4.3 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 in annex E).

5 Standard allowable stress numbers - method B

5.1 Application

The allowable stress numbers shown in figures 1 to 14 are based on the assumption that material composition and heat treatment are appropriately chosen for the size of the gear.

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 is to be added to indicate the relevant percentage (e.g. $\sigma_{H\,lim10}$ for 10 % probability of damage).

With the exception of nitrided, carbo-nitrided and nitro-carburized gear materials, the allowable stress numbers indicated for contour-hardening processes apply for effective case depths of about 0,15 m_n to 0,2 m_n on a finish-machined gear. Excessive case depth can reduce the strength. For the definition of "optimum case depth", see footnote 3 in table 4.

Allowable stress numbers indicated for nitrided test gears are appropriate for effective case depths of 0,4 mm to 0,6 mm.

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. The condition of the elements of the material surface has a much more pronounced influence.

Defects formed during manufacture, such as surface decarburization, inter-granular oxidation, local temper due to grinding, grinding notches (at tooth-roots), grooves and cracks initiated by inadequate grinding and heat treatment processes can effectively reduce the strength of all materials.

In some cases the full hardness range is not permissible. The restricted ranges are indicated by the length of the lines in figures 1 through 14.

For surface-hardened steels (figures 9 through 14), the HV 1 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 C.

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 x 10^7 stress cycles are considered to be the beginning of the longlife strength range (see life factor in ISO 6336-2).

Values of $\sigma_{H\,lim}$ indicated in figures 1, 3, 5, 6, 9, 10 and 13 are appropriate for the reference operating conditions and dimensions of the reference test gears, as shown below[1]:

- Centre distance a = 100 mm
- Helix angle β = 0 (Z_β = 1)
- Module m = 3 mm to 5 mm (Z_X = 1)
- Mean peak-to-valley roughness of the tooth flanks R_z = 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 quality grades 4 to 6 per ISO 1328-1
- Load influence factors $K_A = K_v = K_{H\beta} = K_{H\alpha} = 1$

When these conditions are met[2], test gears are deemed to have failed 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.

1) 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 may be sustained without progressive pitting damage, for a specified number of load cycles.

2) The percentages refer to test evaluations; they are not intended as limits for product gears.

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}, is the basic bending strength of the un-notched test piece, under the assumption that the material condition (including heat treatment) is fully elastic:

$$\sigma_{FE} = \sigma_{F\,lim}\, Y_{ST} \qquad \text{...(1)}$$

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

Values of $\sigma_{F\,lim}$ and σ_{FE} indicated in figures 2, 4, 7, 8, 11, 12 and 14 are appropriate for the reference operating conditions and dimensions of the reference test gears, as shown below (see 5.2, footnote 2):

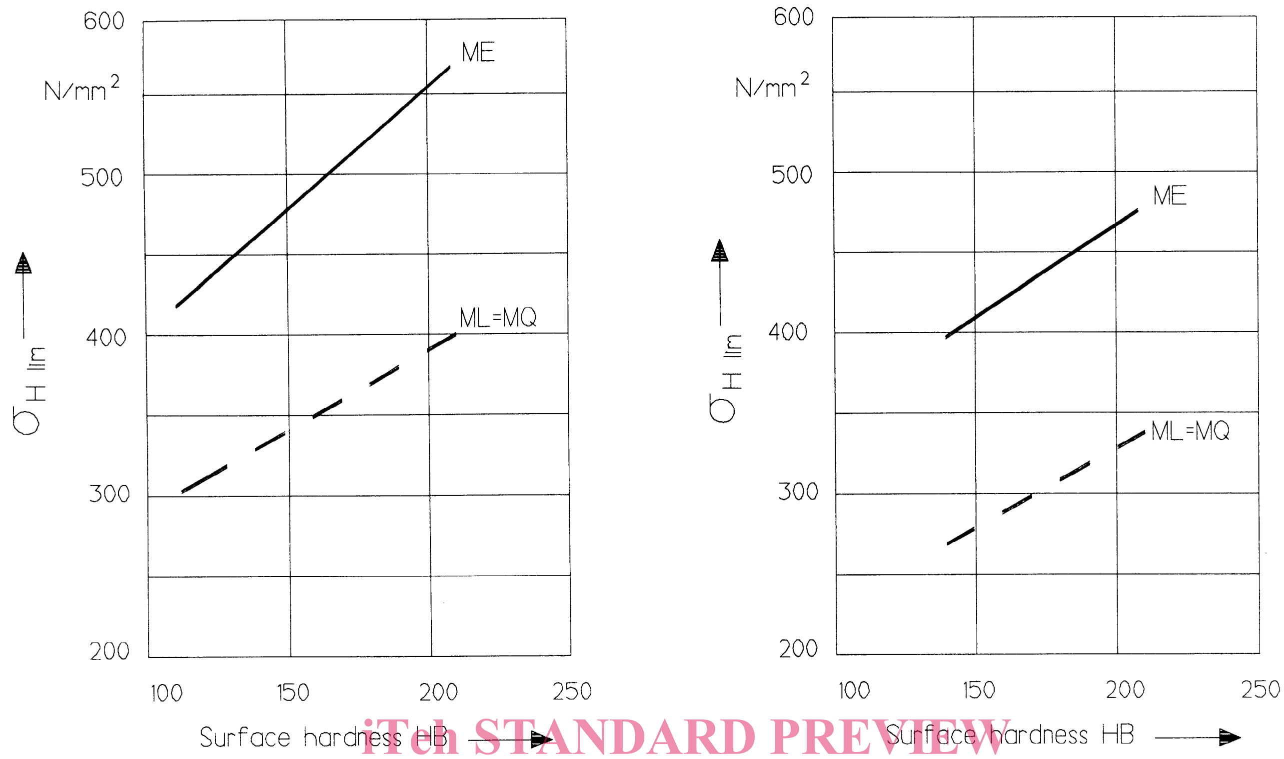
- Helix angle — $\beta = 0$ ($Y_\beta = 1$)
- Module — m = 3 mm to 5 mm ($Y_X = 1$)
- Stress correction factor — $Y_{ST} = 2{,}0$
- Notch parameter — $q_{sT} = 2{,}5$ ($Y_{\delta\,rel\,T} = 1$)
- Peak-to-valley roughness of the tooth fillets — R_z = 10 µm ($Y_{R\,rel\,T} = 1$)
- Gearing quality grades — 4 to 7 per ISO 1328-1
- Basic rack — per 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, 7, 8, 11, 12 and 14 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 by a factor of 0,7. 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 consult the appropriate literature.

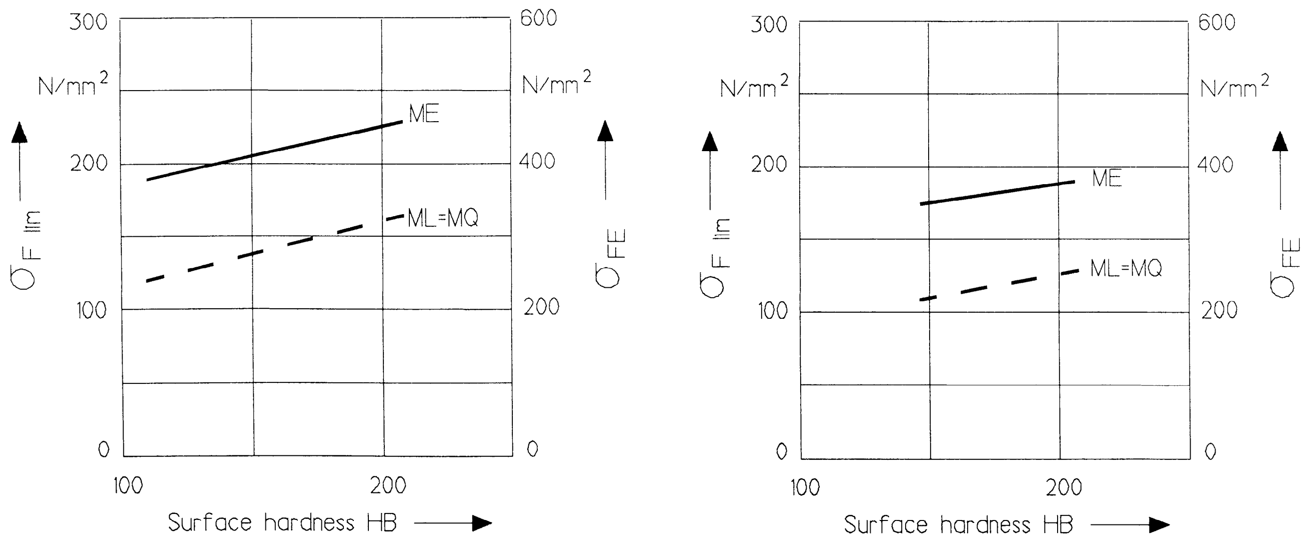
5.4 Graphs for $\sigma_{H\,lim}$ and $\sigma_{F\,lim}$ and σ_{FE}

Allowable stress numbers for hardness values which exceed the boundaries in figures 1 to 14 are subject to agreement between manufacturer and purchaser on the basis of previous experience.



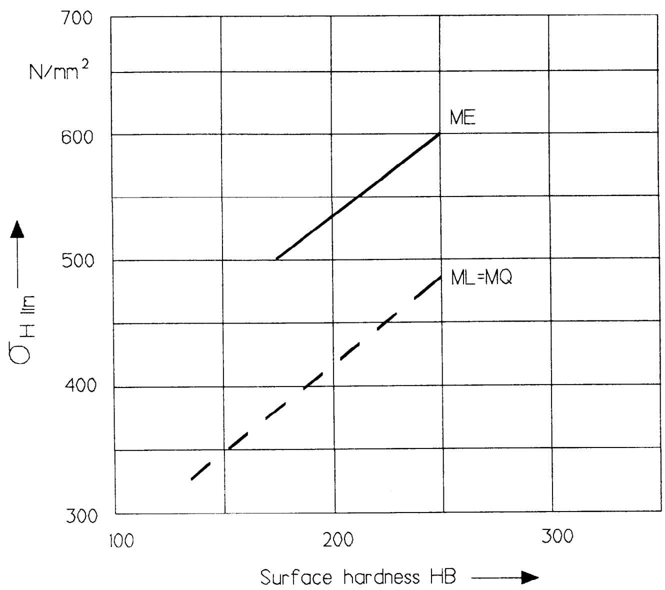
a) Normalized structural steels b) Cast steels

Figure 1 - Allowable stress numbers (contact) for normalized structural steels and cast steels (see 6.2.1)

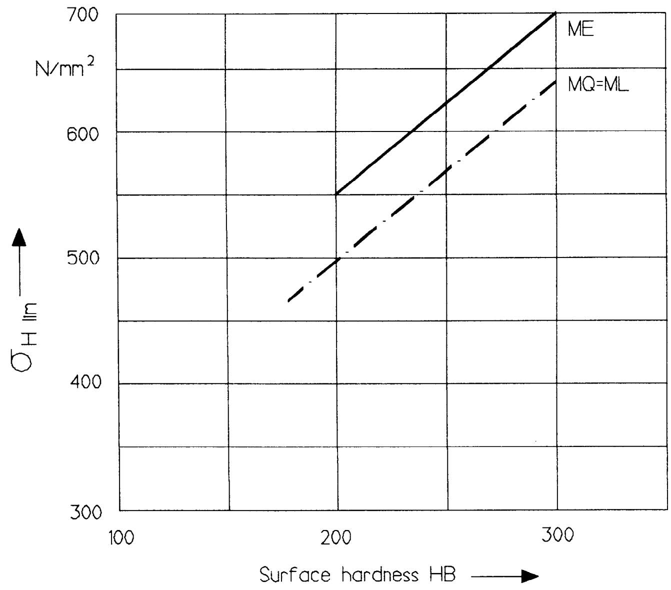


a) Normalized structural steels b) Cast steels

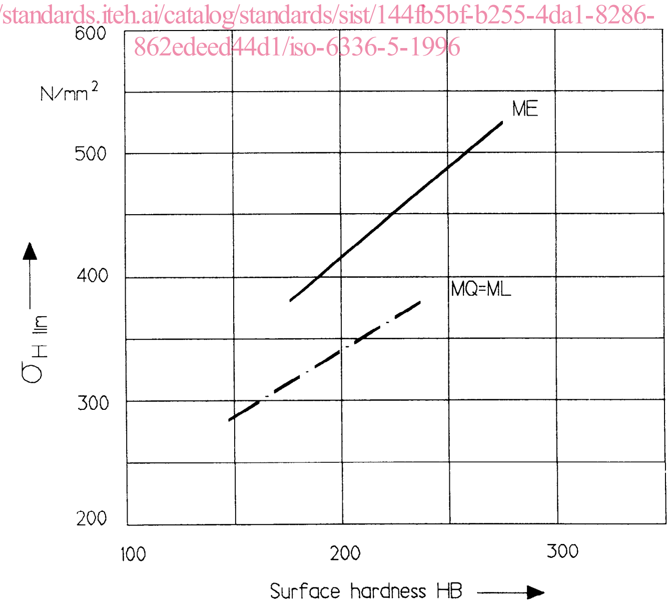
Figure 2 - Nominal and allowable stress numbers (bending) for normalized structural steels and cast steels (see 6.2.1)



a) Black malleable cast iron (see 6.2.2)



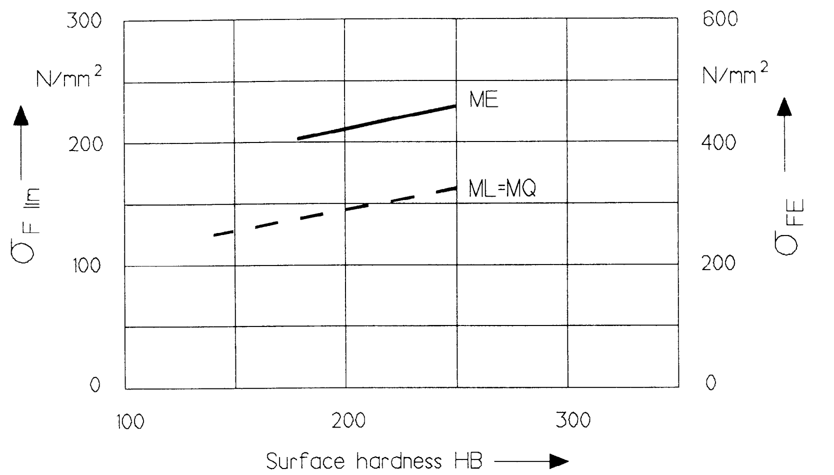
b) Nodular cast iron (see table 1)



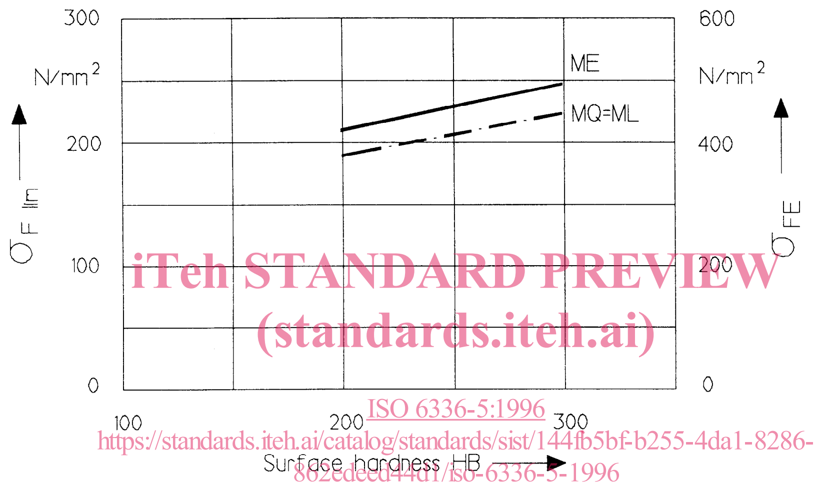
c) Grey cast iron (see table 1)

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

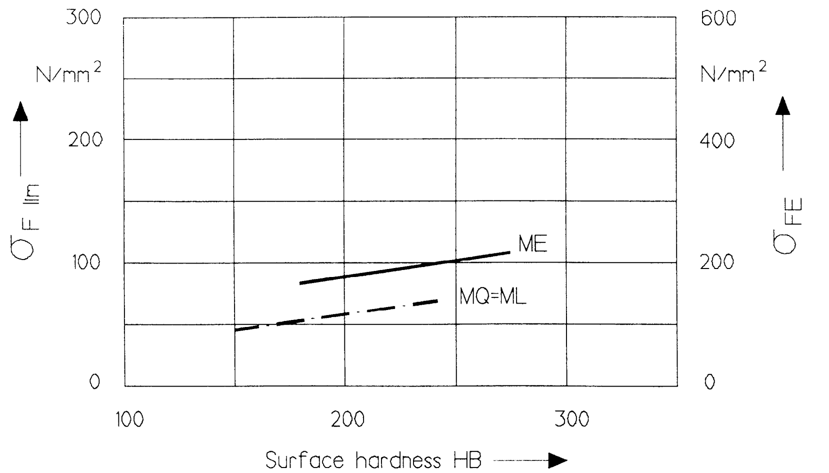
Figure 3 - Cast iron materials: Allowable stress numbers (contact)



a) Black malleable cast iron (see 6.2.2)



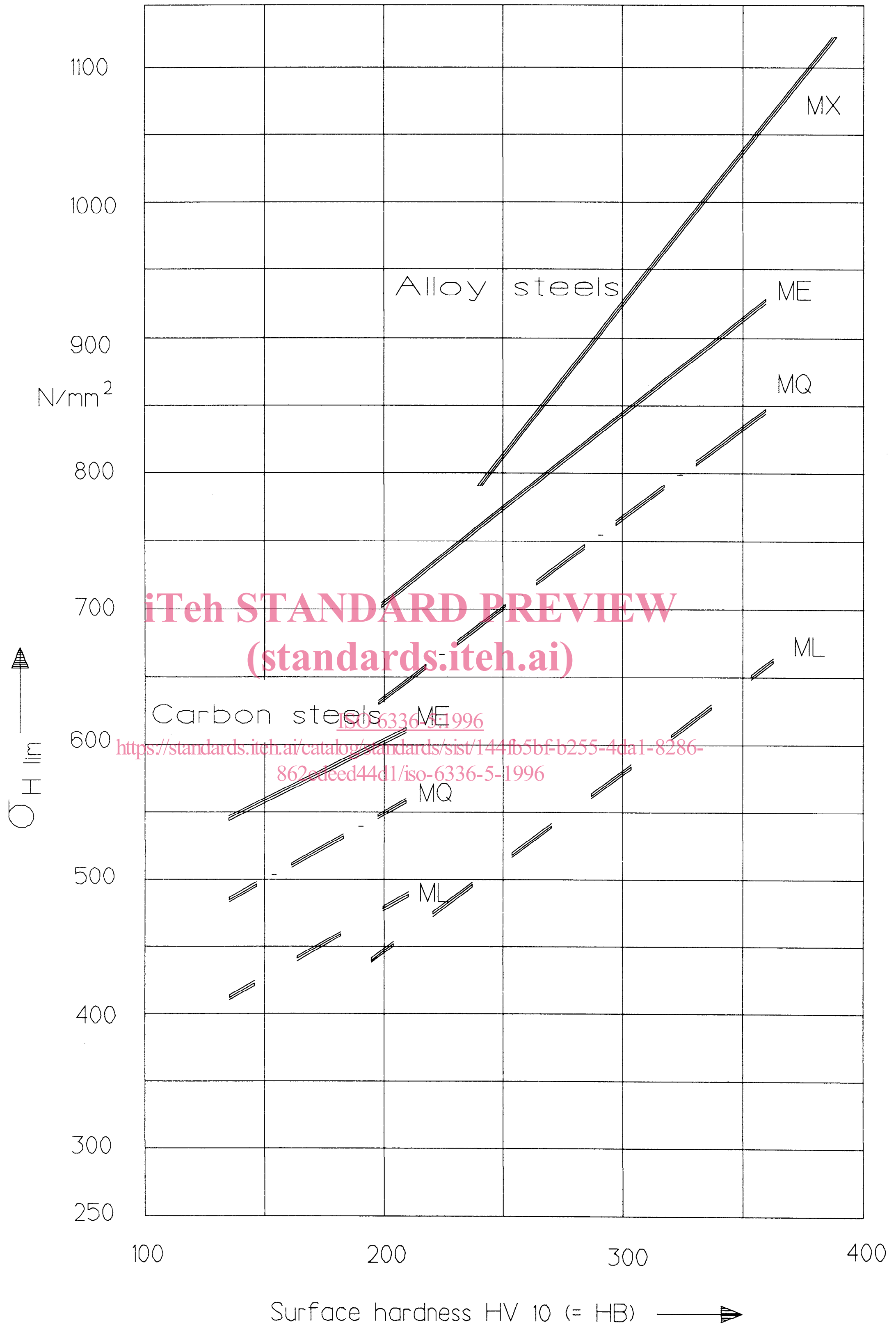
b) Nodular cast iron (see table 1)



Grey cast iron (see table 1)

NOTE – Brinell hardness HB < 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)



NOTE – Nominal carbon content ≥ 0,20 %

Figure 5 - Through hardening steels: Allowable stress numbers (contact) (see table 2)