

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

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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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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of an identical text or by endorsement, at the latest by October 2007, and conflicting national standards shall be withdrawn at the latest by October 2007.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.

According to the CEN/CENELEC Internal Regulations, the national standards organizations of the following countries are bound to implement this European Standard: Austria, Belgium, Bulgaria, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Norway, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, Switzerland and United Kingdom.

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 $\mu\text{m}/\text{mm}^2$, number/ mm^2 , areas in $\mu\text{m}^2/\text{mm}^2$. 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:

$$L_{q-1} < L_x \leq L_q \text{ µm}$$

The width w_x is classified in column k if:

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

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 cleanliness 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 $\leq 10 \text{ } \mu\text{m}$ and the distance e is $\leq 40 \text{ } \mu\text{m}$ and the main axis of the particles are parallel within $\pm 10^\circ$. 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 $\leq 10 \text{ } \mu\text{m}$ and $\leq 40 \text{ } \mu\text{m}$ (see Figure 2b). Particles with $L < 3 \text{ } \mu\text{m}$ or $w < 2 \text{ } \mu\text{m}$ 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 mm².

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

Case b) for $e < 0 \mu\text{m}$, $t \leq 10 \mu\text{m}$: is the width of an inclusion out of two stringers defined as the sum of the stringers' widths and the distance t ($w_{\text{total}} = w_1 + w_2 + t$) (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

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

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

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
β		aligned, globular inclusion type
β_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 , $\mu\text{m}^2/\text{mm}^2$	average field assessment
L	μm	length of inclusions
M	-, μm , $\mu\text{m}^2/\text{mm}^2$	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;

$\overline{n_j}, \overline{nj}$ 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 mm² 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 mm² 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 mm² (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 mm² 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: $H = 350\text{ }\mu\text{m}$, $H = 710\text{ }\mu\text{m}$, $H = 1\,410\text{ }\mu\text{m}$.

These values shall be used with an accuracy of $\pm 0,02\text{ mm}$ 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 $H = 710 \mu\text{m}$ 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 $10 \mu\text{m}$ for $H = 710 \mu\text{m}$. 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 $2 \mu\text{m}$, on the top inclusions with a length of $3 \mu\text{m}$, 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 $710 \mu\text{m}$ ($100\times$) 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 $H = 710 \mu\text{m}$ 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 $H = 710 \mu\text{m}$ (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 $\pm 10^\circ$ 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 $H = 1\,410\ \mu\text{m}$ (50:1) to row 5 at a magnification of $H = 710\ \mu\text{m}$ (100:1) and row 6 at a magnification of $H = 350\ \mu\text{m}$ (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 α, γ, β , 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

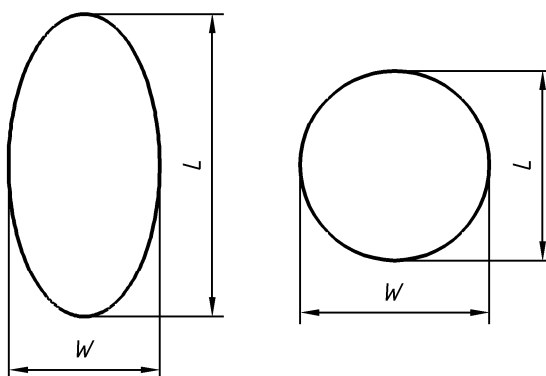
The test results shall be given in accordance with EN ISO/IEC 17025 and the test report shall contain the following information:

- 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					Globular inclusions column 6
			Length $L \geq 3 \mu\text{m}$ and width $w \geq 2 \mu\text{m}$					diameter $d \geq 3 \mu\text{m}$
Row q	L μm		1 or 7	2 or 8	3 or 9	4 or 10	5	6
1	5,50	$w \mu\text{m}$ $a \mu\text{m}^2$ L/w f			2,00 9,00 2,70 0,58			5,50 24 1,00 0,00
2	11	$w \mu\text{m}$ $a \mu\text{m}^2$ 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	$w \mu\text{m}$ $a \mu\text{m}^2$ L/w f			4,00 71 5,40 0,55	12 200 1,90 0,21		22 380 1,00 0,00
4	44	$w \mu\text{m}$ $a \mu\text{m}^2$ 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	$w \mu\text{m}$ $a \mu\text{m}^2$ 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	$w \mu\text{m}$ $a \mu\text{m}^2$ 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	$w \mu\text{m}$ $a \mu\text{m}^2$ 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	$w \mu\text{m}$ $a \mu\text{m}^2$ 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	$w \mu\text{m}$ $a \mu\text{m}^2$ 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

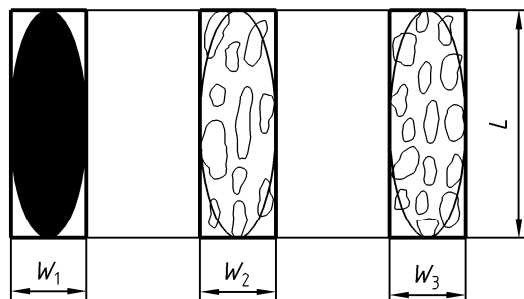
$L \neq w$: ellipse

$1,00 \leq L/w < 1,30$: form circular

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

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

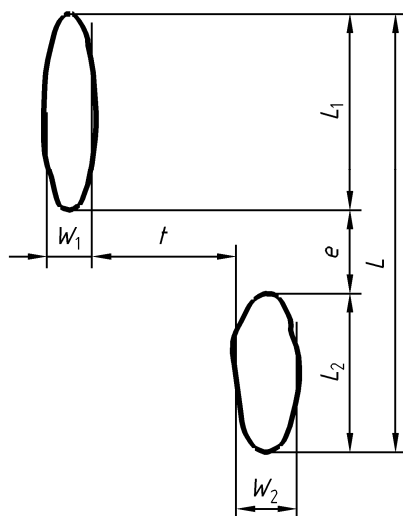
Figure 1a — Definition of ellipse and circle as standard shapes



Key

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

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



Key

If $e \leq 40 \mu\text{m}$ and $t \leq 10 \mu\text{m}$

$$L = L_1 + e + L_2$$

$$w_2 > w_1$$

$$w = w_2$$

(1 inclusion)

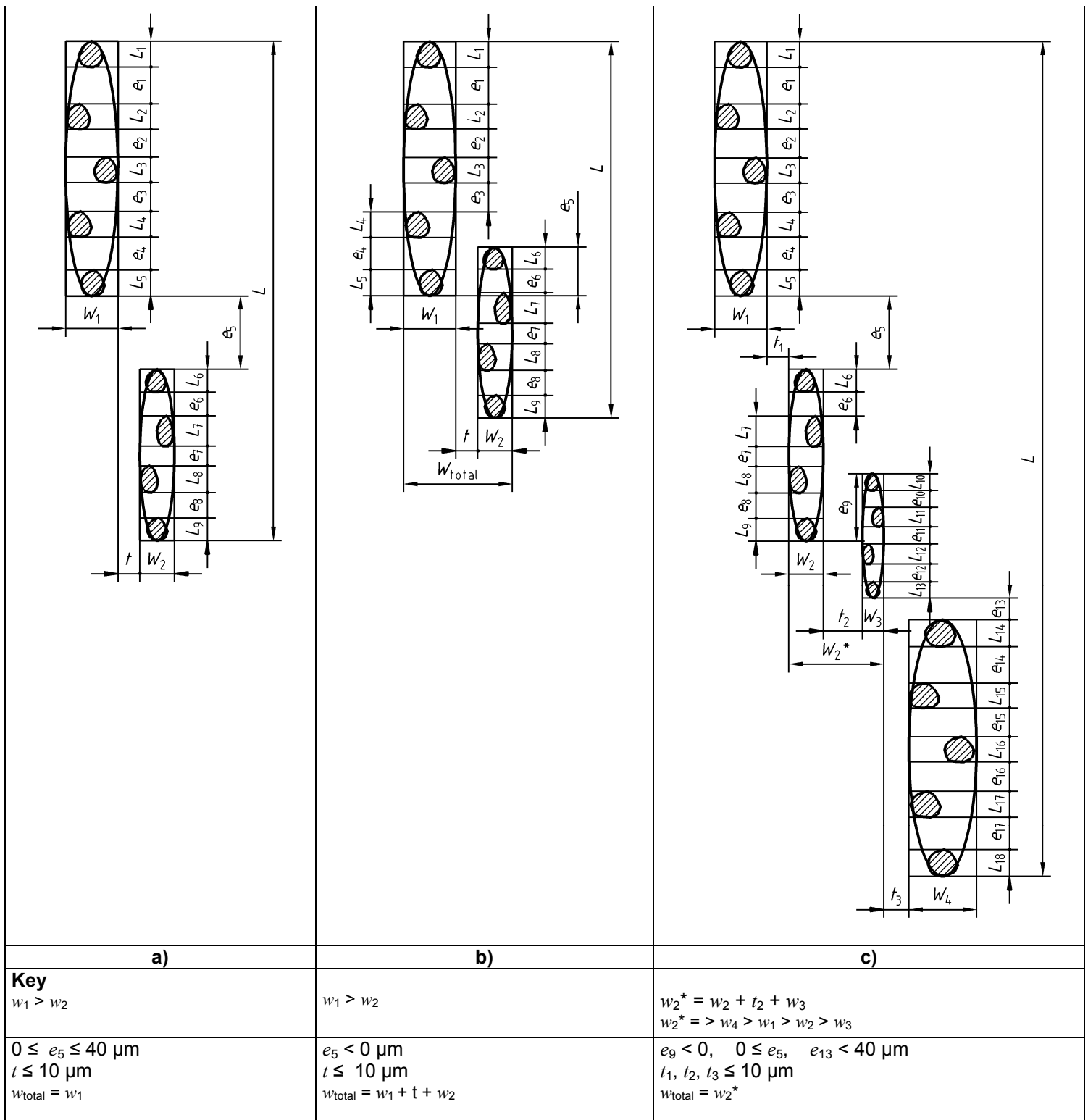
if $e > 40 \mu\text{m}$ or $t > 10 \mu\text{m}$,

$$L_1 = L_1 \quad w_1 = w_1$$

$$L_2 = L_2 \quad w_2 = w_2$$

(2 inclusions)

Figure 2a — Definition of inclusions composed by single particles



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

n = number of particles

if all $t \leq 10 \mu\text{m}$ and if e_1 to e_{17} all $\leq 40 \mu\text{m}$

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

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

Figure 2b — Definition of stringers