Micrographic examination of the non-metallic inclusion content of steels using standard pictures

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British Standards

National foreword

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Micrographic examination of the non-metallic inclusion content of steels using standard pictures

Détermination micrographique de la teneur en inclusions non-métalliques des aciers à l'aide d'images-types

Metallographische Prüfung des Gehaltes nichtmetallischer Einschlüsse in Stählen mit Bildreihen

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Management Centre: rue de Stassart, 36 B-1050 Brussels

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Contents

Foreword

This document (EN 10247:2007) has been prepared by Technical Committee ECISS/TC 2 “Steel - Physico-chemical and non-destructive testing”, the secretariat of which is held by AFNOR.

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by October 2007, and conflicting national standards shall be withdrawn at the latest by October 2007.

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This document supersedes ENV 10247:1998.

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Introduction

This document establishes procedures for the assessment of inclusions in steels, based on their morphology using standard pictures.

These procedures include principles that are coherent with physical results obtained from inclusion measurements.

The results are in physical units: length in µm/ mm^2, number/ mm^2, areas in $µm^2$/ mm^2. In comparison to other inclusion rating standards, in this standard the order of the classification begins with the length (row index q).These results can be transposed into other standard's ratings for comparison purposes.

The conditions of assessments, for instance the rules to scan fields on the specimen, are defined such that there is an optimization between magnification and the number of fields to be assessed. The same precision level is achieved by using the same method in manual evaluation and computer controlled measurements.

The chart of standard pictures is derived from mathematical principles.

The results and their precision may be directly computed from field assessments.

1 Scope

This European Standard defines a method of microscopic non-metallic inclusion assessment using picture charts.

The method does not apply to particles of a length less than 3,0 µm or a width smaller than 2,0 µm. Defined by a product standard or agreement between the involved parties for certain special products, inclusions with a width below 2,0 µm can only be evaluated according to their length. Elongated inclusions with a length above 1 410 µm are counted separately and are beyond the upper application limit of this standard. Globular inclusions with a diameter of 3,0 µm and above are included in the assessment.

It is assumed, if particles are elongated or if there are stringers of particles, that they are parallel to each other. Other arrangements are not covered by this standard. This European Standard applies to samples with a microscopic precipitation approaching random distribution.

From the data of measurements obtained by this method, evaluation according to other standards can be established.

This European Standard does not apply to free cutting steels.

NOTE The basic principle of this European Standard allows the determination of non-metallic inclusion content by image analysis techniques.

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.

EN ISO/IEC 17025, *General requirements for the competence of testing and calibration laboratories (ISO/IEC 17025:2005)*

3 Principles

This method consists of a comparison between inclusions observed in a field of view with chart pictures. The chart pictures defined by this European Standard are based on the shape of inclusions and for each shape on length, width and area, for columns 1 to 10 and number for column 11.

This standard employs an ellipse as a basic shape with the circle as a special case of an ellipse (see Figure 1a). Inclusions with a shape like a rectangle or square are treated as ellipses or circles as their areas are not significantly different for the purpose of this method.

The pictures are arranged in rows and columns. The length changes from row to row, the shape factor changes from column to column. This standard is principally concerned with the morphology and arrangement of inclusions. It does not provide information relevant to crystal structure or chemical constitution of measured inclusions.

General practice usually requires a differentiation between inclusions of different chemical composition. The definition of the types should be defined by the product standards. Should no standard be available, then the definition of characteristic morphologies shall be, by agreement, between the involved parties.

To make description easier, a tree of specific terms is given in Annex A, Figure A.1.

The chart pictures represent the upper limits of classes. The length L_x is classified in row q if:

$$L_{q-1} < L_x \leq L_q \text{ µm} \quad (1)$$

The width w_x is classified in column k if:

$$w_{k-1} < w_x \leq w_k \ \mu m \quad (2)$$

In Figure 5 the first row on the top without number and the first column on the left without number and a thicker surrounding contain the lower limiting pictures. Inclusions with a length shorter than that given in that row or a width smaller than that given in that column are not taken into account for classification.

Inclusions classified as columns 6 and 11 are called globular.

The parameters measured are number, length, width and area. The results of the evaluations can give expressions of worst inclusion, worst field or an average field value, all of which have physical dimensions. In addition to these values, this method gives an estimation of distribution of the inclusions within the test specimens.

The entire chart is mathematically based. It has a limited number of pictures, which limits choice and hence improves reproducibility when used in a manual method. The mathematical basis permits use by manual and image analysis methods providing potential for higher statistical precision. The data produced gives a wide range of features for cleanness definition. The chart employs different shapes and magnifications allowing an application to cleaner steels where shape control is of interest.

This European Standard contains several different methods of evaluation. The choice of method shall be defined by the product standard or be agreed between the involved parties.

By default, the methods of evaluation used are the worst inclusion and the average field method; parameters are given in Annex B.

The methods P_L, P_d; K_n, K_L and K_n, K_d are proposed as standard methods.

4 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

4.1 General

4.1.1
particle
single precipitate, in general non-metallic

4.1.2
inclusion
general designation of particles in association, defined by the size and proximity of particles. It describes a single, separated particle as well as an arrangement of at least 2 particles (see Figure 2a) if the distance t is ≤ 10 µm and the distance e is ≤ 40 µm and the main axis of the particles are parallel within ± 10 °. For an arrangement of only two globular particles, each particle shall be considered as an individual inclusion.

An inclusion can also be formed by several stringers if the distances *t* and *e* are ≤ 10 µm and ≤ 40 µm (see Figure 2b). Particles with L < 3 µm or w < 2 µm are not taken into account (see Figure 2c).

Special cases:

If elongated and more or less spherical particles are combined, see Figure 2d, in general it is treated as one inclusion. In case 4 the width of the largest particle is consulted for the width of the inclusion. If in this case $w_1 > 3\,w_2$ then the particles w_1 and w_2 are treated separately. For an example see Figure 2e.

Some examples for inclusions are given in Figure 2f

4.1.3
stringer
arrangement of at least 3 particles, normally aligned, forming an inclusion (see Figures 2b, 2f), For examples see Annex C and Figure 2f

4.1.4
test area
area on the polished surface of the specimen to be evaluated

NOTE In general, the size of the test area is 200 mm^2.

4.2 Proximity

4.2.1
distances between particles
distance *e* between the particles in the direction of main deformation and distance *t* in the direction perpendicular to it (see Figure 2a)

4.2.2
distance between stringers
similar to that for the distance between particles (see Figure 2b)

4.2.3
scattered
random arrangement of particles.

NOTE For example see Annex C. This is defined in one field of view

4.3 Parameters

4.3.1
length
dimension of an inclusion in the main direction of deformation, always assumed to be greater than the width

4.3.2
diameter
maximum dimension of inclusion classified according to column 6 (globular inclusion)

4.3.3
width

Maximum width perpendicular to the direction of principal deformation. This is the width of the ellipse inscribed to the confining rectangle and having the same length as the inclusion.

For manual evaluation this value can only be estimated. The width is the maximum width perpendicular to the direction of principal deformation for inclusions with only one particle.
The width *w* of an inclusion with 2 particles is given by the largest particle (see Figure 2a).

Width of a stringer (see Figure 1b):

The width of a stringer is defined as the width of an ellipse inscribed to the confining rectangle and having the same length as the stringer

Width of an inclusion out of several stringers (see Figure 2b).

The distance *t* between two stringers is defined as the shortest distance between the confining rectangles in a transverse direction. The distance *e* is defined as the shortest distance between the confining rectangles in a machine direction.

Case a) for $0 \le e \le 40$ µm, $t \le 10$ µm: is the width of an inclusion out of two stringers defined as the width of the widest stringer. ($w_{total} = w_1$, $w_1 > w_2$) (see Figure 2b, a)).

Case b) for e < 0 µm, t ≤ 10 µm: is the width of an inclusion out of two stringers defined as the sum of the stringers' widths and the distance t ($w_{total} = w_1 + w_2 + t$) (see Figure 2b, b).

The width of an inclusion, which consists of several stringers, is determined by the width of the widest stringer. This is identified under consideration of the neighboring stringers corresponding to case a) and b), see Figure 2b, c)

4.3.4
area
area of the ellipse inscribed to the confining rectangle and having the same length as the inclusion (see 4.3.3 and Figures 1a, 1b)

4.3.5
shape factor
exponent f in the equation

$$\frac{L^2}{a} = \frac{4}{\pi}\left(\frac{L}{c}\right)^{f} \qquad (3)$$

NOTE For details see Annex D

4.4 Classes

4.4.1
elongated particles
particles with elliptical shape (see Figure 1a)

4.4.2
globular particles
circular or rectangular particles classified as column 6

4.4.3
type
types of inclusions are separated according to their colour, shape and arrangement and not by chemical composition (see Annex A).

4.5 Others

4.5.1
lot
unit of material processed at one time and subject to similar processing variables

4.5.2
restricted values
values of the average field assessment restricted to inclusions greater than a defined length, shape factor or area

5 Symbols and abbreviations

Symbol	Unit	Designation
a	μm^2	area of inclusions
b		width of the plate
c	μm	factor, 1 μm
d	μm	diameter of inclusions
e	μm	interparticle distance (elongation axis)
f		shape factor
b		black coloured
g		grey coloured (as sulphides)
h		coloured (pink or yellow) (as nitrides)
i		inclusion index
j		field index
k		column number
m		type of inclusion index
max		index of maximum value of *n, L, w, d, a* (in *j* or *s*)
n		number of assessed particles, inclusions
n_s		number of assessed inclusions per specimen
o		black coloured (as oxides)
p		particle index
q		row number
s		specimen index
t	μm	interparticle distance (transverse axis)
u	μm	scale unit in microscope eyepiece
v		width of polished surface
w	μm	width of inclusions
x		variable
av or $^{-}$		average value of *n*, *L, w, a* ....

α		scattered, elongated inclusion type
α_g		scattered, elongated, grey coloured inclusion type
α_b		scattered, elongated, black coloured inclusion type
α_{gb}		scattered, elongated, grey / black coloured inclusion type
ß		aligned, globular inclusion type
$ß_b$		aligned, globular, black coloured inclusion type,
γ		aligned, elongated inclusion type
γ_b		aligned, elongated, black coloured inclusion type
γ_g		aligned, elongated, grey coloured inclusion type
δ		scattered, globular inclusion type
δ_b		scattered, globular, black coloured inclusion type
δ_g		scattered, globular grey coloured inclusion type
δ_{gb}		scattered, globular, grey / black coloured inclusion type
A	μm^2	area of field of view on the specimen
B		polished surface
D		diameter of product
MD		main direction of deformation (e. g. rolling direction)
E	mm	length of test area
G		magnification
H	µm	length of measuring frame on the specimen
I		length of an stage micrometer
K	- , µm, $\mu m^2/mm^2$	average field assessment
L	µm	length of inclusions
M	-, µm, $\mu m^2/mm^2$	worst field assessment
N_j		number of fields
N_s		number of specimens
P		worst inclusion assessment
Q		factor for K-assessment
R		restricted values

W	mm	width of test area (see Figure R.1)

Combined symbols can be written as index or on one line.

EXAMPLE K_L ,KL average field assessment for length;

n_j, nj number of inclusions in a field;

$\overline{n}_j$, $\overline{n}j$ average number of inclusions per field.

6 Sampling

6.1 General

Unless otherwise specified in the technical delivery conditions, the following requirements apply.

6.2 Minimum reduction

The shape of the inclusions depends, to a large extent, on the degree of reduction of the steel. The chart can only be used if the shape of inclusions in the specimen can be compared with that given in the pictures of the chart.

NOTE It is recommended that products should have a minimum reduction by a factor of five. If the deformation is less than a factor of five, care should be taken to differentiate between porosity and inclusions, both of which may be present.

6.3 Size and location of test area

The polished surface of the specimen used to determine the content of inclusions shall be a minimum of 200 mm^2 with a minimum length greater than 20 mm and a minimum width greater than 10 mm (e. g. 25 mm × 20 mm). It should be possible within this area to define a rectangular test area of 200 mm^2 for evaluation with a length to width ratio of 2 (e. g. 20 mm × 10 mm). The longer side of the test area shall be parallel to the direction of the main deformation (e. g. rolling direction).

The sampling and the number of specimens shall be specified in the product standard or shall be subject to agreement between parties.

In the absence of an agreement, the sampling procedure shall be as follows, see Figure 3:

a) bar or billets with a diameter above 50 mm: the test area shall be located halfway between the outer surface and the centre (see Figure 3a);

b) bar with a diameter greater than 25 mm and less than or equal to 50 mm: the surface to be examined consists of half the diametral section (from the center to the edge of the specimen) (see Figure 3b);

c) bar with a diameter less than or equal to 25 mm: the surface to be examined consists of the full diametral section of sufficient length to obtain a total surface of 200 mm^2 (see Figure 3c);

d) plates with a thickness less than 25 mm: the specimen contains the whole thickness (see Figure 3d);

e) plates with a thickness between 25 mm and 50 mm: the specimen contains half the thickness, position between surface and centre;

f) plates with a thickness greater than 50 mm: the specimen contains one quarter of the thickness. The position is not defined.

The positions of the measuring planes for tubes are given in Figure 3e.

For thin products one sample could comprise several specimens. In this case the test area is smaller than 200 mm^2 per specimen.

For any other product, the sampling procedures shall be subject to agreement between parties.

6.4 Number of specimens

Single specimens do not provide a representative index of the content of inclusions of a cast or a batch and therefore the test is to be carried out on a number of specimens. If the number of specimens taken is not defined in the product standard or by special agreement, the content of inclusions shall be determined on not less than six specimens.

6.5 Preparation of specimens

The specimen shall be cut so as to obtain a surface for examination. In order to achieve a flat surface and to avoid rounding the edges of the specimen when polishing, the specimen may be held mechanically or may be mounted.

When polishing specimens, it is important to avoid any tearing out or deformation of the inclusions or contamination of the polished surface, so that the surface is as clean as possible and the appearance of the inclusions is not affected. These precautions are of particular importance when the inclusions are small. It is advisable to use diamond paste for polishing. The kind of lubricant can depend on the inclusion type (water may not be an acceptable lubricant for certain types of inclusions, e.g. sulfides). No particles of a grinding or polishing agent shall be pressed into the polished surface. In certain cases it may be necessary for the specimen to be hardened before polishing in order to retain inclusions.

7 Test method

7.1 Magnification

The magnification G is defined only by the size of the measuring square frame on the specimen. To use the chart with different magnifications, the length H of the side of the measuring frame on the specimen shall have one of the three following values: H = 350 µm, H = 710 µm, H = 1 410 µm.

These values shall be used with an accuracy of ± 0,02 mm for manual evaluation. The area A of one measuring frame on the specimen is given in Table 1.

Table 1 — Area *A* in function of the measuring frame

H µm	***A*** mm^2	***Magnification***
350	0,13	200:1
710	0,5	100:1
1 410	2,0	50:1

EXAMPLE see Annex E.

The length of 710 µm is to be used if nothing else is specified. If it is not possible to use this value, other magnifications can be used and shall be recorded. The magnification shall not be changed during one measurement.

NOTE When analysing images the resolution of the picture is higher than the shortest length to be determined. Magnifying hundredfold (lens of size 10), it should be 1 µm / pixel or finer and orientate oneself at the optical resolution of the complete system, which ranges up to 0,3 µm in the ideal case.

In order to differentiate particles after their grey tone/color, scanning is permissible. The smallest particles to be determined should be mapped at at least 10 pixels.

7.2 Field of view

At a magnification corresponding to H = 710 µm the square frame is given by an etched glass in the eyepiece graticule, as defined in Figure 4a. For broad field microscopes, the etched glass defined in Figure 4b may be used.

Additional information is drawn on the etched glass (see Annex F), and information concerning the manufacturing of the graticules is given in Annex G.

One scale unit in the eyepiece is 10 µm for H = 710 µm. The correct value must be checked by calibration.

When analyzing images the field of view can take up the entire image area of the camera when applying the analyzing method K (see 8.3). If this is the case, an appropriate margin correction shall be provided.

7.3 Definition of the pictures of the chart

7.3.1 Size and Shape

The shape of the inclusions is assumed to be an ellipse, see Figure 1. From this ideal shape the actual pictures are drawn to have an appearance as realistic as possible with a variation of size and shape (see Figure 5). The rules for constructing the pictures are summarised in Annex H.

NOTE Small inclusions are only visible in pictures of original size in the official chart, but not in Figure 5.

7.3.2 Parameters

For manual evaluation the parameters number n, length L, width w and area a of the inclusions are taken into account and can be calculated using these parameters or estimated from the data of the pictures given in Table 2 (see clause 8).

7.3.3 Arrangement of the pictures

The pictures of the chart are arranged in horizontal rows q and vertical columns k (see Figure 5). Columns 1 to 5 contain ellipses with different widths representing elongated inclusions. Column 6 utilises circles for describing globular inclusions. Columns 7 to 10 present globular particles arranged as stringers. The dimensions correspond to the values given for columns 1 to 5. Column 11 shows different numbers of inclusions per field to replace counting by estimation (see 7.4.2).

On the left the squares not numbered show inclusions with a width of 2 µm, on the top inclusions with a length of 3 µm, both are the lower limits of evaluation. Below the pictures the type of the inclusions according to Annex A are shown.

The pictures represent upper limits of classes. The class is denoted by the number of row q and the column k in this sequence.

EXAMPLE The designation of class 3.4 denotes the class row 3, column 4.

For details see Annex K.

7.4 Procedure

7.4.1 General

The prepared specimen is put under the microscope and in general the magnification corresponding to a frame width H of 710 µm (100 x) is used. In each field of view inclusions are compared with the pictures of the chart estimating first the number of row and second, the column of the class for inclusions in the field of view.

For this comparison a chart in original size shall be used, not the pictures of Figure 5. The pictures are upper limits of the classes (see clause 3 and Annex K). To make comparison easier, eyepiece graticules may be used (see Figure 4). The scale dimensions are correct only for the magnification for which the eyepiece was designed.

In addition to their size, inclusions may be classified by the colour, shape and arrangement (see Annex A).

7.4.2 Several inclusions of mixed sizes in one field

7.4.2.1 General

To simplify the manual evaluation where many inclusions occur in one field of view, the following approximations can be employed.

7.4.2.2 Elongated inclusions

Length, width or area (indirectly). Up to 3 stretched inclusions; these are evaluated separately. If there are more than three inclusions in one field of view, evaluation shall be carried out in three steps:

a) inclusions with a length greater than a quarter of the length of the longest inclusion present are evaluated as individuals according to the chart;

b) for the rest of the inclusions, the average length of all inclusions and the average width are estimated. Chart classification (row, column and number) is established using these parameters;

c) number of inclusions is recorded for the class defined in b). This number can be estimated using column 11 (see Figure 5).

7.4.2.3 Globular inclusions

If the inclusions are greater or equal to 11 µm, then each shall be evaluated separately. In other cases, evaluation shall be carried out in three steps:

a) inclusions with a diameter greater than half the diameter of the largest inclusions in the field are evaluated as individuals according to the chart;

b) for the rest of the inclusions the average diameter is estimated and chart classification is carried out by comparison with the pictures of column 6;

c) number of inclusions is determined and recorded for that class. This number can be estimated using column 11 (see Figure 5).

7.4.3 Scanning

For the worst inclusion assessment and the worst field assessment the whole test area shall be scanned . For the average field assessment there are different methods (see 8.3).

7.4.4 Assessment and evaluation

Three types of assessments are defined and used in agreement with the customer or the product standard:

a) worst inclusion assessment (see 8.1);

b) worst field assessment (see 8.2);

c) average field assessment (see 8.3).

For average field assessment, the evaluation can be restricted to inclusions greater than the limit defined by length, diameter or area or made separately for each column. These restrictions shall be specified in the product standards.

7.4.5 Evaluation of different types of inclusions

This European Standard refers only to size, shape and arrangement of inclusions. As additional elements, colours can be taken into account (see Annex A). More information and examples are given in Annex C.

Classes of inclusion types and arrangement can be compared with those of other standards (see Annex L).

7.4.6 Default assumptions

If there is no other agreement, the parameters and assessments listed in Annex B are taken as default.

7.4.7 Recording of results

For recording and final calculations of results it is recommended to use the sheets of Annex M, Annex N and Annex P, or derived arrangements adapted to the needs of the laboratory.

As a default, heterogeneous inclusions partly or completely encapsulated (type EAD), shall be considered as one particle.

The product standard or agreement between the parties shall establish for inclusions with mixed particles such as Figure 2d, example 2, whether the two different types are one particle or two types of particles mixed. Without an agreement, if an inclusion consists of both stretched and globular particles, it shall be analyzed according to the predominant shape.

Numbers lower than 10 are exactly quoted with two digits after the comma, all other values are mathematically rounded to integers.

8 Types of assessment

8.1 Worst inclusion method: method P

8.1.1 Principle

The whole test area must be scanned field by field. The field size is H = 710 µm for any case, see clause 7.1. On each test area, for each type of inclusion, only the inclusion having the greatest value of the selected parameter (*L*, *d* or *a*) is evaluated by comparison with the chart and recorded.

An inclusion crossing the measuring frame shall be resited by a stage movement to lie within the frame.

The result of the evaluation is the average of the individual values of the N_s assessed specimens.

The equations for this method are given in Annex Q.

Assessment and computation sheets with comments and examples are given in Annex M.

8.1.2 Evaluation of P_L (worst length)

Evaluation can be made as a rating according to the length method P_L. In this case just the row number of the greatest inclusion in the test area is recorded following the pictures of the chart. The final result P_L is the average of the N_s samples.

8.1.3 Evaluation of P_d (worst diameter)

This evaluation is valid for globular inclusions. The assessment is similar to that of P_L, but restricted to column 6.

8.1.4 Evaluation of P_a (worst area)

Evaluation can be made as a rating according to area, method P_a. Only the inclusion with the greatest area is recorded. This is realized by classification according to length and width and using the appropriate row and column number to pick up the area from Table 2.

8.2 Worst field method: method *M*

8.2.1 Principle

The value according to Method M is determined by scanning the complete measurement area. The field size is H = 710 µm (100 x), for any case (see 7.1).

On each specimen and each type of inclusions only for the field containing the greatest value of the selected parameter (n, L, w or a) the corresponding row and column are recorded.

An inclusion crossing the measuring frame shall be resited by a stage movement to lie within the frame.

The result of the evaluation is the average of the individual values of the N_s assessed specimens.

Assessment and computation sheets are given with comments and examples in Annex N. The equations this method is based on, are given in Annex Q.

8.2.2 Evaluation of M_n (rating according to number)

For each specimen only the greatest number of inclusions per field M_{ns} is recorded per inclusion type.

If there are few inclusions, they are counted. If not, their number can be estimated by using Figure 5, column 11. For N_s specimens, M_n is the average of the individual values M_{ns}.

8.2.3 Evaluation of M_L (rating according to length)

For the test areas of each specimen s, the worst field is the one with the maximum accumulated length of a particular inclusion type. For one specimen this value is M_{Ls}.

The lengths of all inclusions shall be taken into account.

For N_s specimens, M_L is the average of the individual values M_{Ls}.

8.2.4 Evaluation of M_d (rating according to diameter)

For N_s specimens, M_d is the average of the individual values M_{ds} evaluated like the values of M_{Ls}.

8.2.5 Evaluation of M_a (rating according to area)

The worst field is the one with the maximum accumulated area of a particular inclusion type. For one specimen this value is M_{as}.

8.3 Average field method: method K

8.3.1 Principle

The K value is an average of a parameter for a statistically significant number of fields. The K value is evaluated on scanning the entire test area or until a desired level of confidence is reached (see 8.3.2).

The K value can be calculated:

a) for number (K_n), or number and length (K_n, K_L), or number and area (K_n, K_a) for elongated inclusions;

b) for number (K_n), or number and diameter (K_n, K_d), or number and area (K_n, K_a) for globular inclusions.

The total number of assessed fields N_j, including empty fields, shall be counted.

Assessment and computation is carried out for a level of confidence of 60 %, if there is no other agreement or product standard.

The equations this method is based on, are given in Annex Q, Annex T and Annex U. Assessment and computation sheets are given with comments and examples in Annex P.

8.3.2 Scanning of a specimen for average field assessment

8.3.2.1 General

The test area can be scanned randomly or field by field. The longer side of the test area (rolling direction) shall be orientated within ± 10 ° parallel to the vertical direction (or the y axis, see Figure 4). Random scanning as described in 8.3.2.3 shall be used only if all inclusions are taken into account, not for evaluation of restricted values.

8.3.2.2 Definition of assessment conditions

During the verification of the quality of surface preparation of the specimen or from experience, at 100 x magnification, the operator will estimate the number and average length or average diameter for the most critical types of inclusions. Then, Annex R allows determining magnification and minimum number of fields to assess for a defined level of confidence.

8.3.2.3 Random scanning

Random scanning allows the operator to drastically reduce the number of fields to assess for a predetermined level of confidence. The following rules shall apply:

a) random scanning concerns only the main direction of deformation;

b) each transverse scan shall be continuous across the width and contain the same number of fields until the number of inclusions and the number of fields reaches:

   1) 25 inclusions for 60 % level of confidence, with a minimum of 30 fields;

   2) 100 inclusions for 80 % level of confidence, with a minimum of 50 fields.

Annex R defines the use of a microscope stage for manual or programmed displacements. For a programmed scan the location of the successive transverses shall be randomly chosen.

8.3.2.4 Complete scanning

As an alternative to random scanning the total test area shall be scanned independently from the magnification.

For any evaluation of size values an edge error correction shall be made to make sure that inclusions are counted only once (see Annex S).

8.3.3 Evaluation

8.3.3.1 Complete evaluation

Parameter values (see Table 2) as defined for the classification are upper values (see Annex K). For the evaluation of the average values the values of the parameters are averaged for each class. The calculation is given in Annex T. Only the result of that calculation is needed and therefore repeated in the recording sheets (see Annex P). Independent of the magnification used, the rating always follows the classification described by Annex K using the chart. Of course, an inclusion with a length of 70 µm would be classified according to row 4 at a magnification of H = 1 410 µm (50:1) to row 5 at a magnification of H = 710 µm (100:1) and row 6 at a magnification of H = 350 µm (200:1). But this is corrected by the averaging factor Q (see Table U.1).

8.3.3.2 Restricted evaluation

Before evaluation it may be decided to record only inclusions above a certain value e.g, those of a length above row 4 of the chart etc. Details are given in Annex P, Table P.6 and Table P.7 and Annex Q.3.

8.3.4 Evaluation of K_n, K_L for elongated and K_n, K_d for globular inclusions

For each specimen the number of inclusions is classified field by field for each type of inclusion according to the rows of the chart. An example is given in Table P.2.

For the number of fields to be assessed, see 8.3.2. After finishing the scan, the total number of inclusions per row is recorded as in Table P.2 and the number of fields is evaluated; the total scanned area is derived from that.

The results are calculated using a second sheet, e. g. as in Table P.3.

This second sheet gives all the information to calculate K_n and K_L for $\alpha, \gamma, \beta,$ elongated inclusions and K_n, K_d for δ globular inclusions. These sheets enable the calculation of the average inclusion size per type.

8.3.5 Evaluation of K_n and K_a

Each specimen is rated field by field, counting the number of inclusions according the row and column value.

For the number of fields see 8.3.2. Details of evaluation can be derived from Annex P or the equations given in Annex Q, Annex T and Annex U.

The method of K_a cannot be used to measure true volume fraction. This is defined in ISO 9042.

9 Test report

The test results shall be given in accordance with EN ISO/IEC 17025 and the test report shall contain the following information:

a) reference to this European Standard;

b) steel grade and when applicable, the symbol identifying the steelmaking process;

c) form and dimension of product from which the specimens have been taken;

d) method used as described in clause 8, together with any special condition;

e) result of the evaluation according to the requirement of the product standard or by special agreements between the parties;

f) any abnormalities that may have occurred during the test;

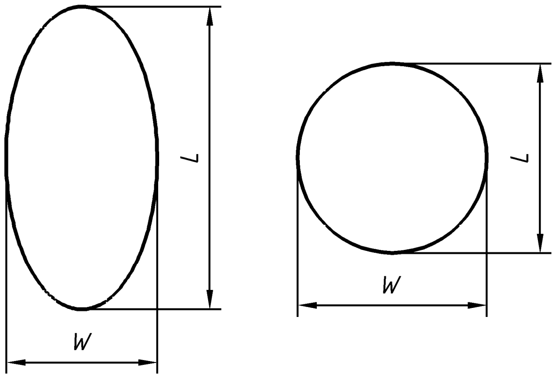
g) magnification used if other than 100 x;

h) reference to image analysis.

Table 2 — Length, width, area and length to width ratio *L/w* and shape factor for the pictures of the chart

			Single and aligned elongated inclusions and stringers of globular inclusions columns 1 to 5 and 7 to 10 **Length *L* ≥ 3 µm and width *w* ≥ 2 µm**					**Globular inclusions column 6** **diameter *d* ≥3 µm**
Row q	*L* µm		1 or 7	2 or 8	3 or 9	4 or 10	5	6
1	5,50	*w* µm *a* µm² *L*/*w* f			2,00 9,00 2,70 0,58			5,50 24 1,00 0,00
2	11	*w* µm *a* µm² *L*/*w* f			3,00 25 3,80 0,56	8,00 71 1,34 0,12		11 95 1,00 0,00
3	22	*w* µm *a* µm² *L*/*w* f			4,00 71 5,40 0,55	12 200 1,90 0,21		22 380 1,00 0,00
4	44	*w* µm *a* µm² *L*/*w* f		2,00 71 22 0,81	6,00 200 7,60 0,54	16 565 2,70 0,26		44,0 1 525 1,00 0,00
5	88	*w* µm *a* µm² *L*/*w* f		3,00 200 30 0,76	8,00 565 11 0,53	23,0 1 600 3,80 0,3	65,0 4 525 1,30 0,07	88,0 6 100 1,00 0,00
6	176	*w* µm *a* µm² *L*/*w* f		4,00 565 43 0,73	12 1 600 15 0,53	33 4 525 5,40 0,33	93 12 800 1,90 0,12	176 24 500 1,00 0,00
7	353	*w* µm *a* µm² *L*/*w* f	2,00 566 177 0,88	6,00 1 600 61 0,70	16 4 525 22 0,52	46,0 12 800 7,60 0,35	131 36 200 2,70 0,17	
8	705	*w* µm *a* µm² *L*/*w* f	3,00 1 600 244 0,84	8,00 4 525 86 0,68	23 12 800 30 0,52	65 36 200 11 0,36		
9	1410	*w* µm *a* µm² *L*/*w* f	4,00 4 525 345 0,81	12,0 12 800 122 0,66	33,0 36 200 43 0,52	93,0 102 400 15 0,38		

NOTE Inclusions with a ratio L / w < 1,30 are considered as a globular inclusion, see Figure 1a.



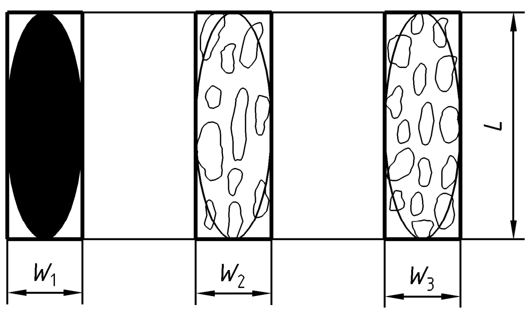
Key

$L \neq w$: ellipse $1{,}00 \leq L/w < 1{,}30$: form circular

$$a = \frac{\pi}{4} \times L \times w$$

$$w = \frac{4}{\pi} \times \frac{a}{L}$$

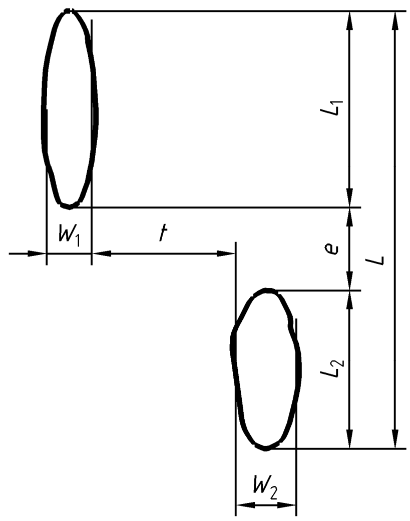
Figure 1a — Definition of ellipse and circle as standard shapes



Key

$$w_1 = w_2 = w_3 = w \qquad a_1 = a_2 = a_3 = a = L \times w \times \frac{\pi}{4} \approx 0{,}8 \times L \times w$$

Figure 1b — Three different inclusions with the same length *L*, width *w* and area *a* of involved material



Key

If $e \leq 40$ µm and $t \leq 10$ µm

$L = L_1 + e + L_2$

$w_2 > w_1$

$w = w_2$

(1 inclusion)

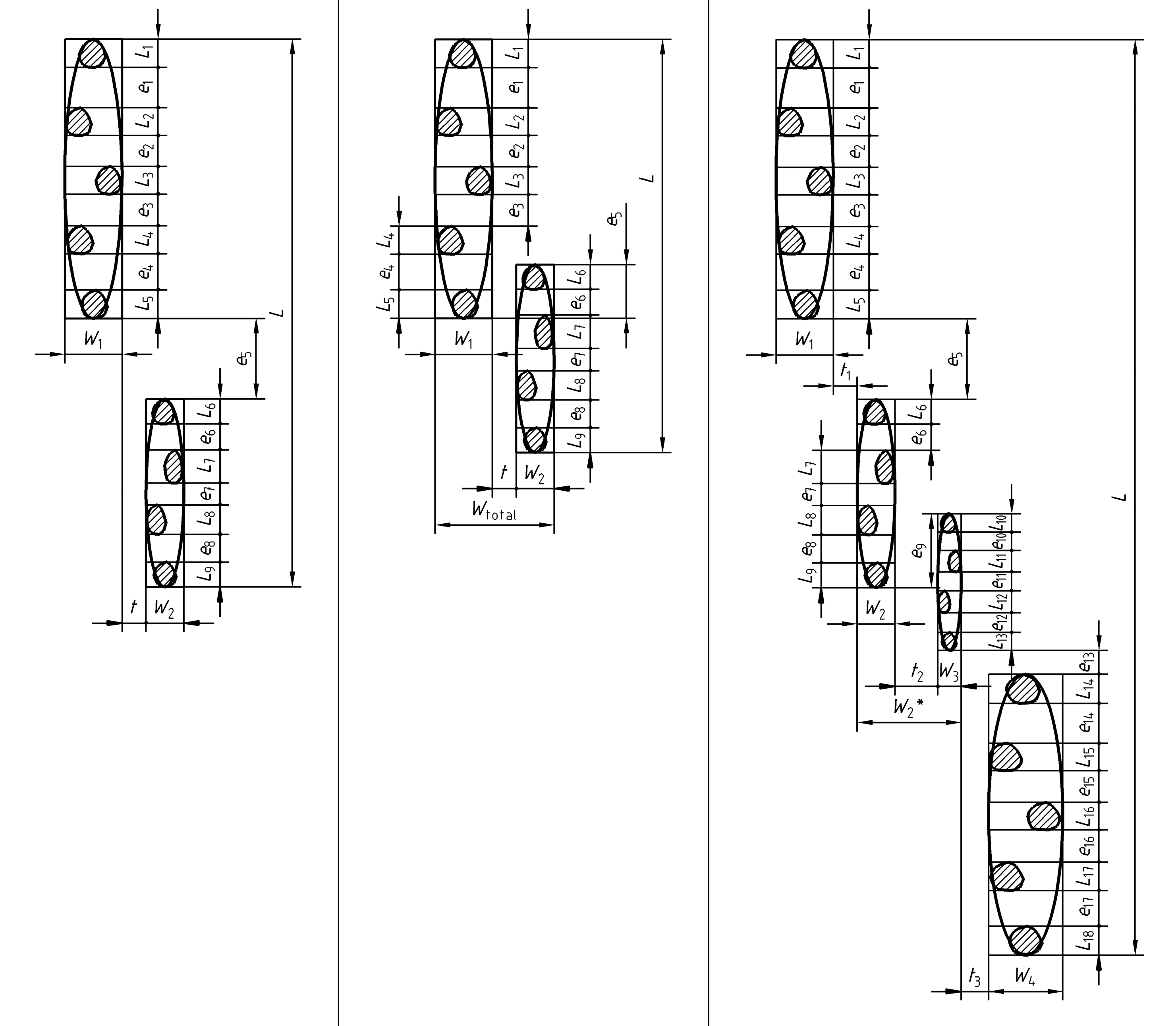
if $e > 40$ µm or $t > 10$ µm,

$L_1 = L_1$ $w_1 = w_1$

$L_2 = L_2$ $w_2 = w_2$

(2 inclusions)

Figure 2a — Definition of inclusions composed by single particles



a)	b)	c)
Key $w_1 > w_2$	$w_1 > w_2$	$w_2^* = w_2 + t_2 + w_3$ $w_2^* = > w_4 > w_1 > w_2 > w_3$
$0 \leq e_5 \leq 40$ µm $t \leq 10$ µm $w_{total} = w_1$	$e_5 < 0$ µm $t \leq 10$ µm $w_{total} = w_1 + t + w_2$	$e_9 < 0$, $0 \leq e_5$, $e_{13} < 40$ µm t_1, t_2, $t_3 \leq 10$ µm $w_{total} = w_2^*$

w = width of an ellipse inscribed to the confining rectangle and having the same length as the stringer

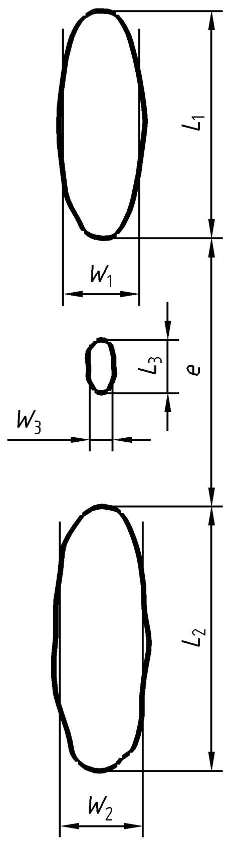
n = number of particles

if all $t \leq 10$ µm and if e_1 to e_{17} all ≤ 40 µm

$L = L_1 + e_1 + L_2 + e_2 \ldots e_{17} + L_{18}$

$$L = L_n + \sum_{x=1}^{n-1} \left(L_x + e_x\right)$$

Figure 2b — Definition of stringers



Key

$L_1 > 3$ µm

$w_1 > 2$ µm

$L_3 < 3$ µm

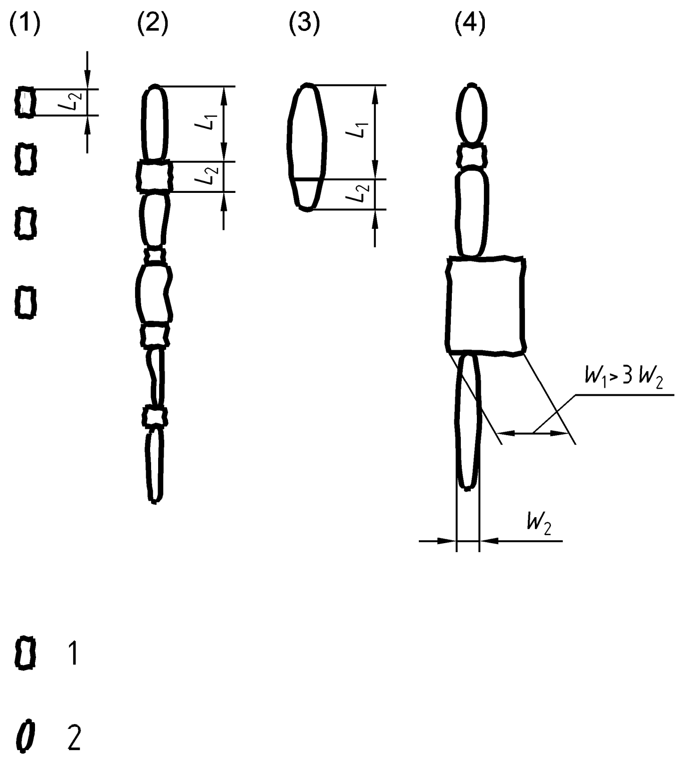
$w_3 < 2$ µm

$L_2 > 3$ µm

$w_2 > 2$ µm

if $e > 40$ µm
2 inclusions

Figure 2c — Definition of inclusions: Particles below minimum size are not taken into account



Key

1 spherical or rectangular particle

2 elongated particle

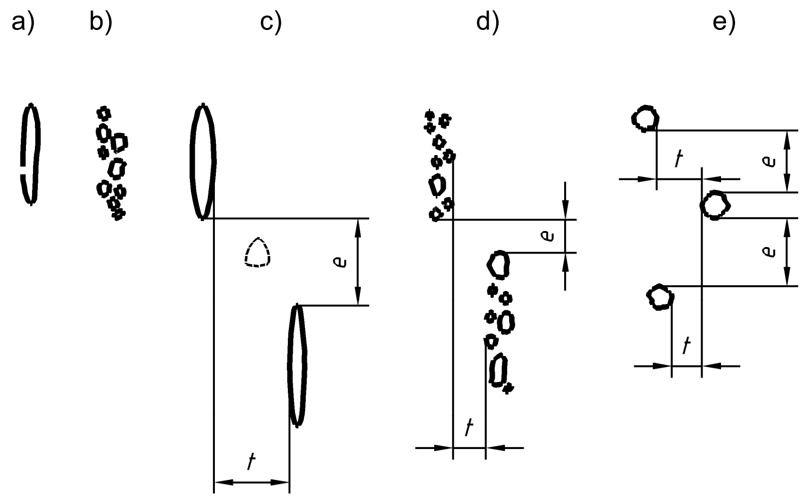
( ) number of the example

Figure 2d — Inclusions, combined by more or less spherical and elongated particles

Example for case 2 in Figure 2d

Example for case 4 in Figure 2d

Figure 2e- Inclusions of particles with different shapes



Key

a) 1 particle, 1 inclusion α, if grey EA, if black EC

b) 9 particles, 1 stringer, 1 inclusion β, EB

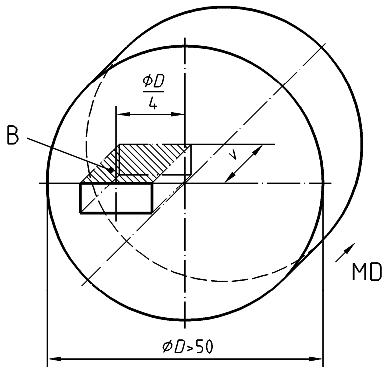
c) dotted particle L < 3 µm or w < 2 µm not taken into account, $e \leq 40$ µm and $t \leq 10$ µm, 2 particles, 1 stringer, 1 inclusion γ if grey EA, if black EC

d) $e \leq 40$ µm and $t \leq 10$ µm, 17 particles, 2 stringers, 1 inclusion β, EB

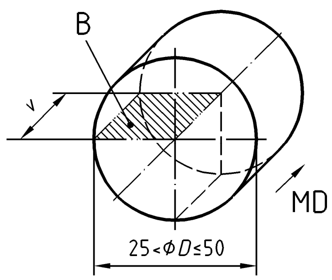
e) $e > 40$ µm or $t > 10$ µm, 3 particles, 3 inclusions δ, ED

NOTE *t* is gripped at the maximum width of the stringer

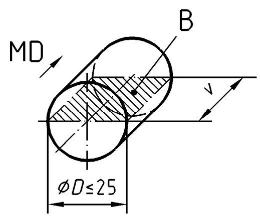
Figure 2f — Definition of an inclusion, examples (see Annex A)



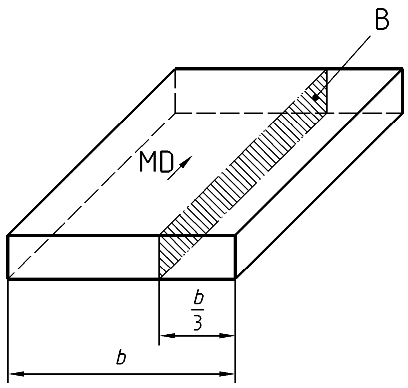
a) — Size of polished surface subject to agreement



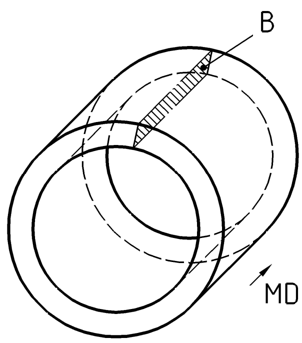
b)



c)



d)



e)

Key

B polished surface

b width of plate

MD main direction of deformation

D diameter

v width of polished surface

Figure 3 — Sampling from products of different size

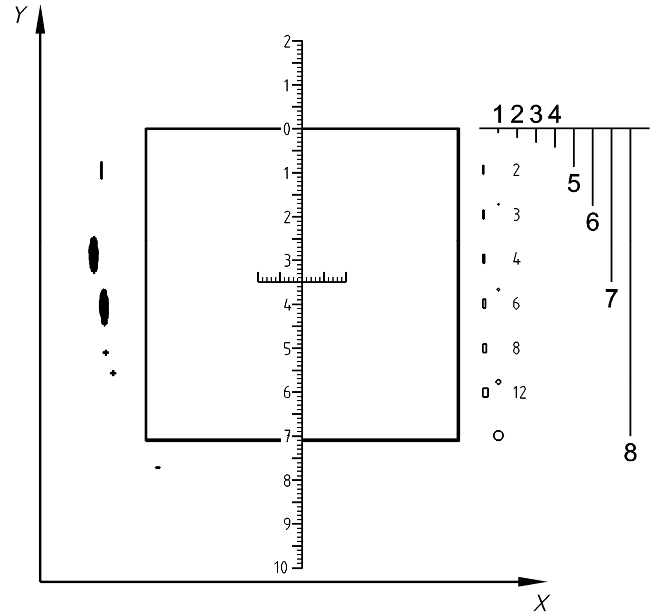


Figure 4a) — Eyepiece graticule for all microscopes for a magnification of H = 710 µm, 100:1. 1 scale unit = 10 µm. For details see Annex G

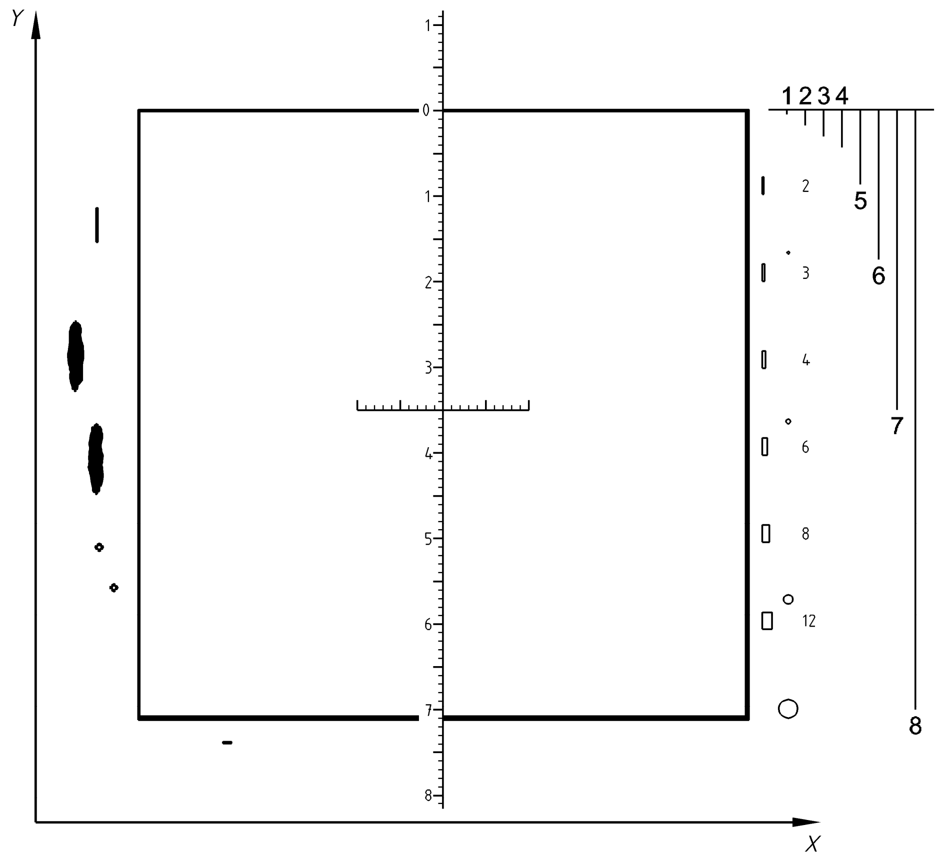


Figure 4b) — Eyepiece graticule for broad field microscopes at a working magnification of 200:1 to give a scale equivalent to H = 710 µm of the 100:1 combination. 1 scale unit = 10 µm. For details see Annex G

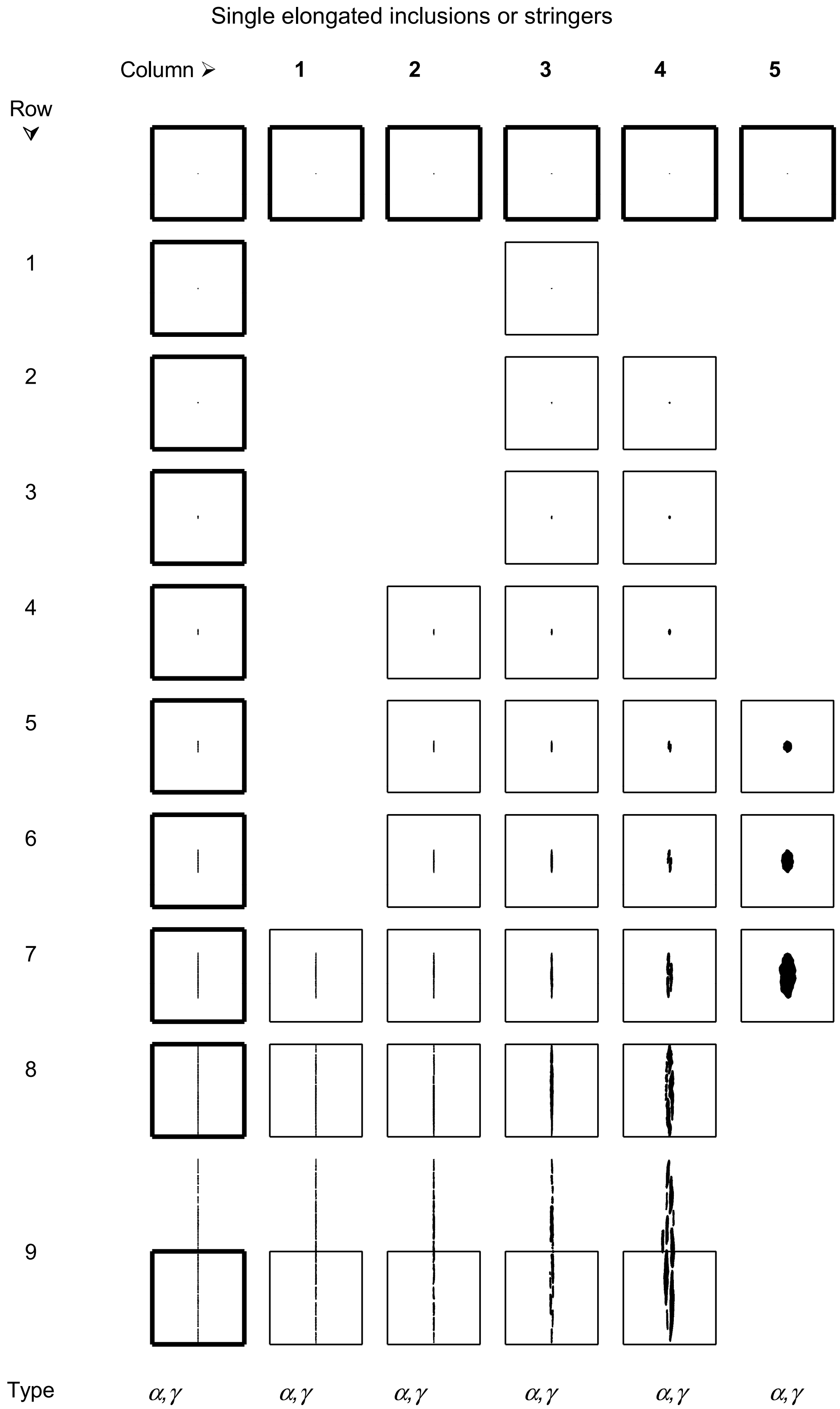
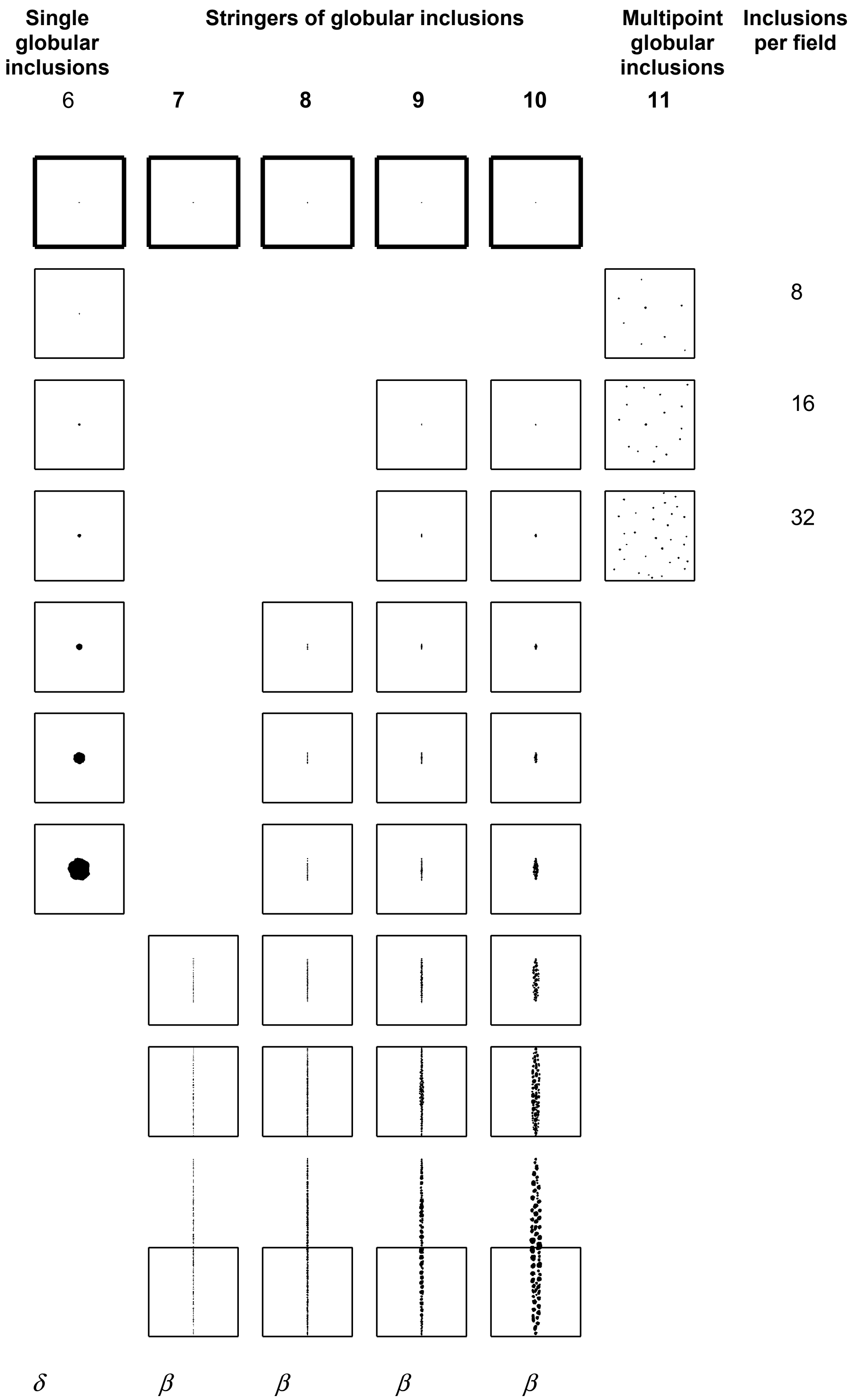


Figure 5 — Chart



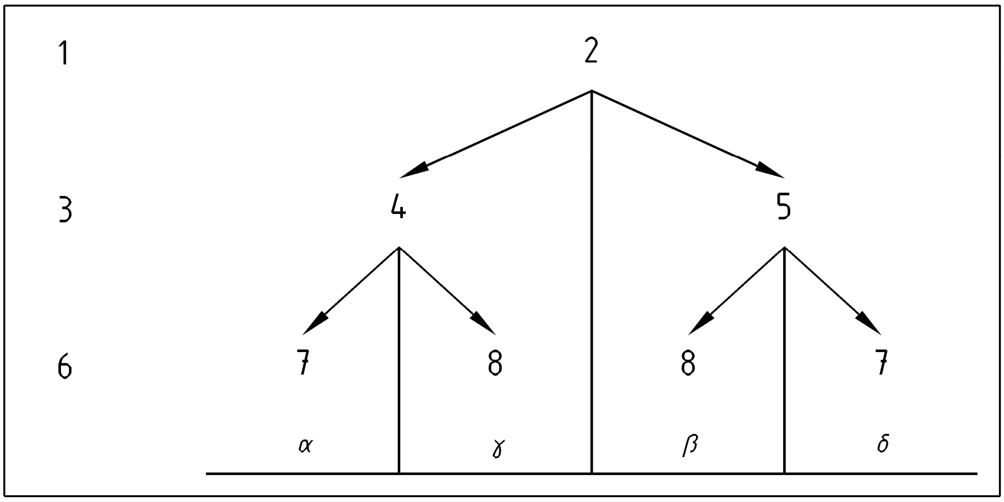
NOTE The Figure should not be used for evaluation. For evaluation the original chart should be used. Please contact Beuth Verlag GmbH, D - 10772 Berlin. The sale number is 14299.

Figure 5 — Chart *(concluded)*

Annex A
(normative)

Type of inclusions

In addition to their size, inclusions may be classified by their colour, shape and arrangement. Figure A.1 shows the different types of inclusions. One type e. g. are grey elongated inclusions in an aligned arrangement, denoted as type γ. Ca-treated steel inclusions which appear "grey/black" may especially be found (see Figure A.2). These inclusions (type EAD) can be classified in column 4, 5, 6 or 11 according to their size and number.



Key

1 Colour
2 Grey or black
3 Shape
4 Elongated
5 Globular
6 Arrangement
7 Scattered
8 Aligned

Figure A.1 — Type of inclusions

To have a summarizing notation, the designation given in Figure A.2 is introduced.

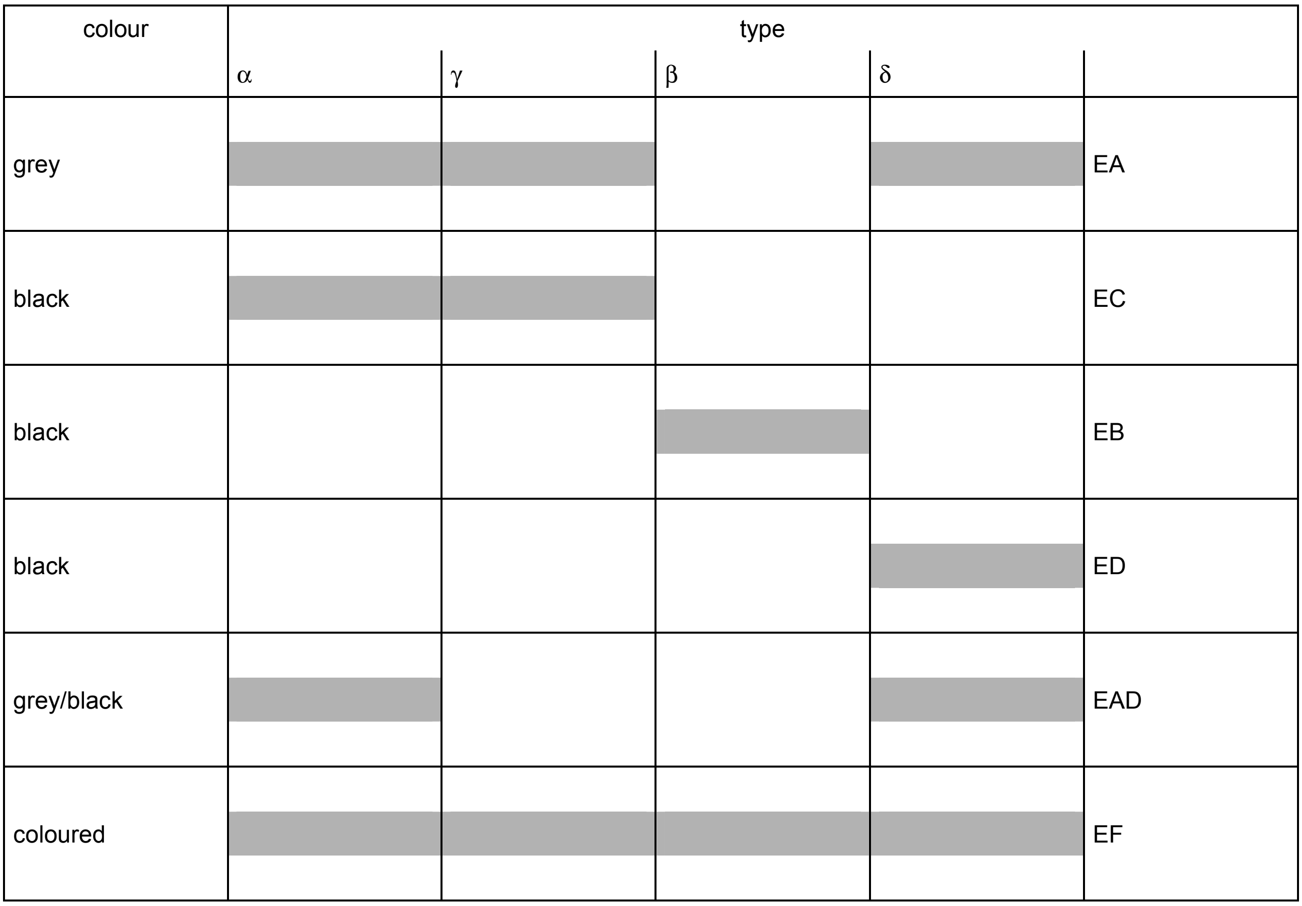


Figure A.2 — Summarizing notation of types of inclusions

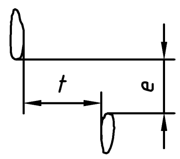
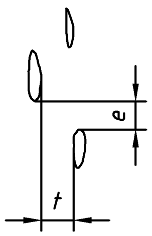
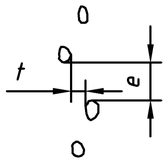
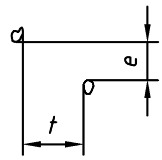
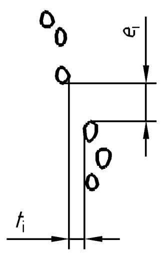
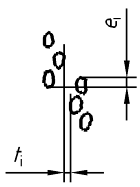
For comparison with other standards see Annex L.

Annex B
(normative)

Parameters and assessments to be used if not otherwise specified

The evaluation shall be carried out with the parameter and type of assessment as defined in Table B.1. The symbols are e.g. L_{ms}: length of inclusion type m for specimen s.

Table B.1 — Parameters and assessments for evaluation

Elements	**Shape**			
Type	**Elongated inclusions**		**Globular inclusions**	
	α	**γ**	**β**	**δ**
Proximity factor e, t in µm	Without proximity : scattered particles  $n < 3$ or $e > 40$ or $t > 10$	With proximity : aligned particles  $n \geq 3$ and $e \leq 40$ and $t \leq 10$		Without proximity : scattered particles  $n < 3$ or $e > 40$ or $t > 10$
Particle L, w, d in µm a in µm^2	$L \geq 3$ µm $w \geq 2$ µm	Only grey and black particles are taken into account separately		$d \geq 3$ µm
Inclusion L, w, d in µm a in µm^2		Between two stringers  $0 \leq e_i \leq 40$ $t_i \leq 10$ $e_i < 0$ $t_i \leq 10$		
Specimen s (worst characteristics per specimen)	Assessments Method P - Worst inclusion : P_{Lm}, P_{dm} , at H = 710 µm (100:1), (see 8.1) Method K - Average field method : : K_n, K_L and K_n, K_d at H = 710 µm (100:1), (see 8.3)			

Annex C
(informative)

Examples for inclusions of different types

Some non-metallic inclusions have typical morphology and colour, which can be used to indicate their chemical composition. But these correlations are only valid if the size of the individual particles is greater than 5 µm. Small sulphides, made non-deformable by the addition of rare earth elements, may appear as black as oxides. It is part of product standards to define, if different types of inclusions should be evaluated separately.

For sufficiently large particles, the following correlations may be valid.

— Grey: Manganese-Sulphides.

— Black, globular: oxides.

— Yellow or pink, globular: (often squares): titanium nitrides.

If a product standard requires that inclusions shall be evaluated separately according to their appearance, it shall be noted on the recording sheets (see Annex M, Annex N and Annex P) and in the test report (see clause 9e)).

Figure C.1 gives examples for scattered and aligned arrangement and different morphology.

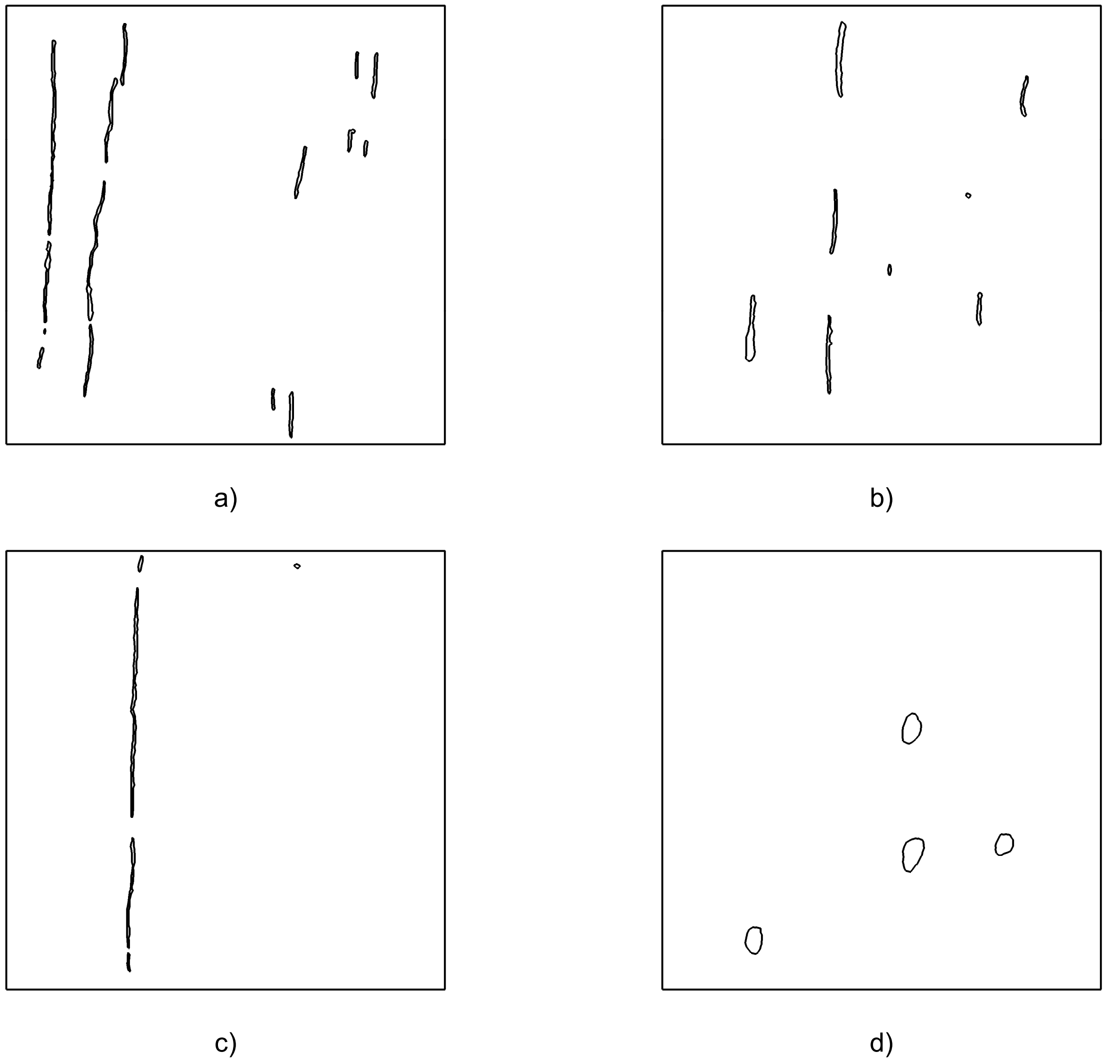
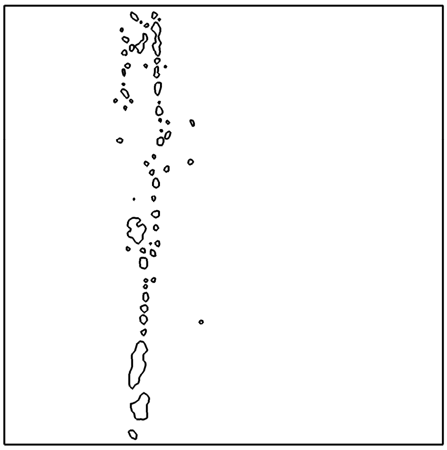
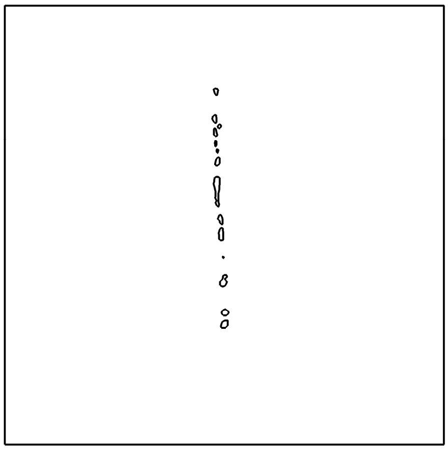


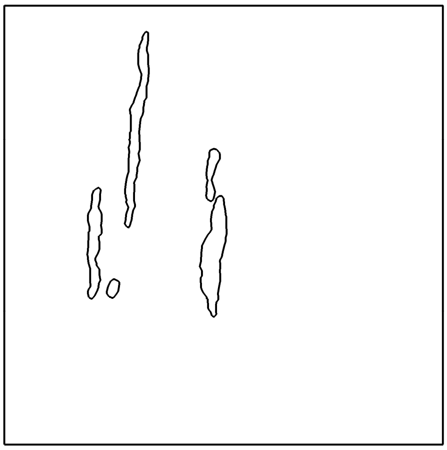
Figure C.1 - Examples for the appearance of non-metallic inclusions. Magnification H = 710 µm (100:1)
a), b), c) and d) group EA, various types grey, manganese sulfides



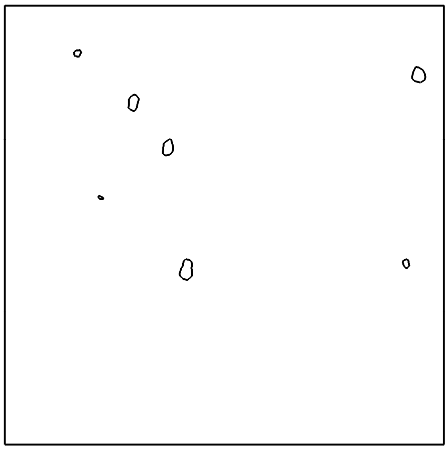
a)



b)

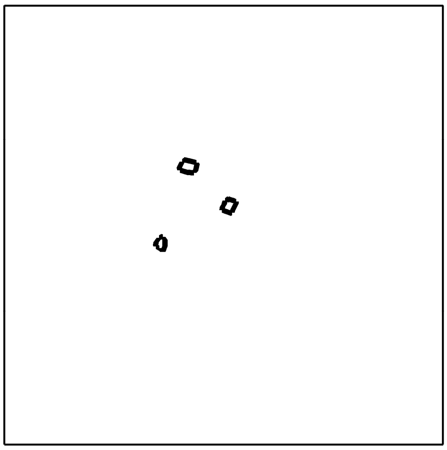


c)

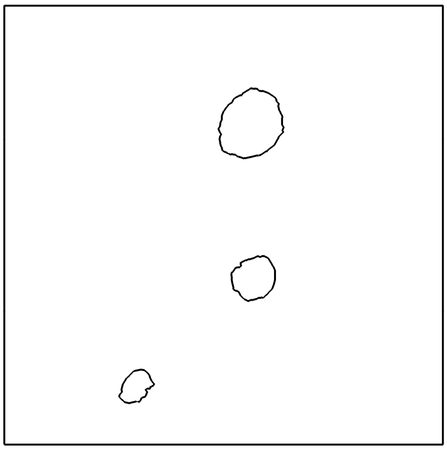


d)

Figure C.2 — Examples for the appearance of non-metallic inclusions. Magnification H = 710 µm (100:1)
a) and b) group EB, type β, black c) group EC, types α, γ, black d) group ED, type δ, black



a) 100:1



b) 500:1

Figure C.3 — Examples for the appearance of non-metallic inclusions. Magnification H = 710 µm (100:1) (Figure C.3a) and 500:1 (Figure C.3b)
a) yellow titaniumcarbonitride, group EF
b) heterogeneous inclusions, partly encapsulated, group EAD

Annex D
(informative)

Shape factor

The shape factor f used in this context is defined as:

$$\frac{L^2}{a} = \frac{4}{\pi}\left(\frac{L}{c}\right)^f \qquad (D.1)$$

where

c = 1 µm

or

$$f = \frac{\ln\left(\frac{\pi}{4} \times \frac{L^2}{a}\right)}{\ln\frac{L}{c}} \qquad (D.2)$$

Taking an ellipse shape gives:

$$a = \frac{\pi}{4} \times L \times w \qquad (D.3)$$

From these equations follows, that the shape factor f is not constant for one column (see Table 2), but is around the following average values:

Table D.1 — Average shape factors

Column k	*Shape factor f*
1	0,85
2	0,70
3	0,55
4	0,30
5	0,15
6	0

The calculated values are listed in Table 2.

Annex E
(informative)

Examples for magnification

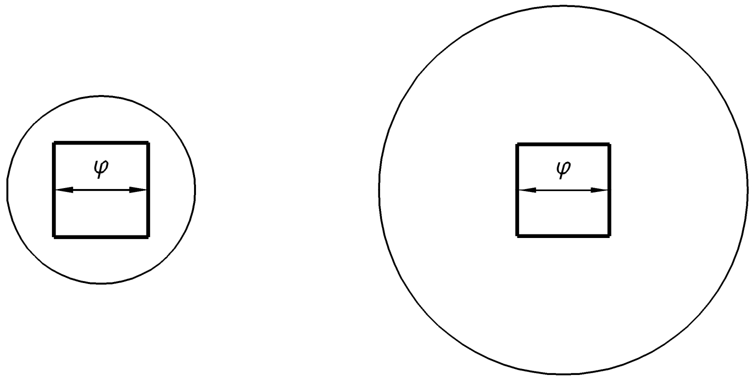
To clarify the consequence of the definition in 7.1, Figure E.1 gives examples for the fact that the same size measuring frame can be achieved on the specimen with different magnifications. The advantage of this definition is that the large field of view of new microscopes (broad field microscopes), can be used without changing the chart principles, i.e. a visual comparison between the length of the measuring frame and the length or width of an inclusion.

The chart figures are drawn for a magnification of 100:1 (length of measuring frame of H = 710 µm on the specimen). Inclusions of e.g, 1 410 µm length shall be measured at a magnification of 50:1 (length of measuring frame of H = 1 410 µm). It is not necessary to use a magnification of 200:1. For very clean steels 200:1 may be used to make the evaluation easier for the operator. In this case, particles with L < 3 µm and w < 2 µm are still not taken into account. It may happen that at 200:1 small particles are visible, which would not be seen at 50:1 (see Figure 2c). In this case, only two particles are still counted (see 4.1.3).

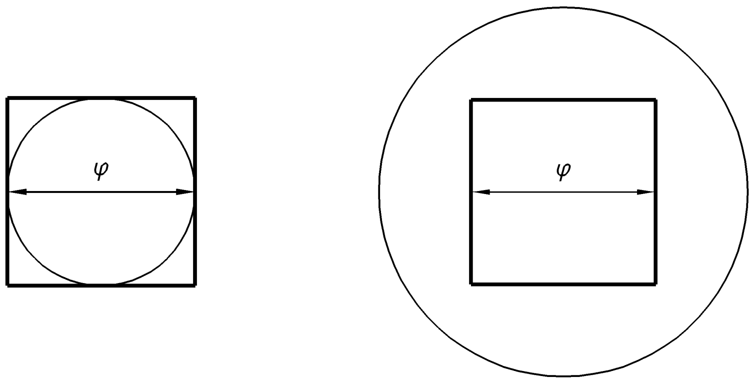
As a rough estimate, to choose the correct magnification, the largest inclusion should not be greater than $0{,}75 \times H$, three quarters of the length of the measuring frame.

Figure E.1 demonstrates that at a magnification of 200:1, the circular field diaphragm of a narrow field microscope is smaller than the square of 710 µm × 710 µm, but not in the broad field microscope. This is used to make evaluation of clean steels easier by using a broad field microscope at a magnification of 200:1 and the modified graticule (see Figure 4b). The graticule shown in Figure 4b is scaled to give the same length of side equivalent to 710 µm (100:1) when used at 200:1 as that used in 100:1 magnifications with normal and broad field eyepieces.

	Narrow field microscope	Broad field microscope
Magnification by lenses	100:1	100:1
Length H on specimen	710 µm	710 µm



	a)	b)
Apparent diameter of field diaphragm in the ocular	100 mm	200 mm
Magnification by lenses	200:1	200:1
Length H on specimen	710 µm	710 µm



	c)	d)
Apparent diameter of field diaphragm in the ocular	100 mm	200 mm

Figure E.1 — Influence of type of microscope on the size of the field of view. The length of the side H of the square (measuring frame) on the specimen is constant H = 710 µm. φ is the length of an object micrometer with a length of 710 µm

Annex F
(informative)

Details of the eyepiece graticules

To make evaluation easier, the graticules (see Figure 4), have additional information.

On the left side two elongated particles and two globular particles are presented with the distance e = 40 µm and a sidewise step t = 10 µm, these are the limits of proximity to form an inclusion (see clause 4).

The line above has a length of 40 µm in a vertical direction and a thickness of 2 µm. On the right side there are circles and lines with sizes representing width and length limits of elongated inclusions and class limits of globular inclusions. The scale has a unit of 10 µm at a magnification of H = 710 µm (100:1) (details see Annex G).

Annex G
(normative)

Manufacturing of eyepiece graticule

G.1 General

The eyepiece graticule is necessary to give a square field of view in the microscope. According to 7.2 two eyepiece graticules should be available. All the values described in clauses G.2 and G.3 shall be produced with an accuracy of 1 %.

G.2 Narrow field microscopes

In the microscope the diameter of the circular field of view is 1 000 µm on the specimen at 100:1 magnification. Therefore the eyepiece graticule type A shall have the dimensions listed in Table G.1. For the arrangement see Figure 4a).

Table G.1 — Dimensions of graticule type A

<table>
<tr><th colspan="2"></th><th>Eyepiece graticule
mm</th><th>Object
µm</th></tr>
<tr><td colspan="2">Dimension of square</td><td>7,1 × 7,1</td><td>710 × 710</td></tr>
<tr><td colspan="2">Line thickness left and top edges</td><td>0,02</td><td>2</td></tr>
<tr><td colspan="2">Line thickness right and bottom edges</td><td>0,04</td><td>4</td></tr>
<tr><td colspan="2">Line thickness of scale</td><td>0,02</td><td>2</td></tr>
<tr><td colspan="2">Scale unit</td><td>0,1</td><td>10</td></tr>
<tr><td colspan="2">Width of lines on the right side for width assessment</td><td>0,02
0,03
0,04
0,06
0,08
0,12</td><td>2,0
3,0
4,0
6,0
8,0
12,0</td></tr>
<tr><td colspan="2">Length of lines on the right side for width assessment</td><td>0,2</td><td>20</td></tr>
<tr><td colspan="2">Diameter of circles on the right side</td><td>0,030
0,055
0,11
0,22</td><td>3,0
5,5
11,0
22,0</td></tr>
<tr><td colspan="2">Length of lines on the right side for length assessment</td><td>0,055
0,11
0,22
0,44
0,88
1,76
3,53
7,05</td><td>5,5
11
22
44
88
176
353
705</td></tr>
<tr><td colspan="2">Width of lines on the right side for length assessment</td><td>0,02</td><td>2</td></tr>
<tr><td rowspan="2">Line on the left side</td><td>thickness</td><td>0,02</td><td>2</td></tr>
<tr><td>length</td><td>0,4</td><td>40</td></tr>
<tr><td rowspan="2">Line on the bottom</td><td>thickness</td><td>0,02</td><td>2</td></tr>
<tr><td>length</td><td>0,1</td><td>10</td></tr>
<tr><td rowspan="6">Two ellipses and two circles on the left side, see Figure G.1</td><td>$L_1 = L_2$</td><td>0,8</td><td>80</td></tr>
<tr><td>$w_1 = w_2$</td><td>0,14</td><td>14</td></tr>
<tr><td>e</td><td>0,4</td><td>40</td></tr>
<tr><td>t</td><td>0,1</td><td>10</td></tr>
<tr><td>diameter of circles</td><td>0,07</td><td>7</td></tr>
<tr><td>e_2</td><td>0,6</td><td>60</td></tr>
</table>

G.3 Broad field microscopes

These microscopes when used at a magnification of 200:1 give a field of view of 1 000 µm diameter on the specimen. Therefore, the values of the eyepiece graticule type B shall be the dimensions listed in Table G.2. For the arrangement see Figure 4b.

Table G.2 — Dimensions of graticule type B

		Eyepiece graticule mm	Object µm
Dimension of square		14,2 × 14,2	710 × 710
Line thickness left and top edges		0,04	2
Line thickness right and bottom edges		0,08	4
Line thickness of scale		0,02	1
Scale unit		0,2	10
Width of lines on the right side for width assessment		0,04 0,06 0,08 0,12 0,16 0,24	2,0 3,0 4,0 6,0 8,0 12,0
Length of lines on the right side for width assessment		0,4	20
Diameter of circles on the right side		0,06 0,110 0,220 0,440	3,0 5,5 11,0 22,0
Length of lines at the right side for length assessment		0,11 0,22 0,44 0,88 1,76 3,53 7,05 14,10	5,5 11 22 44 88 176 353 705
Width of lines at the right side for length assessment		0,04	2
Line on the left side	thickness	0,04	2
	length	0,8	40
Line on the bottom	thickness	0,04	2
	length	0,2	10
Two ellipses and two circles on the left side, see Figure G.1	$L_1 = L_2$	1,6	80
	$w_1 = w_2$	0,28	14
	e	0,8	40
	t	0,2	10
	diameter of circles	0,14	7
	e_2	1,2	60

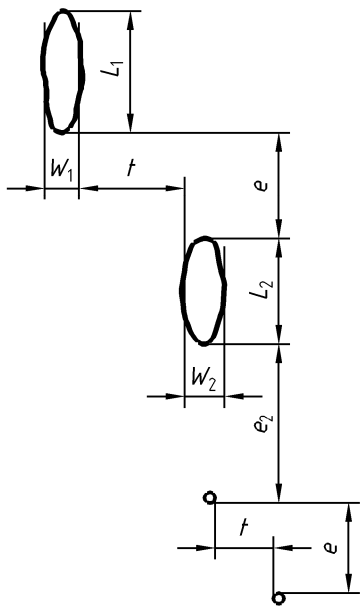


Figure G.1 — Parameters for the inclusions on the left side in Figure 4
t = 10 µm, e = 40 µm, e_2 > 40 µm

Annex H
(normative)

Calculation basis for the pictures of the chart

H.1 Shape

Ellipse with:

$$a = L \times w \times \frac{\pi}{4} \quad \text{(H.1)}$$

Circle with:

$$a = d^2 \times \frac{\pi}{4} \quad \text{(H.2)}$$

H.2 Column k, different rows q progress as:

$$L_{q+1} = 2 \times L_q \quad \text{(H.3)}$$

$$w_{q+1} = \sqrt{2} \times w_q \quad \text{(H.4)}$$

$$a_{q+1} = 2 \times \sqrt{2} \times a_q \quad \text{(H.5)}$$

H.3 Row q, different columns k progress as:

$$L_{k+1} = L_k \quad \text{(H.6)}$$

$$w_{k+1} = 2 \times \sqrt{2}\, w_k \quad \text{(H.7)}$$

$$a_{k+1} = 2 \times \sqrt{2}\, a_k \quad \text{(H.8)}$$

H.4 According to clause 1 the maximum length is 1 410 µm. Starting from maximum length, all values L_q are calculated. For *a* and *w* the starting point for the calculation is row 6, column 3 with L = 176,25 µm, and a = 1 600 µm². From that is calculated w = 11,56 µm. The values are rounded (see Table 2).

NOTE By this definition, the same values of the areas appear in each column with a shift of one row.

The change of the length to width ratio between two rows within one column is given by:

$$\frac{L_{q+1}}{w_{q+1}} = \sqrt{2}\,\frac{L_q}{w_q} \quad \text{(H.9)}$$

and between two columns for one row:

$$\frac{L_{k+1}}{w_{k+1}} = \left(2\sqrt{2}\right)^{-1} \times \frac{L_k}{w_k} \quad \text{(H.10)}$$

H.5 For column 6 is $L = w$. In this case yields:

$$L_{q+1} = 2 \times L_q \tag{H.11}$$

$$w_{q+1} = 2 \times w_q \tag{H.12}$$

$$a_{q+1} = 4 \times a_q \tag{H.13}$$

H.6 In Table 2 the values calculated according to clause H.1 to clause H.5 are presented after rounding.

Annex K
(normative)

Rules for classification

K.1 Definition of classes

The chart is designed for manual operation by comparison. Therefore it is proposed that the pictures show the upper class limits. For one inclusion, first the length is classified to row q, secondly the width is classified to column k. For width e.g. the notation is $w_{5.3}$ if the inclusion is classified according to its length in row 5 and according to its width in column 3. The classification gives upper values for the parameters length, width and area. For the calculation of the final results in the average field assessment average values are used (see Annex P and Annex U).

K.2 Classification of length

A length L_x is classified in class q if:

$$L_{q-1} < L_x \leq L_q \quad \text{(K.1)}$$

L_x lies above the limit of the lower class and is less than or equal to the limit of the upper class.

L_q and L_{q-1} are pictures of the chart and the decision can be made by immediate comparison. A length L_x of row 9, Table 2, is defined by:

$$L_8 < L_x \leq L_9 \text{ or } 705 < L_x \leq 1410 \text{ µm} \quad \text{(K.2)}$$

K.3 Classification of width

A width w_x is part of the class k if:

$$w_{k-1} < w_x \leq w_k \quad \text{(K.3)}$$

A width in row 7 is defined to be in column 3 if:

$$w_{7.2} < w_{7.x} \leq w_{7.3} \text{ or } 6 < w_{7.x} \leq 16 \text{ µm} \quad \text{(K.4)}$$

The first classes contain inclusions with length or diameter and width according to:

$$3 < L_x \leq L_1 \text{ µm} \quad \text{(K.5)}$$

$$2 < w_x \leq w_1 \text{ µm} \quad \text{(K.6)}$$

if not otherwise specified in product standards.

K.4 Classification of diameter

Inclusions classified to column 6 are globular. For example an inclusion classified to row 2 by its length is globular if:

$$w_{2.4} < w_{2.x} \leq w_{2.6} \text{ or } 8 < w_{2.x} \leq 11{,}0 \ \mu\text{m} \qquad \text{(K.7)}$$

For row 5 yields:

$$w_{5.5} < w_{5.x} \leq w_{5.6} \text{ or } 65 < w_{5.x} \leq 88{,}0 \ \mu\text{m} \qquad \text{(K.8)}$$

In these examples length and width are identical with the diameter of the globular inclusion.

K.5 Classification of area

An area is part of row q and column k if:

$$a_{q.k-1} < a_{q.x} \leq a_{q.k} \qquad \text{(K.9)}$$

For an inclusion classified by its length to row 4, the area is classified to row 4, column 3 if:

$$a_{4.2} < a_{4.x} \leq a_{4.3} \text{ or } 71 < a_{4.x} \leq 200 \ \mu\text{m}^2 \qquad \text{(K.10)}$$

Annex L
(informative)

Comparison of inclusion types in different standards

According to its colour the type of inclusions defined in Annex A can be compared with classes of other standards as summarized in Table L.1.

Table L.1 — Classes of types of inclusions as defined in different standards (see Annex W)

ASTM E45	DIN 50602	NF 04-106	SS 111116	EN 10247
A	SS	A	A	EA
C	OS	C	C	EC
B	OA	B	B	EB
D	OG	D	D	ED
-	-	-	-	EAD
-	-	-	-	EF

Annex M
(informative)

Worst inclusion assessment

For worst inclusion assessment the recording and computation sheet below (Table M.1) is recommended. It shows the results of elongated α type (EA) inclusion assessment P_L, P_a and globular δ type (ED) inclusion assessment P_d, P_a.

In the example, Table M.1, is assumed that in specimen 1 the worst inclusion of type α is classified to row 7, column 2. This gives according to Table 2: a length L of 353 µm $\rightarrow P_{L1}$ = 353 µm, an area of 1 600 µm^2 $\rightarrow P_{a1}$ = 1 600 µm^2 (Similar for the next specimens the values of P_{Ls} and P_{as}).

For the globular type δ the worst inclusion found was classified to row 4, column 6. This gives according to Table 2 a diameter d of 44 µm $\rightarrow P_{d1}$ = 44 µm, an area a of 1 525 µm^2 $\rightarrow P_{a1}$ = 1 525 µm^2 (similar for the next specimens).

In the example the average length of worst inclusions, of 3 specimens id P_L = 206 µm (617:3 µm) and P_a = 1 255 µm^2 for α type and P_d = 26 µm (77:3 µm) and P_a = 667 µm^2 for δ type inclusions.

Table M.1 — Recording and computation sheet for worst inclusion assessment

Elongated α type inclusion assessment, P_L, P_a										Globular δ type inclusion assessment P_d, P_a		
Specimen number [a]	α column 1 to 5			γ column 1 to 5			β column 7 to 9			δ column 6		
	stand. picture[b]	P_{Ls}[c]	P_{as}[e]	stand. picture	P_{Ls}	P_{as}	stand. picture	P_{Ls}	P_{as}	stand. picture	P_{ds}[d]	P_{as}[f]
1	7,2	353	1 600							4,6	44	1 525
2	5,3	88	565							3,6	22	380
3	6,3	176	1 600							2,6	11	95
...												
Total		617	3 765								77	2 000
average value P in µm	P_L	206								P_d	26	
average value P_a in µm²			1 255									667
magnification, area of field	H = 710 µm (100:1) 0,50 mm²											
Total test area of the specimens	600 mm² on 3 specimens											

[a] Number of the specimens.

[b] Number of the picture: row q, column k.

[c] Value of length of picture q.k.

.

[d] Diameter of picture q.6.

[e] Value of area of picture q.k.

[f] Value of area of picture q.6.

Annex N
(informative)

Worst field assessment

N.1 General

For worst field assessment the recording and computation sheet Table N.1 is recommended. It shows the results of elongated α, γ, β type (EA) inclusion assessments M_n, M_L, and globular δ type (ED) inclusion assessments M_n, M_d For evaluation of M_n and M_a of ED and EA type inclusions Table N.2 is recommended.

N.2 Evaluation of M_n

M_{ns} is the maximum number of inclusions per field in a specimen for each type, independent of the size. For recording the sheet described in Table N.1 may be used as it is primarily designed for recording of M_L and M_d.

N.3 Evaluation of M_n, M_L and M_d

M_{ns} is the number of inclusions per field in the worst field independent of the size. It is recorded in the row according to the length or diameter (column 6) in the example, Table N.1. In the worst field 4 (α-type) inclusions with a length according to row 2 were found with 11 µm each, which gives 44 µm total length. One inclusion has a length corresponding to row 3 with 22 µm etc. For each specimen the total number and the total length are summed up. The final value is given by averaging the values for all specimens:

$$M_n = \frac{\sum M_{ns}}{N_s} \text{/ field} \quad M_L = \frac{\sum M_{Ls}}{N_s} \text{µm/field and } M_d = \frac{\sum M_{ds}}{N_s} \text{µm/field}$$

For several fields scanned (for example 3, field 1 to field 3), it is easier to note separately.

Field 1: $4\times(2)+1\times(3)+1\times(4)+1\times(5) \rightarrow M_{L1} = 4\times11+1\times22+1\times4+1\times88 = 198\text{µm/field}$

Field 2: $1\times(1)+2\times(3)+1\times(4)+1\times(5) \rightarrow M_{L2} = 1\times5{,}5+2\times22+1\times44+1\times88 = 181{,}5\text{µm/field}$

Field 3: $2\times(1)+2\times(3)+2\times(4) \rightarrow M_{L3} = 2\times5{,}5+2\times22+1\times44 = 99\text{µm/field}$

Among the different results, report the worst result per inclusion type M_L = max (M_L), M_d = max (M_d). In this case M_{Ls} = 198 µm/field.

N.4 Evaluation of M_n and M_a

For M_a Table N.2 provides guidance for evaluation together with M_n. In one specimen there have been in the worst field 4 α-type inclusions classified in row 2, column 3 with an area of 25 µm^2 (see Table 2) that gives a total area of 100 µm^2.

Summing up provides 7 inclusions with a total area of 936 µm^2. For δ-type there was an inclusion with an area of 95 µm^2.

The final value for all specimens is calculated as:

$$M_n = \frac{\sum M_{ns}}{N_s} \text{ / Field and } \quad M_a = \frac{\sum M_{as}}{N_s} \text{ µm}^2 \text{ / Field}$$

For several fields scanned (for example 2), it is easier to note separately.

Field 1: $4 \times (2,3) + 1 \times (3,3) + 1 \times (4,3) + 1 \times (5,3) \rightarrow M_{a1} = 4 \times 25 + 1 \times 71 + 1 \times 200 + 1 \times 565 = 936$ µm^2/field

Field 2: $1 \times (1,3) + 2 \times (2,4) + 1 \times (4,3) + 2 \times (5,2) \rightarrow M_{a1} = 1 \times 9 + 2 \times 71 + 1 \times 200 + 2 \times 200 = 751$ µm^2/field

Among the different results, report the worst result per inclusion type. In this example 936 µm^2/field.

Table N.1 — Recording and computation sheet for worst field assessment

Elongated *α, γ, β* type inclusion assessments M_n, M_L **Globular *δ* type inclusion assessment M_n, M_d**										
Row		*α* column 1 to 5		*γ* column 1 to 5		*β* column 7 to 10		*δ* column 6		
number	L_{max} µm [a]	No. of inclusions [b]	total length [c]	No. of inclusions	total length	No. of inclusions	total length	No. of inclusions	total diameter	d_{max} µm
1	5,5									5,5
2	11	4	44					1	11	11
3	22	1	22							22
4	44	1	44							44
5	88	1	88							88
6	176									
7	353									
8	705									
9	1 410									
> 9										
M_{ns}		7						1		
M_{Ls} or M_{ds} in µm/field			198						11	
magnification: *H* = 710 µm (100:1) area of field : 0,50 mm²						Total scanned area of the specimen: 200 mm²				

[a] L_{max} in µm: length parameter of the picture per row.

[b] Number of assessed inclusions per row.

[c] Total length corresponding to the assessments in this row $c = a \times b$.

Table N.2 - Recording and computation sheet for worst field assessment M_n, M_a

Worst field assessment																
Row number	α column 1 to 5				γ column 1 to 5				β column 7 to 10				δ column 6			
	No. of inclusion [a]	picture q.k [b]	*a* max µm² [c]	total area [d]	No. of inclusion [a]	picture q.k [b]	a max µm² [c]	total area [d]	No. of inclusion [a]	picture q.k [b]	a max µm [b]	total area [d]	No. of inclusions [a]	picture q.k [b]	a max µm² [c]	total area [d]
1																
2	4	2.3	25	100									1	2.6	95	95
3	1	3.3	71	71												
4	1	4.3	200	200												
5	1	5.3	565	565												
6																
7																
8																
9																
> 9																
M_{ns}	7												1			
M_{as}				936												95

magnification: H = 710 µm (100:1)

Total test area of the specimen 200 mm²

area of field: 0,50 mm²

[a] No. inclusions: number of inclusions assessed in the same field.

[b] Specify row q and column k of picture q.k to determine a_{max}.

[c] a_{max} in µm²: area parameter of the picture per row q, column k. This parameter corresponds to the maximal area assessed to standard picture q.k.

[d] Total area corresponding to the assessments in the row: $d = a \times c$.

Annex P
(informative)

Average field assessment

P.1 General

For average field assessment the recording and calculation sheets presented in Table P.2 to Table P.5 are recommended. For calculation, the average values of the classes are needed, calculated according to Annex T and summarized in Annex U. The final table therefore is repeated in Table P.1 to make the use easier.

P.2 Evaluation of K_n, K_L and K_d

During the scan (see 8.3.2) for each field all inclusions are classified, by length, i. e. for the appropriate row number the number of inclusions is recorded on the sheet according to Table P.2 separately for each type of inclusion. At the end of one scan the sum of the inclusions per row is calculated and from the number of field the area scanned is calculated.

These data are transferred to the sheet Table P.3. In this example data for one specimen only is recorded in Table P.2. If several specimens are used to improve sampling, in sheet Table P.3 the sum of numbers of all specimens is recorded. From that value the total length of inclusions is calculated.

The subtotal is the sum of all inclusions (for α 39) and the total length (for α 1 111 µm). According to the magnification used, the average factor is 0,71 (see Table P.1). For α and δ together the total length is 1 556,5 µm. Multiplying by 0,71 gives the weighted size of 1 105 µm.

Now the final values are calculated by referring to the total area scanned for 15 mm^2.

The value K_n for α_g and δ_g type together is 98/15 = 6,5 inclusions/mm^2. The value K_L is 1 105/15 = 74 µm/mm^2. The average size per inclusion is the weighted size divided by the number of inclusions: 1 105/98 = 11 µm.

P.3 Evaluation of K_n and K_a

The parameter K_a shall always be evaluated together with K_n. For area, each inclusion in the scanned fields shall be classified according to row q and column k. In Table P.4 for each column and for all rows the number of inclusions shall be recorded. The total number and the scanned area are calculated at the end of scanning as for evaluation of K_L (see Table P.2). These values are transferred to Table P.5. In this Table an additional column for globular inclusions δb is added with data corresponding to Table P.3. The further calculation is similar to that for K_L (see Table P.3).

P.4 Restricted values

In some cases it is not necessary to calculate the average for all inclusions but only for the large ones. In this case the evaluation is started e.g. from a defined row. Starting from row 4 e.g. means that all inclusions with a length less than or equal to the pictures given in Figure 5 row 4 are not taken into account. This shall be noted on the recording sheet.

It is a bit more complicated for K_a taking into account only inclusions having an area greater than a given value. From Table 2 follows that for constant area the row changes with the column. Restricting the evaluation to inclusions that have an area greater than 200 μm^2, gives the starting points of row 4, column 4 or 10, row 5 column 3 or 9, row 6 column 2 or 8 and row 7 column 1 or 7 for classification.

In Table P.6 the values are listed as number 7 'starting point' extended by row 3 column 6 for δ-type inclusions that have an area greater 95 μm^2.

Inclusions classified to column 7 are only taken into account, if its length is classified to row 7, 8 or 9. Beside this restriction the evaluation is the same (see Table P.6 and Table P.7) as described for K_n und K_a (see Tables P.4 and P.5).

Table P.1 — Average factors *Q*

	Magnification		
	H = 1 410 μm	H = 710 μm	H = 350 μm
Length or diameter	1,41	0,71	0,355
Width	1,00	0,50	0,25
Area for elongated inclusions	1,41	0,355	0,088
Area for globular inclusions	2,00	0,50	0,125

Table P.2 — Recording sheet for average field assessment K_n, K_L, K_d

Elongated *α, γ* type inclusion assessments K_n, K_L Globular *δ* type inclusions assessment K_n, K_d [a]								
Row number [c]	elongated				globular			
	α_g		γ_g		δ_g		δ_b	
	No. inclusion	total	No. inclusion	total	No. inclusion	total	No inclusion	total
1	[b]	[d]			1, 2, 1, 3, 1, 1, 1, 1, 1, 2, 3, 1, 2, 1, 1, 1, 3, 2, 1, 1, 2, 1, 1, 3	37	1, 2, 1, 3, 2, 1, 1, 1, 1, 2, 1, 1, 2	19
2	1, 1, 1, 2, 1, 1, 1, 1, 1, 1, 1, 1	13			2, 1, 1, 1, 1, 1, 1, 2, 1, 1, 2, 1, 1, 2, 1, 1, 1, 1	22	1, 1, 1, 2, 1	6
3	1, 1, 2, 3, 1, 2, 1, 1	12			[b]	[d]		
4	1, 3, 2, 1, 1, 1, 1, 1, 1	12						
5	1, 1	2						
6								
... > 9								
Total number per type[e]		39				59		25
Magnification: H = 710 µm (100:1) Area of fields: 0,5 mm^2			30 fields × 0,5 mm^2 = 15 mm^2 [f] Number of fields test area			58 fields × 0,5 mm^2 = 29 mm^2		
number of inclusions assessed with one picture in one field								

[a] Assessment in number, length or diameter: the assessment is realized according to the stand pictures without taking width into account.

[b] Number of inclusions: the operator records the number of inclusions corresponding to the row q. The assessment of an inclusion type, for one field, can be a sum of several standard pictures, e. g.: 1 inclusion row 5 + 2 inclusion row 3.

[c] Number of the row, defining length or diameter.

[d] Total numbers per row of assessed inclusions to report in the computation sheet.

[e] Total numbers per type of assessed inclusions to report in the computation sheet.

[f] The operator notes the total number of scanned fields, the field area and computes test area to report in the computation sheet. The area scanned can be different for the different inclusion types.

Table P.3 — Computation sheet for average field assessment K_n, K_L, K_d

Elongated *α, γ, β* type inclusion assessments K_n, K_L - Globular *δ* type inclusion assessment K_n, K_d											
Row number	a	*αg* column 1 - 5		*δg* column 6		*γ* column 1 - 5		*β* column 7 - 10		*δ*b column 6	
	Maximum size µm	no. of inclusion	Total length	no. of inclusion	Total diameter	no. of inclusion	Total length	no. of inclusion	Total length	no. of inclusion	Total diameter
1	5,5	b	c	37	203,5					19	104,5
2	11	13	143	22	242					6	66
3	22	12	264								
4	44	12	528								
5	88	2	176								
6	176										
> 9	> 1 400	e_1	f_1	e_2	f_2					e_3	f_3
Subtotal [d]		39	1 111	59	445,5					25	170,5
Average factor			g	0,71						g	0,71
Weighted size in µm			h_1	1 105						h_2	121
Scanned area in mm^2			a_1 = 15							a_2 = 29	
K_n, average no. of inclusion/mm^2			i_1	6,5						i_2	0,9
average size in µm per inclusion			j	11							4,8
K_L or K_d in µm/mm^2			k	74						k	4,2

a Max size in µm: length or diameter values of the picture per row. This parameter corresponds to the maximal size of the row.

b Number of assessed inclusions.

c Total length or diameter corresponding to the assessments in this row: $c = a \times b$.

d Subtotal: total number of inclusions in e and total lengths of the inclusions in f.

g Average factor of Table P.1.

h Weighted size: total average sizes (length or diameter) h ; $h_1 = (f_1 + f_2) \times g$ and $h_2 = f_3 \times g$.

i K_n average number of inclusions per mm^2: total number e divided by (scanned area). $e = e_1 + e_2$ and $e = e_3$, $i_1 = (e_1+e_2) / a_1$ and $i_2 = e_3 / a_2$

j Average size per inclusion: length or diameter $j = h/e$.

k Average size per mm^2: K_L in length or K_d in diameter $k = h$/(scanned area).

Note In this example weighted and averaged values are calculated for the collective of grey ($\alpha_g+\delta_g$) and for black (only δ_b) inclusions.

Table P.4 — Recording sheet for average field assessment K_n, K_a aligned and globular EA inclusions

Elongated *α* type inclusion assessment K_n, K_a -Globular *δ* type inclusion assessment K_n, K_a [a b] (same type of sheet for *γ* type or *β* type inclusions)												
Row [c] q	*αg* column 1 no incl.	Total	*αg* column 2 no incl. [c, d]	Total	*αg* column 3 no incl.	Total	*αg* column 4 no incl.	Total	*αg* column 5 no incl.	Total	*δg* column 6 no incl.	Total
1					[d]	[e]					1, 2, 1, 3, 1, 1, 1, 1, 1, 2, 3, 1, 2, 1, 1, 1, 3, 2, 1, 1, 1, 1, 1, 3	37
2					1, 1, 1	3	1, 2, 1, 1, 2, 1, 2	10			2, 1, 1, 1, 1, 1, 1, 2, 1, 1, 2, 1, 1, 2, 1, 1, 1, 1	22
3					1, 1, 1, 1, 1	5	1, 1, 1, 2, 1, 1	7			[d]	[e]
4					1, 2, 1, 1, 1	6	1, 1, 1, 1, 1, 1	6				
5					1, 1	2						
6												
... 9												
Total per type						16		23				59
Magnification: H = 710 µm (100:1) area of fields: 0,5 mm^2						[f] 30 fields×0,5 mm^2 = 15 mm^2 number of fields scanned area						

[a] Number of inclusions per type: for each field, the operator records the number of inclusions per type. The assessment of an inclusion type, for one field, can be a sum of several stand. pictures e.g.: 1 incl. stand. pict. 2.3+1 incl. stand. pict. 2.4.

[b] Assessment in area: the assessment is realised according to the pictures. Width is taken into account by column number k.

[cq] Number of the row, defining length and diameter.

[ck] Number of the column, defining width and area.

[d] Number of inclusions: the operator records the number of inclusions corresponding to the standard picture.

[e] Total number of assessed inclusions to report in the computation sheet.

[f] The operator notes the total number of scanned fields and the field area, to report scanned area on the computation sheet.

Table P.5 — Computing sheet for average field assessment K_{n}, K_{a}

Elongated *αg* type inclusion assessment K_a, K_n - Globular *δ* type inclusion assessment K_a, K_n (same type of sheet for *γ* type or *β* type inclusion)																		
Row number	*αg* column 1,2			*αg* column 3			*αg* column 4			*αg* column 5			*δg* column 6			*δb* column 6		
	no	Pict. param.	Total area	no	Pict. param.	Total area	no [b]	Pict. param.[a]	Total area c	no	Pict. param.	Total area	no	Pict. param.	Total area	no	Pict. param.	Total area
1					9	–	–	–	–	–	–	–	37	24	888	19	24	456
2				3	25	75	10	71	710	–	–	–	22	95	2090	6	95	570
3				5	71	355	7	200	1400	–	–	–		380			380	
4				6	200	1200	6	565	3390	–	–	–		1525			1525	
5				2	565	1130		1600						6100			6100	
6					1600	–		4525						24500			24500	
... > 9		–	–		–	–	e	–	f		–	–		–	–		–	–
Subtotal [d]				16		2760	23		5500				59		2978	25		1026
Totals	Total number of inclusions [l]			39		8260	Total area of inclusions [m].						59		2978	25		1026

		αg	δg column 6	δb column 6
Average factor	g	0,355	0,5	0,5
Weighted area in µm^2	h	2932	1489	513
Scanned area in mm^2		15	15	29
K_n, number/mm^2	i	2,6	3,9	0,9
Average area per inclusion in µm^2	j	75	25	21
K_a, µm^2/mm^2	k	195	99	18

[a] *a* in µm^2: area parameter of the stand. picture q.k in Table 2. This parameter corresponds to the maximal area of inclusions assessed according to the picture q.k.

[b] Number of assessed inclusions.

[c] Total area of the inclusions corresponding to the assessments according to picture q.k: $c = a \times b$.

[d] Subtotal: number of inclusions recorded in column k[e]; total areas of recorded inclusions in column k[f].

[f] Average factor according to Table P.1.

[g] Weighted area: $h = m \times g$.

[i] K_n, average number of inclusions per mm^2 : total number l/(scanned area).

[j] Average area per inclusion: $j = h/l$.

[k] K_a average area per mm^2: k = h/(scanned area).

[l] Total number of inclusions

[m] Total area of inclusions

Table P.6 — Recording sheet for average field assessment K_n, K_{aL}, K_{ad}, restricted assessment

Elongated *βb*, type inclusion assessment K_n, K_{aL} - Globular *δb*, type inclusion assessment K_n, K_{ad} [a, b, g]
(same type of sheet for *α* type or *γ* type inclusions)

Row [cq]	*βb* column 7		*βb* column 8		*βb* column 9		*βb* column 10		*δb* column 6	
	no incl. [ck]	Total	no incl.	Total	no incl.	Total	no incl.	Total	no incl.	Total
3			[d]	[e]					1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1	16
4									1, 1, 1, 1	4
5					1, 1, 1	3			[d]	[e]
6			1, 1, 1, 1, 1, 1	6	1	1				
7										
8										
> 9										
Total per type				6		4				20

Magnification: *H* = 710 µm (100:1)

[f] 6 specimens×200 mm² = 1 200 mm²

Area of fields: 0,5 mm²

[a] Number of inclusions per type.

[b] Assessment in area.

[cq] Number of the row, defining length.

[ck] Number of the column, defining width.

[d] Number of inclusions: the operator records the number of inclusions corresponding to the standard picture.

[e] Total number of assessed inclusions to report in the computation sheet.

[f] Complete scanning of all the specimens for restricted assessment.

[g] Starting point for elongated inclusions: a > 200 µm²

row: 4 5 6 7 column: 4 3 2 1

or column: 10 9 8 7

Starting point for globular inclusions: a > 95 µm²

row 3 column 6

Table P.7 — Computation sheet for average field assessment K_n, $K_{\underline{aL}}$, K_{ad}, restricted assessment

Elongated ***βb***, type inclusion assessment K_n, K_{aL} - Globular ***δb***, type inclusion assessment K_n, K_{ad} [n] (same type of sheet for *α* type or *γ* type inclusions)															
Row number	*βb* column 7			*βb* column 8			*βb* column 9			*βb* column 10			*δb* column 6		
	no	pict. param.	Total area	no	pict. param.	Total area	no [b]	pict. param. a	Total area c	no	pict. param.	Total area	no	pict. param.	Total area
3	–	–	–	–	–	–		71			200		16	380	6 080
4	–	–	–		71			200			565		4	1 525	6 100
5	–	–	–		200		3	565	1 695		1 600			6 100	
6	–	–	–	6	565	3 390	1	1 600	1 600		4 525			24 500	
7			566		1 600			4 525			12 800		–	–	–
8			1 600		4 525			12 800			36 200		–	–	–
... > 9		–	–				e	–	f		–	–			
Subtotal [d]				6		3 390	4		3 295				20	12 180	
Totals	Total number of inclusions [l]			10		6 685	m	Total area of inclusions					20	12 180	
Average factor		g				0,355									0,5
Weighted area sum in μm^2		h				2 373									6 090
Scanned area in mm^2		o				1 200									1 200
K_n number/mm^2		i				0,0083									0,017
Mean area per inclusion in μm^2		j				237									305
K_a $\mu m^2/mm^2$		k				2									5,1

a *a* in µm²: area parameter of the stand. picture q.k in Table 2. This parameter corresponds to the maximal area of inclusions assessed according to the picture q.k. b Number of assessed inclusions. c Total area of the inclusions corresponding to the assessments according to picture q.k: c = a X b . d Subtotal: number of inclusions recorded in column k e total areas of recorded inclusions in column k[f]. g Average factor according to Table P.1. h Weighted area: $h = m \times g$.	i K_n, average number of inclusions per mm² total number l/ (scanned area). j Average area per inclusion: $j = h/l$. k K_a average area per mm²: k = h/(scanned area). l Total number of inclusions m Total area of inclusions n Starting point for elongated inclusions: a > 200 µm² row: 4 5 6 7 column: 4 3 2 1 or column: 10 9 8 7 Starting point for globular inclusions: a > 95 µm² row 3 column 6 o Complete scanning of all the specimens e.g.: 6×200 = 1 200 mm².

Annex Q
(normative)

Calculation basis for the assessment

Q.1 Worst inclusion assessment

The assessment is done at a magnification of H = 710 µm only. The symbol for worst inclusion assessment is P. It is combined with the parameters L, d and a and s for specimen. For a simple description of the calculation, see Annex M.

All values can be evaluated for different types of inclusions.

The value P_L, the greatest length of an inclusion, is given for the worst inclusion in one field as: $P_{Ls} = L_q$ µm

$$P_L = \frac{\sum P_{Ls}}{N_s} \text{µm} \qquad \text{(Q.1)}$$

For globular inclusions yields: $P_{ds} = d_q$ µm for the worst inclusion:

$$P_d = \frac{\sum P_{ds}}{N_s} \text{µm} \qquad \text{(Q.2)}$$

If there is rated according to the area, the calculation gives $P_{as} = a_{q.k}$ µm^2 for the worst inclusion:

$$P_a = \frac{\sum P_{as}}{N_s} \text{µm}^2 \qquad \text{(Q.3)}$$

Q.2 Worst field assessment

The assessment is done at a magnification of H = 710 µm only. Therefore the result is related to an area of 0,5 mm^2. A simple description of the calculation is given in Annex N.

Q.2.1 Calculation of M_n

If M_{ns} is the number of inclusions in the worst field of one specimen the final value is:

$$M_n = \frac{\sum M_{ns}}{N_s} \text{field} \qquad \text{(Q.4)}$$

Q.2.2 Calculation of M_L

The length M_{Ls} is the sum of the length of all inclusions in the worst field, classified to a row q.

$$M_{Ls} = \sum L_q \text{ µm/field} \qquad \text{(Q.5)}$$

The final value is:

$$M_L = \frac{\sum M_{Ls}}{N_s} \text{ µm / field} \qquad \text{(Q.6)}$$

Q.2.3 Calculation of M_d

For this value the same is valid as for M_L:

$$M_{ds} = \sum d_q \text{ µm/field} \qquad \text{(Q.7)}$$

$$M_d = \frac{\sum M_{ds}}{N_s} \text{ µm / field} \qquad \text{(Q.8)}$$

Q.2.4 Calculation of M_a

The area M_{as} is the sum of the area of all inclusions in the worst field classified according to row q and column k as $a_{q.k}$.

$$M_{as} = \sum a_{q.k} \text{ µm}^2 \text{ / field} \qquad \text{(Q.9)}$$

The final value is:

$$M_a = \frac{\sum M_{as}}{N_s} \text{ µm}^2 \text{ / field} \qquad \text{(Q.10)}$$

Q.3 Average field

Evaluation of K_n, K_L, K_d and K_a..

For each field scanned the inclusions are classified according to the length (i.e. row) and its number n_q recorded. From that the total length $n_q \times L_q$ is calculated for each row and the total number of inclusions and the total length calculated.

$$\sum_{q=1}^{9} n_q \times L_q \qquad \text{(Q.11)}$$

The length is multiplied with the factors Q calculated in Annex U. The scanned area is calculated by the area A per field (see 7.1) and the number of fields scanned N_i:

$$K_n = \frac{\sum_{q=1}^{9} n_q}{A \times N_i} 1/\text{mm}^2 = \frac{\sum_{1}^{N_i} n_i}{A \times N_i} 1/\text{mm}^2 \qquad \text{(Q.12)}$$

$$K_L = \frac{Q \times \sum_{q=1}^{9} n_q \times L_q}{A \times N_i} \mu m / mm^2 \qquad (Q.13)$$

$$K_d = \frac{Q \times \sum_{q=1}^{9} n_q \times d_q}{A \times N_i} \mu m / mm^2 \qquad (Q.14)$$

$$K_a = \frac{Q \times \sum_{q=1}^{9} \sum_{k=1}^{5} n_{q.k} \times a_{q.k}}{A \times N_i} \quad \mu m^2 / mm^2 \qquad (Q.15)$$

In equation Q.15 the summation for different columns is made from 1 to 5. For column 6 the calculation is made separately as well as for columns 7 to 10, if it is not otherwise specified.

Annex R
(normative)

Determination of precision and scanning parameters for average field assessment

The following is only valid for evaluation of non-restricted values (see 8.3.3.2). For restricted values the whole test area shall be scanned.

To make evaluation more effective for none restricted values, depending on the level of confidence LC desired and the size of the inclusions, the number of fields to be evaluated can be calculated. From a first estimation the average length of the inclusions (e. g. 22 μm) and its average number (e. g. 4) per mm^2 are recorded [one field of view at H = 710 μm (100:1) has an area of 0,5 mm^2]. With these data and the desired level of confidence LC the number of fields to be evaluated can be taken from Table R.1. This table is limited to a maximum number of fields to be scanned of 2 000. The combinations of value in the table to the right (as shown by the arrows) are permitted.

EXAMPLE:

average length 22 μm, 1 inclusion per mm^2 and a confidence level of 60 % gives 50 fields at a magnification of H = 710 μm (100:1). If the average length is 22 μm and there are as an average 2 inclusions per mm^2, to obtain a confidence level of 60 % at a magnification of H = 1 410 μm, it is necessary to scan 30 fields or 100 fields to obtain a confidence level of 80 % at a magnification of H = 710 μm or 1 600 fields to obtain a confidence level of 90 % at a magnification of H = 350 μm.

If the average length of the inclusions is 5,5 μm, there is no path to any confidence level at a magnification of H = 710 μm. (This would give a very high number of fields to be scanned). Table R.1 gives a working chart for manual stages. For the calculation of Table R.1 is assumed that the inclusion distribution follows a Poisson distribution.

The determination of the scanning parameters may be restricted to one specimen of a sample.

Table R.1 — Estimation of number of fields to be scanned LC: level of confidence

	Average size in µm					
L or *d*	5.5	11	22	44	88	≥176
row n°	1	2	3	4	5	≥ 6

LC %	Average number per mm²						
	0,4	1	2	4	10	20	40
60	30	30	**30**	30	30	30	30
80	125	50	30	30	30	30	30
90	500	200	100	50	30	30	30
Magnification *H* = 1410 µm (50:1)							
60	125	50	30	30	30	30	30
80	500	200	**100**	50	30	30	30
90	2 000	800	400	200	80	50	30
Magnification *H* = 710 µm (100:1)							
60	500	200	100	50	30	30	30
80	2 000	800	400	200	80	50	30
90			**1 600**	800	320	160	80
Magnification *H* = 350 µm (200:1)							

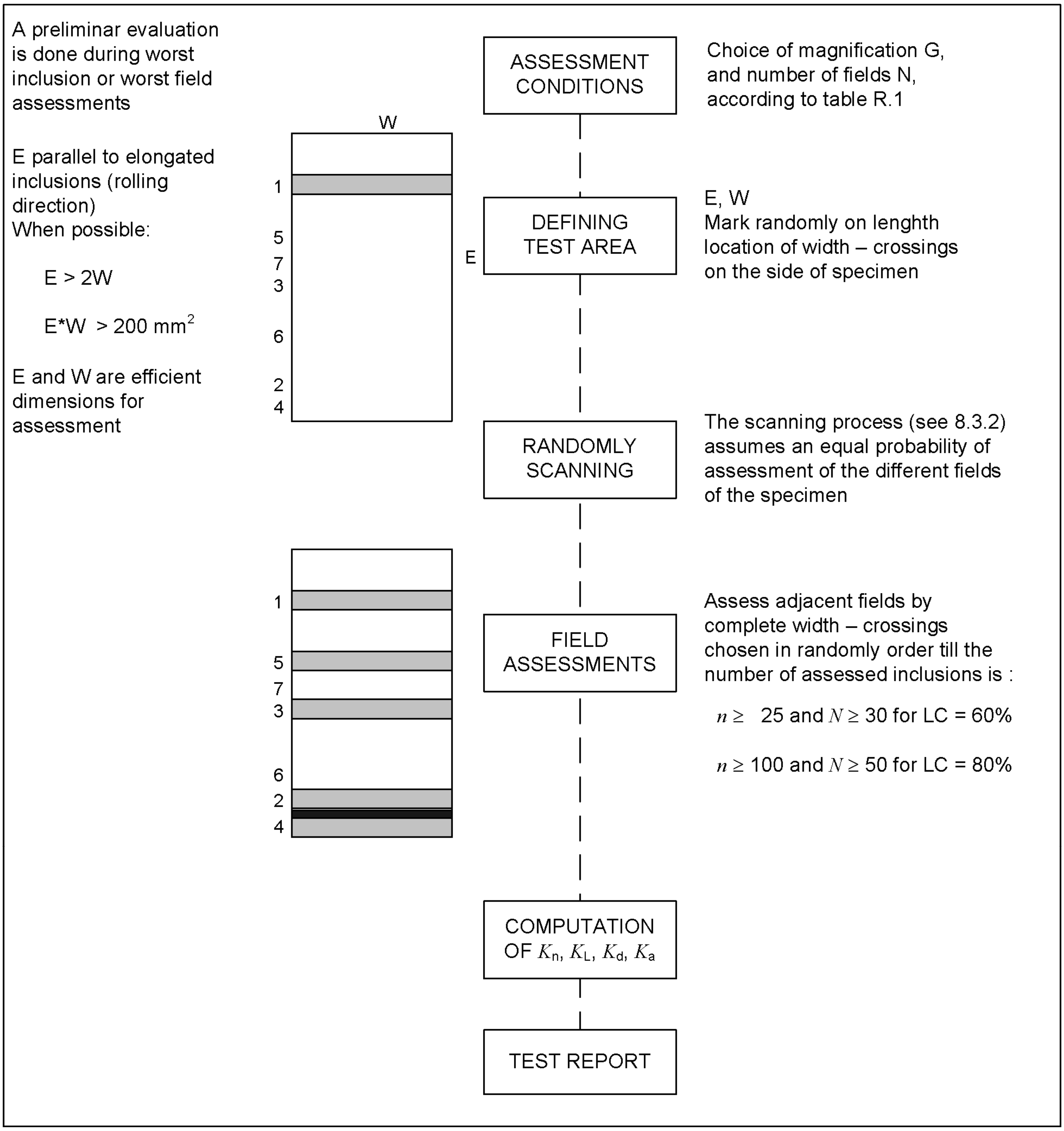


Figure R.1 — Procedure for microscopes with manual stage

Annex S
(informative)

Edge Errors correction

S.1 General

For particle sizing using standard stereological principles edge errors in each field shall be considered. It is a basic principle that the evaluation shall be done in such a way that one particle or inclusion is not counted twice. This is made easy by the rectangular measuring field (see 7.2). Edge error correction is necessary for the average field method (see 8.3).

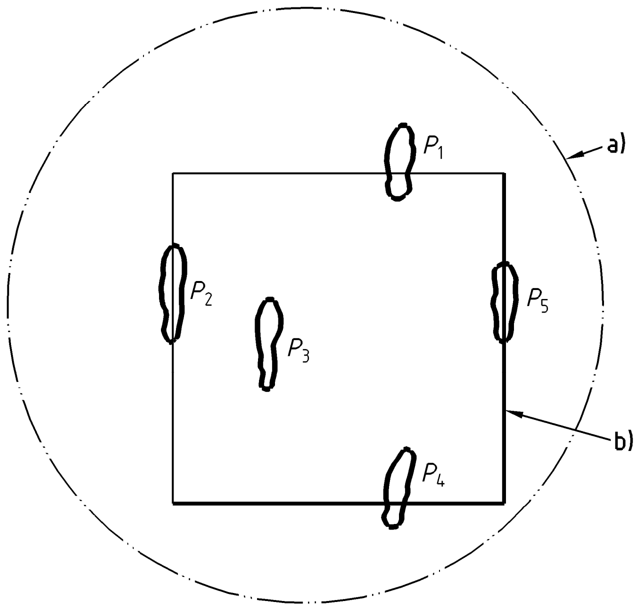
S.2 Field by field measurement

If the measurement is done field by field or by random field assessment (see 8.3.2) an edge errors correction shall be used. Inclusions crossing the upper and the left side of the field of measurement are measured, inclusions crossing the lower and the right side are ignored. For this edge error correction the field of view must be greater than the measuring frame (see Figure S.1). To act as a reminder the lower and right side are drawn more thickly than the left and upper side in the graduated eyepieces (see Figure 4).

Simplification for manual evaluation of number of inclusions per unit area only: inclusions crossing the right and bottom side are counted as 0,5, all other inclusions are counted as 1.

S.3 If a magnification with a measuring frame H (see 7.1 and Figure 4) of 350 µm or 710 µm is used and an inclusion has a length greater than 350 µm or 710 µm, it is permitted to follow the inclusion into adjacent fields to measure its full length taking precautions to avoid the inclusion being counted twice.

NOTE This can be achieved e.g. by recording the coordinates of the stages for the field of view containing that inclusion, before moving along the inclusion.



Key

a) field of view — Measured: P_1, P_2, P_3

b) measuring frame — Not measured: P_4, P_5

Figure S.1 — Edge errors correction

Annex T
(normative)

Calculation of average values of parameters for one class

For the average field method see 8.3; for calculation the average values of the parameters of each class defined in Annex K are used. These values are calculated by using the geometrical averaging. Taking for class q.k all values as 1, in Figure T.1 the values of the surrounding limits of this class are given to the rules defined in Annex H and Annex K. At the centre of this square in Figure T.1 the factors Q for giving the average values are listed. In Table T.1 the general equations for the calculation are given. With these data the factors summarized in Table U.1 are calculated. These values are not correct for the limiting classes row 1 and column 1, but this can be neglected for manual evaluation.

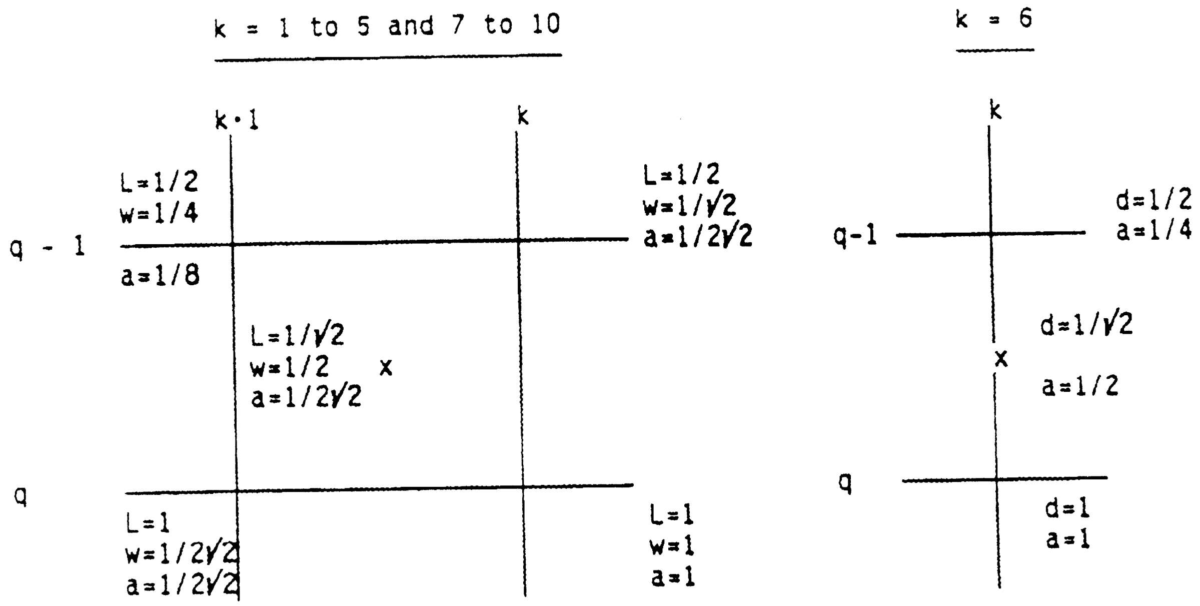


Figure T.1 — Mathematical rules for averaging

Table T.1 — Formula for the calculation of factors *Q*

Length or diameter	$\frac{1}{\sqrt{2}} \times \frac{H}{710}$
Width	$\frac{1}{2} \times \frac{H}{710}$
Area for elongated inclusions	$\frac{1}{2\times\sqrt{2}} \times \left(\frac{H}{710}\right)^2$
Area for globular inclusions	$\frac{1}{2}\left(\frac{H}{710}\right)^2$

Annex U
(normative)

Average values of parameters

The values of length, width and area, given in Table 2 are upper class limits. To get the average value of a class used for the calculation of average field values (see 8.3) the upper limits of Table 2 are multiplied by a factor Q, listed below which shall be used. For the calculation itself see Annex T.

Table U.1 — Average factors *Q*

	Magnification		
	H = 1 410 µm	H = 710 µm	H = 350 µm
Length or diameter	1,41	0,71	0,355
Width	1,00	0,50	0,25
Area for elongated inclusions	1,41	0,355	0,088
Area for globular inclusions	2,00	0,50	0,125

Annex V
(informative)

Comments of the working group

V.1 General

The working group discussed this European Standard at eight meetings. A lot of time was necessary for decisions, in cases, several methods or ways can be proposed. To make the decisions understandable, for some definitions given in the standard the reasons are given in this annex.

V.2 Length

The main parameter for manual evaluation is the length *L* of each inclusion, which changes in the chart from row to row by a factor of 2.

The main purpose of the pictures is for manual comparison. Therefore, the steps between two pictures must be sufficiently large so that an operator can distinguish the difference without measurement.

The factor of 2 gives a clear differentiation between two rows and allows a change of magnification. There is a general agreement verified by tests that a factor of $\sqrt{2}$ for the length is too small, especially for small inclusions which have a length below 10 µm. For an evaluation including a measurement, the steps may be smaller.

V.3 Width

The second parameter is the width of each inclusion which changes in steps of 2 $\sqrt{2}$ between two columns of the chart to enable a clearer differentiation. In every case classification is first made according to length, defining the row, after that the width is classified, defining the column.

V.4 Number

Additionally the number of inclusions per measuring field can be determined as an important parameter for characterizing inclusion density.

V.5 Resolution

For resolution, according to physical principles, it was defined that for inclusions the minimum length L or diameter d for quantitative measurements with light microscopes is given by 3 µm, the minimum width by 2 µm, independent of the magnification used. The limitation to macroscopic inclusions was taken at a length of 1 410 µm, the length of the measuring frame at 50:1 magnification.

The magnification necessary to measure a width of 1 µm e.g. to differentiate particles with a width of 1 µm and 2 µm, is 200 times for a human operator to ensure 0,2 mm width in the eyepiece. This is a lower limit. Therefore 2 µm was taken to make the evaluation less tedious.

Constructing the pictures, the maximum length of the measuring frame was divided by 2, 4... to get the length of the inclusions. The advantage of this is that the length of an inclusion to classify is 1/2, 1/4 ... of the length of the measuring frame and therefore easier to estimate during manual operation.

V.6 Area

If the rating of the inclusions is to be independent of the degree of deformation, the only parameter that is independent of deformation is the volume fraction, which equals the area fraction if the inclusions are distributed randomly in space. To allow comparison between assessments at different magnifications, in each column there are pictures having the same area.

V.7 Description of inclusions

There was general agreement that particles being close together must be treated as one inclusion for two reasons:

1) particles are often bended and therefore in the section only parts of a particle are visible, see Figure V.1;

2) at the end of a particle the stress-intensity-factor is increased, promoting crack propagation, if the next particle is within this stress field.

The limit of the sidewise shift *t* of 10 µm (see Figure 2a)) was taken as the limitation by the resolution of a light optical microscope at 50 times magnification. It was decided to hold this value constant for all magnifications to ensure that the results are independent of the magnification used.

The final results should be proportional to physical values such as length, area, number. Area per unit area shall be described by the dimension $\mu m^2/mm^2$ instead of a dimensionless value to make the origin of the dimension clear.

The equation shown in Figure 1a can be used to determine length, width or area. To take a factor of 2 for the area e.g. $a_{q+1} = 2 \times a_q$ gives a constant value of w in one column, which is not in agreement with the real appearance of inclusions. Therefore, it is proposed to define $w_{q+1} = \sqrt{2} \times w_q$. This gives a sequence within 10 rows, from w_{min} = 2 µm to w_{max} = 68 µm. Introducing:

$$L_{q+1} = 2 \times L_q \tag{V.1}$$

and

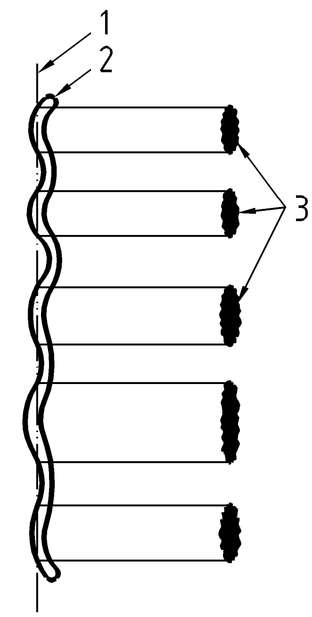
$$w_{q+1} = \sqrt{2} \times w_q \tag{V.2}$$

gives

$$a_{q+1} = 2 \times \sqrt{2} \times a_q \tag{V.3}$$

It was decided that one value of the area should be 1 600 μm^2.

From the calculations described in Annex H follows that there are particles having a width less than 2 µm as well as particles having a length to width ratio less than 1,3. These particles will not be presented in the chart. For manual evaluation its difference to a circle is too small. In column 5 there are no values for rows 8 and 9, in column 6 no values for rows 6, 7, 8 and 9. Such large particles cannot be found in steels. Therefore there are no pictures.



Key

1 Cutting plane

2 Particle

3 Particles visible in the cutting plane

Figure V.1 — Appearance of particles

V.8 Globular particles

One column should present globular particles. A calculation shows that if a progression factor of 2 for the diameter of the circles of the pictures is taken from row to row, the difference in area between a circle and a square is much less than the difference in area between two rows. Therefore, it was decided to have pictures with circles only (to be used for squares). The diameter of the globular particles was set to be identical with the length of the deformable particles, see Table 2, to make manual evaluation as easy as possible. The disadvantage is that between two rows q the area changes by $a_{q+1} = 4 \times a_q$ instead of $2 \times \sqrt{2}$ as for columns 1 to 5. But ease of evaluation was given highest priority.

V.9 Shape factor

In the first meetings a constant shape factor f, defined in Annex D, was discussed to generate for the same length features with different widths.

For f the values 0,85, 0,70, 0,55, 0,30, 0,15 and 0,0 were proposed.

For the inclusions with "medium" width ($f \approx 0{,}55$ according to equation (D.1) in Annex D) the area of 1 600 µm^2 was correlated to a length of 176 µm (see Table 2 row 6 column 3). For the same length, between two columns k the area was changed by:

$$a_{k+1} = 2 \times \sqrt{2} \times a_k \qquad (V.4)$$

By this definition, the same values of area are just shifted by 1 row between two columns.

But with $L_{k+1} = L_k$ then it follows that w: $w_{k+1} = 2 \times \sqrt{2} \times w_k$. By these definitions the value of f is not constant for columns 1 to 5 (see Table 2) but are around the values given above. Constant values of f give a very complex correlation between area, length and width and a shape not as close to reality as the values presented in Table 2.

V.10 Combined inclusions

This standard gives no correlation to properties and no information about the crystal structure and chemical composition. Therefore, in the case, drawn in Figure 2d) it is proposed, to measure plastic and non-deformable inclusions as one inclusion. If as shown in Figure 2d) case (4), the width w_1 of the non deformable exceeds that of w_2, the deformable part, by $w_1 > 3 \times w_2$, then it shall reported separately. An example of such arrangements is shown in Figure 2e).

V.11 Measuring frame

It was decided to have a square as a measuring frame instead of a circle. This has the great advantage that the length of particles and inclusions can easily be compared with the length of the measuring frame and edge error correction is easier. For particles having a length of 30 % of the frame length, the error in estimating its true length is a factor of 2 without edge error correction. It was decided to draw length marks on the measuring frame to give some help for manual measurements. Because the field diaphragm is circular, the rectangle field must be realized by inserting an etched glass in the eyepiece or at another suitable position in the microscope.

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