



International  
Standard

**ISO 4967**

**Steel — Determination of the  
non-metallic inclusion content —  
Micrographic method**

*Acier — Détermination de la teneur en inclusions non métalliques  
— Méthode micrographique*

**Fourth edition  
2026-05**



**COPYRIGHT PROTECTED DOCUMENT**

© ISO 2026

All rights reserved. Unless otherwise specified, or required in the context of its implementation, no part of this publication may be reproduced or utilized otherwise in any form or by any means, electronic or mechanical, including photocopying, or posting on the internet or an intranet, without prior written permission. Permission can be requested from either ISO at the address below or ISO's member body in the country of the requester.

ISO copyright office  
CP 401 • Ch. de Blandonnet 8  
CH-1214 Vernier, Geneva  
Phone: +41 22 749 01 11  
Email: [copyright@iso.org](mailto:copyright@iso.org)  
Website: [www.iso.org](http://www.iso.org)

Published in Switzerland

# Contents

Page

|                                                                                              |           |
|----------------------------------------------------------------------------------------------|-----------|
| <b>Foreword</b>                                                                              | <b>iv</b> |
| <b>Introduction</b>                                                                          | <b>vi</b> |
| <b>1 Scope</b>                                                                               | <b>1</b>  |
| <b>2 Normative references</b>                                                                | <b>1</b>  |
| <b>3 Terms and definitions</b>                                                               | <b>1</b>  |
| <b>4 Symbols</b>                                                                             | <b>3</b>  |
| <b>5 Principle</b>                                                                           | <b>4</b>  |
| <b>6 Sampling</b>                                                                            | <b>6</b>  |
| <b>7 Preparation of specimens</b>                                                            | <b>11</b> |
| <b>8 Determination of the content of inclusions</b>                                          | <b>11</b> |
| 8.1 Method of observation                                                                    | 11        |
| 8.2 Actual examination                                                                       | 12        |
| 8.2.1 General                                                                                | 12        |
| 8.2.2 Method A                                                                               | 12        |
| 8.2.3 Method B                                                                               | 12        |
| 8.2.4 General rules for methods A and B                                                      | 13        |
| <b>9 Expression of results</b>                                                               | <b>15</b> |
| 9.1 General                                                                                  | 15        |
| 9.2 Case of method A                                                                         | 15        |
| 9.3 Case of method B                                                                         | 15        |
| <b>10 Test report</b>                                                                        | <b>15</b> |
| <b>Annex A (normative) ISO chart images for inclusion types A, B, C, D and subgroup DS</b>   | <b>17</b> |
| <b>Annex B (normative) Examples of assessment of inclusions</b>                              | <b>31</b> |
| <b>Annex C (informative) Examples of assessment of complex inclusions</b>                    | <b>35</b> |
| <b>Annex D (informative) Illustration of the width definitions</b>                           | <b>37</b> |
| <b>Annex E (informative) Assessment result examples and global inclusion content metrics</b> | <b>39</b> |
| <b>Annex F (informative) Relationship between indices and inclusion measurements</b>         | <b>52</b> |
| <b>Bibliography</b>                                                                          | <b>56</b> |

## Foreword

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

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see [www.iso.org/directives](http://www.iso.org/directives)).

ISO draws attention to the possibility that the implementation of this document may involve the use of (a) patent(s). ISO takes no position concerning the evidence, validity or applicability of any claimed patent rights in respect thereof. As of the date of publication of this document, ISO had not received notice of (a) patent(s) which may be required to implement this document. However, implementers are cautioned that this may not represent the latest information, which may be obtained from the patent database available at [www.iso.org/patents](http://www.iso.org/patents). ISO shall not be held responsible for identifying any or all such patent rights.

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT), see [www.iso.org/iso/foreword.html](http://www.iso.org/iso/foreword.html).

This document was prepared by Technical Committee ISO/TC 17, *Steel*, Subcommittee SC 7, *Methods of testing (other than mechanical tests and chemical analysis)*.

This fourth edition cancels and replaces the third edition (ISO 4967:2013), which has been technically revised.

The main changes are as follows:

- added the mandatory clauses normative references (see [Clause 2](#)) and terms and definitions (see [Clause 3](#)), and renumbered the subsequent clauses;
- modified the proximity conditions for stringers (allowing for legacy conditions): the new transverse conditions mirror the conditions used longitudinally and remove ambiguity;
- changed the width definition (allowing for legacy/alternative definitions): the new definition avoids the sensitivity to misalignment of the bounding box and the underestimation of the “largest particle” approach;
- added further illustrations of width definitions, including the largest particle approach to inclusions with overlapping particles;
- clarified the treatment of inclusions intersecting the field of view, particularly for long inclusions (allowing for legacy treatment);
- clarified the treatment of B/C hybrid stringers;
- modified [Tables 2](#) and [3](#);
- added sampling specifications and the possibility to use stacking and/or rectangular fields for cross-section thicknesses under 0,71 mm;
- included the DS subgroup into D thick rating;
- clarified the treatment of DS inclusions in Method B;

## ISO 4967:2026(en)

- clarified the averaging of cross sections in Method A;
- modified most of the chart diagrams;
- replaced the global metrics for Method B (allowing for legacy metrics);
- added more analysis examples.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at [www.iso.org/members.html](http://www.iso.org/members.html).

## Introduction

Every routine inclusion rating by necessity applies the analysis of an incomplete sample to an entire heat. On the one hand, only a very small fraction of the total material volume is analysed, and on the other hand the analysis is performed on a two-dimensional section of three-dimensional inclusions. Standards like this document cannot eliminate the associated statistical uncertainties but can strive to add as little uncertainty as possible by defining the process as clearly as possible.

Despite the statistical shortcomings, methods like those described in this document are widely used to assess the suitability of a steel product for a given use. However, since it is difficult to achieve reproducible results owing to the distributional randomness of non-metallic inclusions, even with a large number of specimens, precautions should be taken when using the method.

One way to reduce the scatter inherent to the method is to avoid relying on subjective human judgment. Image analysis has shown itself to be a useful tool to improve reproducibility — if the hardware is appropriately configured and if the rules in the standard are indisputably clear for the software developer. This document addresses the minimal system requirements for resolution and reduces ambiguity in its rules compared to the previous revision.

However, it is acknowledged that neither steel producers and customers can instantly change specifications, nor can software developers immediately change the rules for evaluation. To allow for an adaptation period, where methods and definitions have changed, it is permitted to continue to use the methods and definitions that have been established in the past. This document refers to such methods and definitions as well as derived interpretations as “legacy.” Because of the ambiguities of previous editions, there is no one legacy approach, but instead a variety of legacy approaches.

Another clarification relative to the 2013 revision concerns the DS inclusions. There was much ambiguity surrounding them because they were presented as another type of inclusions. This made it unclear whether large globular particles were part of the D rating as well, since one important rule of inclusion rating is to rate every inclusion once and only once. With the redefinition of DS as a subgroup of type D designed for easy rating and reporting of oversized type D inclusions it is clear that every DS particle is rated in the  $D_{\text{thick}}$  rating, just as every oversized sulfide is rated in the  $A_{\text{thick}}$  rating.

Historically, ISO 4967 has always shown a significant similarity to the ASTM E 45 standard. With the revised definitions, particularly those defining proximity limits, there is a greater separation between the standards, though due to the inherent statistical uncertainties the ratings will correlate in most instances. However, these increased differences convinced the ISO/TC 17/SC 7 to continue using the terms “fine” and “thick” in order to more clearly distinguish ISO 4967 results from ASTM E 45 results.

Revisions always take place on a strict timeline and often the deadline forces the publication of a standard that is good enough, but not yet perfect. Topics that further revisions can address include the treatment of particle clusters, easier oversized reporting for Types A to C, and more guidelines on computer-assisted rating.

It is worth remembering that the changes in this inclusion rating method do not change a good steel into a bad steel, but serve the goal of a clearer, more differentiated description of the steel.

# Steel — Determination of the non-metallic inclusion content — Micrographic method

## 1 Scope

This document specifies a micrographic method of determining the non-metallic inclusions in rolled or forged steel products having a reduction ratio of at least 3 using the images of a standard reference chart or direct measurement by image analysis technologies.

The standard reference chart described in this document is not entirely applicable for certain types of steel (e.g. free cutting steels).

## 2 Normative references

There are no normative references in this document.

## 3 Terms and definitions

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

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

- ISO Online browsing platform: available at [www.iso.org/obp](http://www.iso.org/obp)
- IEC Electropedia: available at [www.electropedia.org](http://www.electropedia.org)

### 3.1 particle

single precipitate, in general non-metallic

### 3.2 stringer

arrangement of at least 2 particles for type A and C inclusions and 3 particles for type B, aligned in a plane parallel to the hot working axis and offset by no more than 10 µm, with a separation of no more than 40 µm between any two nearest neighbour particles

### 3.3 inclusion

general designation of a rateable feature composed of at least one particle, defined by the size and proximity of its constituents

Note 1 to entry: The inclusion can describe a single particle or a single stringer.

### 3.4 length

*l*

dimension of a particle or an inclusion in the main deformation direction, usually larger than the width

### 3.5 width

*w*

largest local dimension of a particle or an inclusion measured perpendicular to the main deformation direction (calliper width), as shown in [Figure 1](#)

Note 1 to entry: The calliper width clarifies an ambiguity in previous editions. A “largest particle” and a “bounding box” approach were among the most frequent alternatives. Further illustrations are shown in [Annex D](#).



**Figure 1 — Schematic of particle and inclusion width**

### 3.6 aspect ratio ratio of length to width

### 3.7 diameter *d* dimension of a globular particle or inclusion in the main deformation direction

### 3.8 worst-field rating rating in which the specimen is rated for each group and subgroup of inclusion by assigning the value for the highest severity rating observed of that inclusion group and subgroup anywhere on the evaluated area of the specimen

### 3.9 type categorization of inclusions according to morphology, colour and proximity

### 3.10 class categorization by width or diameter within types (fine and thick)

### 3.11 group categorization by type and class

### 3.12 globular particle particle with an aspect ratio less than 3

### 3.13 elongated particle particle with an aspect ratio more than or equal to 3

### 3.14 hybrid stringer stringer consisting of both globular and elongated particles

### 3.15

#### reduction ratio

ratio between original and final cross-sectional area after rolling or forging

### 3.16

#### calibration factor

parameter indicating the actual size on the specimen surface corresponding to the pixel length

## 4 Symbols

The symbols used are given in [Table 1](#).

**Table 1 — Symbols**

| Symbols             | Definitions                                                                                                                                                                                                                                                                                            | Values                           |
|---------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------|
| $A$                 | Area of an individual inclusion<br>A bar above the symbol indicates an average.<br>Superscripts used: variable index $i$ , “excess”, variable class<br>Subscripts used: selected type/class/group, “tot” (total), $S$ (specimen), “ox” (“oxidic”), “glob” (globular), fixed index (e.g. “ $i = 0,5$ ”) | $A = \frac{\pi}{4} (l \times w)$ |
| $t$                 | Wall thickness, as shown in <a href="#">Figure 9</a>                                                                                                                                                                                                                                                   |                                  |
| $C_i$               | Weighted global severity indices<br>Superscripts used: selected type/class/group, “tot” (total)<br>The subscript “ $i$ ” stands for “inclusion” and is not the index number.                                                                                                                           |                                  |
| $d$                 | Dimension of a globular particle or inclusion in the main deformation direction<br>A bar above the symbol indicates an average.<br>Superscripts used: variable class $c$ , variable index $i$<br>Subscripts used: “min”, “max”, and selected type/class/group                                          |                                  |
| $e$                 | Longitudinal distance between particles as shown in <a href="#">Figures 11</a> to <a href="#">12</a>                                                                                                                                                                                                   |                                  |
| $f$                 | Inclusion area fractions<br>Subscripts used: “tot” (total), “ox” (“oxidic”), “glob” (globular)                                                                                                                                                                                                         |                                  |
| $f_{\text{number}}$ | Inclusion number frequency<br>Superscripts used: selected type/class/group                                                                                                                                                                                                                             |                                  |
| $i$                 | Index                                                                                                                                                                                                                                                                                                  |                                  |
| $l$                 | Dimension of a particle or an inclusion in the main deformation direction, usually larger than the width<br>A bar above the symbol indicates an average.<br>Superscripts used: index $i$<br>Subscripts used: “min”, “max”                                                                              |                                  |
| $n$                 | Number of type D globular oxides per field<br>A bar above the symbol indicates an average.<br>Superscripts used: index $i$<br>Subscripts used: “min”                                                                                                                                                   |                                  |
| $N$                 | Number of rated fields                                                                                                                                                                                                                                                                                 |                                  |
| $r$                 | Width of plate as shown in <a href="#">Figures 4</a> to <a href="#">6</a>                                                                                                                                                                                                                              |                                  |

Table 1 (continued)

| Symbols               | Definitions                                                                                                                                                                                                                                | Values                                                                   |
|-----------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------|
| $R$                   | Relative area fractions<br>Superscripts used: selected type/class/group or combination thereof such as “ox” (“oxidic”)<br>Subscripts used: Ratio expressed, e. g. “B:C”, “f:t” (fine to thick), “G:nG” (globular to elongated)             |                                                                          |
| $s$                   | Transverse distance between particles as shown in <a href="#">Figures 11 to 12</a>                                                                                                                                                         |                                                                          |
| $S$                   | Specimen area                                                                                                                                                                                                                              |                                                                          |
| $w$                   | Dimension of a particle or an inclusion perpendicular to the main deformation direction<br>A bar above the symbol indicates an average.<br>Superscripts used: class c, index i<br>Subscripts used: “min”, “max”, selected type/class/group |                                                                          |
| $x$                   | Inclusion interdistance<br>Subscripts used: selected type/class/group                                                                                                                                                                      |                                                                          |
| Legacy global metrics |                                                                                                                                                                                                                                            |                                                                          |
| $C_t$                 | Cleanness index (“t” stands for “total”)                                                                                                                                                                                                   | $C_t = \left( \sum_{i=0} n_i \times F_i \right) \times \frac{1\,000}{S}$ |
| $F_i$                 | Weighting factor of index $i$ , always rounded to one significant digit                                                                                                                                                                    | $F_i = 10^{\frac{i-2,5}{1,5}}$                                           |
| $i_{\text{moy}}$      | Mean index for the entire assessed surface                                                                                                                                                                                                 | $i_{\text{moy}} = \frac{i_{\text{tot}}}{N}$                              |
| $i_{\text{tot}}$      | Total index for the entire assessed surface                                                                                                                                                                                                | $i_{\text{tot}} = \sum_{i=0} i \times n_i$                               |
| $n_i$                 | Total number of fields (A, B, C, and D) and inclusions (DS) rated as index $i$                                                                                                                                                             |                                                                          |

## 5 Principle

**5.1** The method consists of comparing the observed field to the chart images defined in this document and taking in consideration separately each group and subgroup of inclusions. In the case of image analysis, fields are rated according to [Table 2](#), [Table 3](#), and the relationships given in [Annex F](#). Automatic image analysis can be used provided that the accuracy of the method has previously been validated. Digitized images should have a calibration factor of 1 µm/pixel or preferably finer.

**5.2** The chart images correspond to square fields of view, each with an area of 0,50 mm<sup>2</sup>, as obtained with a longitudinal plane-of-polish and as observed with bright field illumination at 100×

**5.3** According to the grey level, shape, and distribution of the inclusions, the chart images are divided into four main types, bearing the reference A, B, C, and D. These four types represent the most commonly observed inclusion types and morphologies:

- **Type A (“sulfide” type):** highly malleable, individual light grey elongated particles with a wide range of aspect ratios and generally rounded ends;

- **Type B (“aluminate” type):** numerous non deformable, angular, low aspect ratio ( $< 3$ ), black or bluish particles (at least three) aligned in the deformation direction;
- **Type C (“silicate” type):** highly malleable, individual black or dark grey elongated particles with a wide range of aspect ratios ( $\geq 3$ ) and generally smooth outlines, often with sharp ends;
- **Type D (globular “oxide” type):** non deformable, angular or circular, low aspect ratio ( $< 3$ ), black or bluish, randomly distributed particles.

NOTE The chemical composition of the inclusions present in a steel sample cannot be determined with the methods described in this document. The apparent chemical names attributed to the types A, B, C, and D derive from the typical composition historically found when analysing inclusions of such morphology and colour. The same is true for the non-traditional inclusion types in the paragraphs that follow.

**5.4** Non-traditional inclusion types may also be rated based on their morphology compared to the above four types and a statement about their apparent chemical nature. As an example, globular sulfides would be rated as a D type and denoted with a descriptive subscript (e.g.  $D_{\text{sulf}}$ ) defined in the test report. Examples of subscripts include  $D_{\text{cas}}$  (globular calcium sulfides);  $D_{\text{RES}}$  (globular rare earth sulfides); and  $D_{\text{Dup}}$  (globular duplex inclusions, such as calcium sulfide surrounding an aluminate). The treatment of complex inclusions should be separately agreed between the parties. Examples are given in [Annex C](#).

**5.5** Types of precipitate, such as borides, carbides, carbonitrides or nitrides may also be rated based on their morphology compared to the above four types and a statement about their apparent chemical nature as described in [5.4](#). Examination at a magnification greater than  $100\times$  may be used to identify the nature of the non-traditional inclusions before performing the test.

**5.6** The categorization of inclusions into types A, B, C and D is based on their grey level and then, after forming stringers, on their morphologies. Each of the four types shall be further categorized into two classes based on their width or diameter, as specified in [Annex A](#), with six images representing increasing inclusion content. The images for indices 3,5 and higher and the limit values for indices 5,5 and higher are not given in this document. For simplifying the frequent oversized reporting for Type D inclusions with a diameter  $> 13\text{ }\mu\text{m}$  an additional subgroup DS is defined. Oversized Type D inclusions are rated as  $D_{\text{thick}}$  and also as DS.

**5.7** The chart images in [Annex A](#) carry an index number,  $i$ , from 0,5 to 3, the numbers increasing with the inclusion lengths (Types A, B, C) or by the number (Type D) or by the diameter (Subgroup DS), as defined in [Table 2](#), and categorized by thickness, as defined in [Table 3](#). The total length of inclusions, or number of inclusions, or diameter of the inclusion in each chart image is the lower boundary value of [Table 2](#). For example, the images for A 2 depict inclusions with a morphology in accordance with type A and with the total length corresponding to the lower boundary value of  $i = 2$ . For indices larger than 3,0, the rating is performed by comparing measured values with [Table 2](#).

**Table 2 — Inclusion rating limits**

| Index<br>$i$ | Type                               |                                    |                                    |                   | Subgroup                        |
|--------------|------------------------------------|------------------------------------|------------------------------------|-------------------|---------------------------------|
|              | A<br>total length<br>$\mu\text{m}$ | B<br>total length<br>$\mu\text{m}$ | C<br>total length<br>$\mu\text{m}$ | D<br>count number | DS<br>diameter<br>$\mu\text{m}$ |
| 0,5          | $\geq 37$                          | $\geq 17$                          | $\geq 18$                          | $\geq 1$          | $> 13$                          |
| 1,0          | $\geq 127$                         | $\geq 77$                          | $\geq 76$                          | $\geq 4$          | $\geq 19$                       |
| 1,5          | $\geq 261$                         | $\geq 184$                         | $\geq 176$                         | $\geq 9$          | $\geq 27$                       |
| 2,0          | $\geq 436$                         | $\geq 343$                         | $\geq 320$                         | $\geq 16$         | $\geq 38$                       |
| 2,5          | $\geq 649$                         | $\geq 555$                         | $\geq 510$                         | $\geq 25$         | $\geq 53$                       |
| 3,0          | $\geq 898$                         | $\geq 822$                         | $\geq 746$                         | $\geq 36$         | $\geq 76$                       |
| 3,5          | $\geq 1\,181$                      | $\geq 1\,147$                      | $\geq 1\,029$                      | $\geq 49$         | $\geq 107$                      |

Table 2 (continued)

| Index<br><i>i</i> | Type                    |                         |                         |                   | Subgroup             |
|-------------------|-------------------------|-------------------------|-------------------------|-------------------|----------------------|
|                   | A<br>total length<br>μm | B<br>total length<br>μm | C<br>total length<br>μm | D<br>count number | DS<br>diameter<br>μm |
| 4,0               | ≥ 1 498                 | ≥ 1 530                 | ≥ 1 359                 | ≥ 64              | ≥ 151                |
| 4,5               | ≥ 1 848                 | ≥ 1 973                 | ≥ 1 737                 | ≥ 81              | ≥ 214                |
| 5,0               | ≥ 2 230<br>(< 2 641)    | ≥ 2 476<br>(< 3 042)    | ≥ 2 163<br>(< 2 639)    | ≥ 100<br>(< 121)  | ≥ 303<br>(< 429)     |
| ⋮                 | ⋮                       | ⋮                       | ⋮                       | ⋮                 | ⋮                    |

Table 3 — Inclusion width and diameter parameters

| Type                                                                                              | Fine class |     | Thick class |      |
|---------------------------------------------------------------------------------------------------|------------|-----|-------------|------|
|                                                                                                   | μm         | μm  | μm          | μm   |
| A (width)                                                                                         | ≥ 2        | ≤ 4 | > 4         | ≤ 12 |
| B (width)                                                                                         | ≥ 2        | ≤ 9 | > 9         | ≤ 15 |
| C (width)                                                                                         | ≥ 2        | ≤ 5 | > 5         | ≤ 12 |
| D (diameter)                                                                                      | ≥ 2        | ≤ 8 | > 8         | ≤ 13 |
| NOTE Type D inclusions with a width less than 2 μm are also not included in the inclusion rating. |            |     |             |      |

## 6 Sampling

**6.1** The shape of the inclusion depends to a large extent on the reduction ratio of the steel; therefore, comparative measurements should only be carried out on prepared specimens taken from samples with a similar reduction ratio.

**6.2** Unless something else is defined in the product standard or agreed by the parties involved, the polished surface of the specimen used to determine the content of inclusions should be about 200 mm<sup>2</sup>.

**6.3** When the cross-section thickness is insufficient to prepare a single specimen of 200 mm<sup>2</sup>, more than one specimen shall be taken from the same sampling location to conform to 6.2. Where reaching 200 mm<sup>2</sup> or more is onerous, the total length of the longitudinal pieces taken from each sampling location shall not be less than 100 mm. These specimens shall be analysed as one whole specimen.

**6.4** In general, single sections less than 0,71 mm in thickness are not analysed using this document, since this is restricted by the field side length. However, as part of a mutual agreement, narrower sections may be assessed by

- stacking two or more sections together and thereby creating a thicker aggregate section, making sure that no small gaps or edge artefacts between the stacked sections are categorised as inclusions
- using a rectangular field as long as the field area is 0,5 mm<sup>2</sup>, e.g. 1,0 mm×0,5 mm, provided that the rectangular field fits within the visual field of the microscope at the applied magnification.

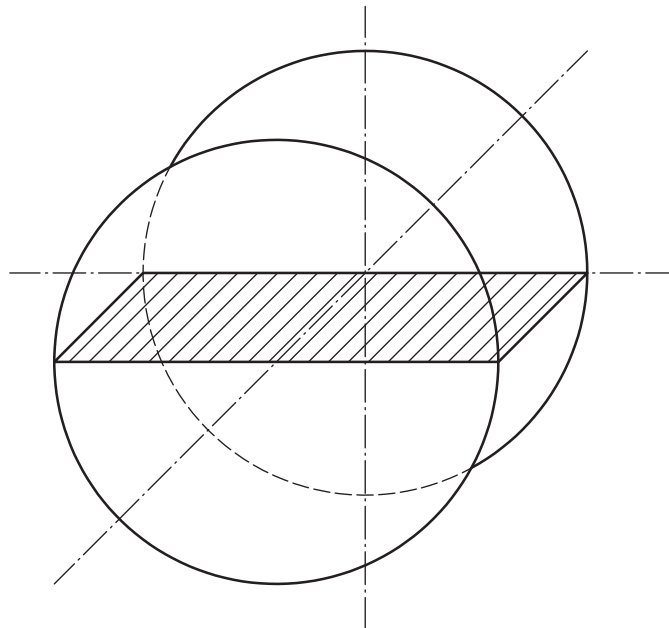
**6.5** The method of sampling, including the sampling location and the number of sampling locations, shall be defined in the product standard or subject to agreement between the parties.

**6.6** In the absence of such specifications, the sampling procedure should be as follows:

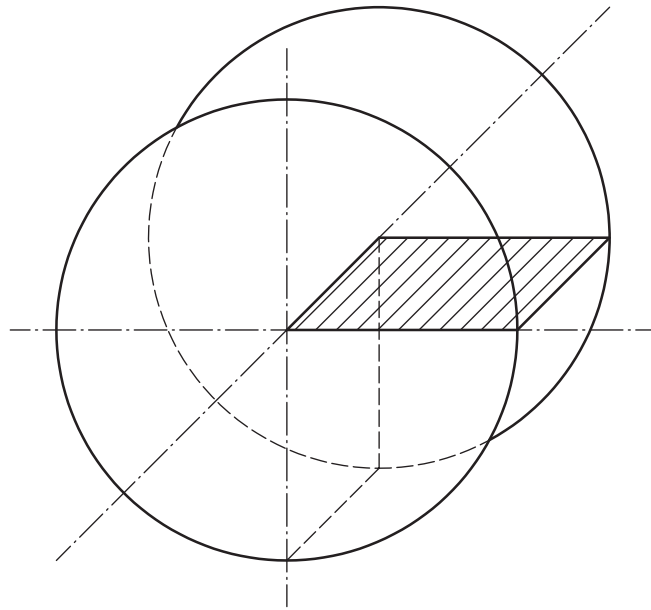
- bar, wire rod, or wire with a diameter less than or equal to 25 mm: the surface to be examined consists of the full diametral section of length sufficient to obtain a surface conform to 6.2 (see Figure 2);

- bar, wire rod, wire, or billet with a diameter greater than 25 mm and less than or equal to 40 mm: the surface to be examined consists of at least half the diametral section (from the centre to the edge of the sample) (see [Figure 3](#));
- bar, wire rod, wire, or billet with diameters greater than 40 mm: the surface to be examined consists of a part of diametral section located halfway between the outer surface and the centre (see [Figure 4](#));
- plate with a thickness less than or equal to 25 mm: the surface to be examined consists of the whole thickness, and located at the quarter of the width (see [Figure 5](#));
- plate with a thickness greater than 25 mm and less than or equal to 40 mm: the surface to be examined consists of at least half the thickness from the surface to the centre and is located at the quarter of the width (see [Figure 6](#));
- plate with a thickness greater than 40 mm: the surface to be examined consists of quarter the thickness and is located halfway between the outer surface and the middle of the thickness and at the quarter of the width (see [Figure 7](#));
- tube or pipe with a wall thickness less than or equal to 25 mm: the surface to be examined consists of the full diametral section of a length sufficient to obtain a sufficient surface, and, for welded products, located far away from the welding bead (see [Figure 8](#));
- tube or pipe with a wall thickness greater than 25 mm: the surface to be examined consists of a part of the diametral section located halfway between the outer diameter and the inner diameter, and, for welded products, far away from the welding bead (see [Figure 9](#)).

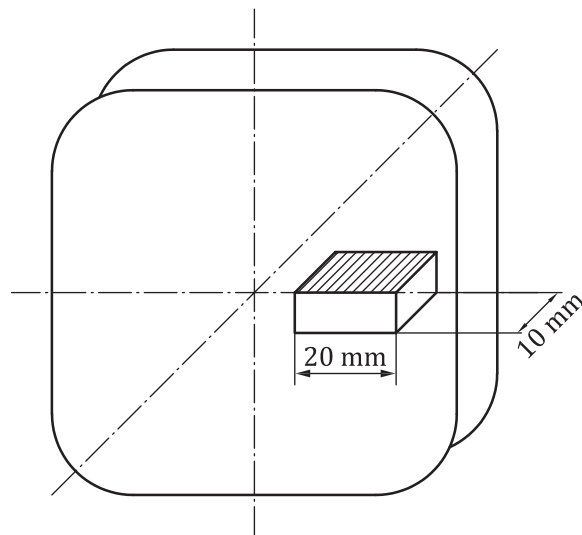
**6.7** The number of samples to be taken is defined in the product standard or by special agreement. For any other product, the sampling procedures shall be subject to agreement between the parties.



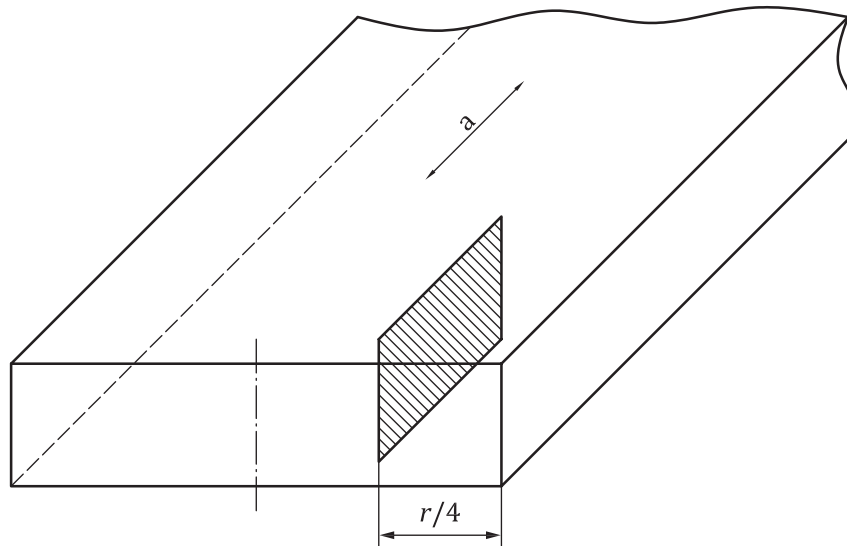
**Figure 2 — Sample from bar with a diameter  $\leq 25$  mm**



**Figure 3 — Sample from bar or billet with a diameter or length of side  $> 25$  mm and  $\leq 40$  mm**



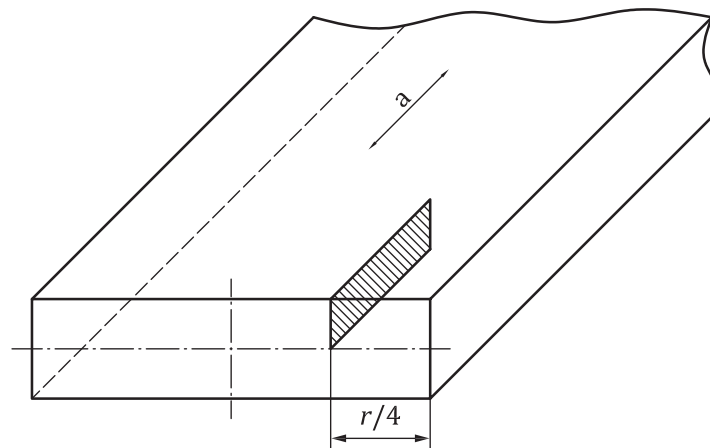
**Figure 4 — Sample from bar or billet with a diameter or length of side  $> 40$  mm**



**Key**

$r$  width  
 $a$  rolling direction

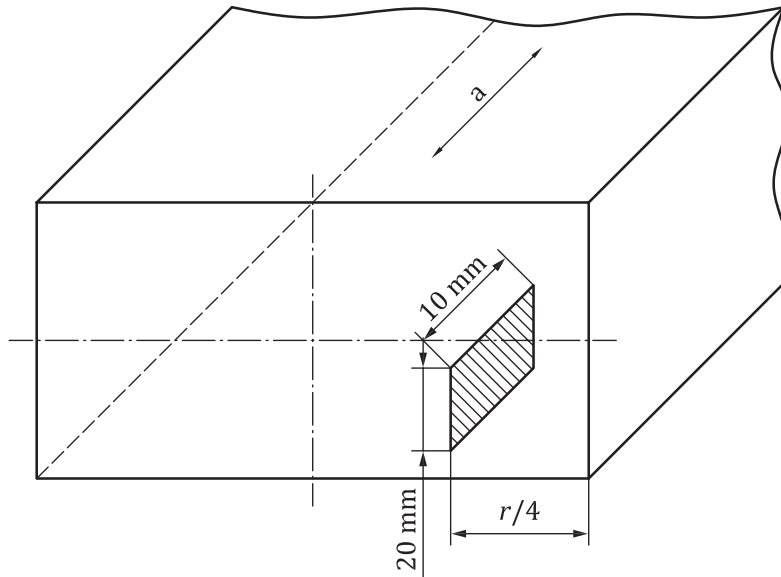
**Figure 5 — Sample from plate with thickness  $\leq 25$  mm**



**Key**

$r$  width  
 $a$  rolling direction

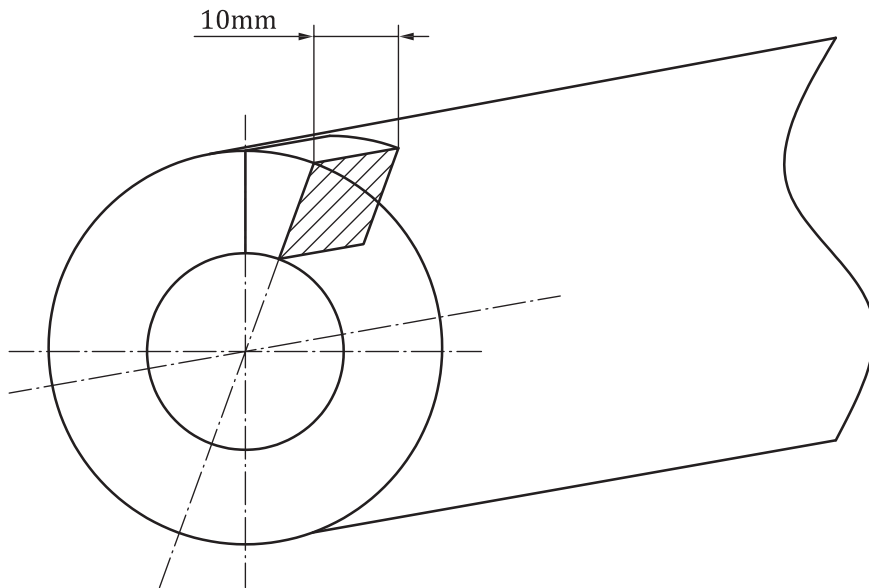
**Figure 6 — Sample from plate with thickness  $> 25$  mm and  $\leq 40$  mm**



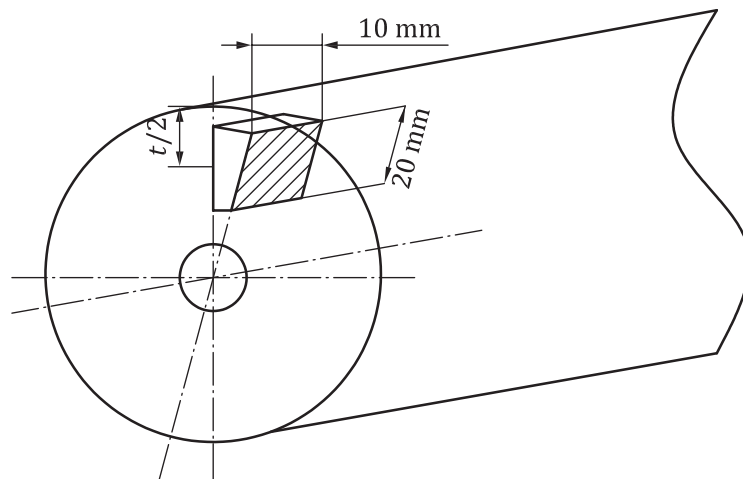
**Key**

$r$  width  
 $a$  rolling direction

**Figure 7 — Sample from plate with thickness > 40 mm**



**Figure 8 — Sample from tube or pipe with a wall thickness  $\leq 25$  mm**

**Key**

$t$  wall thickness

**Figure 9 — Sample from tube or pipe with a wall thickness > 25 mm**

## 7 Preparation of specimens

**7.1** 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.

**7.2** 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 shape 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. In certain cases, it can be necessary for the specimen to be heat treated before polishing in order to give it the maximum possible hardness.

## 8 Determination of the content of inclusions

### 8.1 Method of observation

**8.1.1** Examination with the microscope may be by one of two methods:

- by images on the computer screen, ground glass, or other similar device;
- by observation by means of an eyepiece.

**8.1.2** The method of observation chosen shall be maintained throughout the test.

**8.1.3** If the image is displayed on a computer screen, ground glass, or other similar device, the magnification shall be  $100 \times \pm 2 \times$  on the screen. It is recommended to place an overlay (see [Figure 10](#)) of a  $71 \text{ mm} \pm 1 \text{ mm}$  square ( $0,50 \text{ mm}^2$  true area) over or behind the computer screen, ground glass, or other projection screen. The image within the  $71 \text{ mm}$  square is compared to the chart images of the standard chart as specified in [Annex A](#).

**8.1.4** If the inclusions are examined through the microscope eyepieces, insert a reticle with the test pattern equivalent to the one shown in [Figure 10](#) in the microscope at the appropriate location so that the test grid area is  $0,50 \text{ mm}^2$  at the image plane. In some cases, a magnification greater than  $100 \times$  may be used,

provided that the same reference field size (0,5 mm<sup>2</sup>) is applied for the standard images. This approach shall be recorded in the test report.

NOTE Separating the scale (one eyepiece) from the square and the reference shapes (the other eyepiece) allows for measuring the length and width of an inclusion by rotating the scale independently and leaving the field reference fixed.

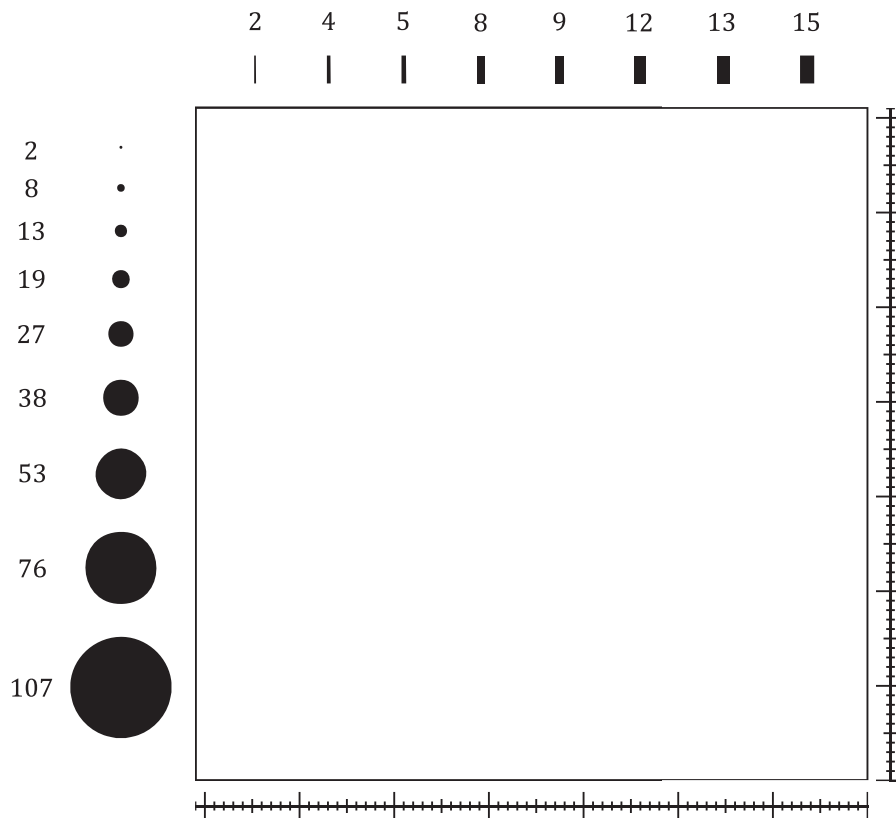


Figure 10 — Suggested test pattern for grid overlays or reticles

## 8.2 Actual examination

### 8.2.1 General

Two methods are defined as described in [8.2.2](#) and [8.2.3](#). For both methods, if different types of inclusions or inclusions of the same type but of a different class are observed in the same field, they shall be assessed separately.

### 8.2.2 Method A

Method A is a worst-field rating method. The entire polished surface is examined and, for each type and class of inclusions, a note is made of the index number *i* of the chart image which corresponds to the worst field examined.

### 8.2.3 Method B

**8.2.3.1** Method B is a field frequency method. The entire polished surface is examined, and each field of the specimen is compared with the chart images. The index number *i* of the field which best corresponds to the field examined for each type and class of inclusions is noted. Each inclusion group shall be assessed separately, as specified in the assessment example in [Annex B, B.1](#).

**8.2.3.2** In order to minimize the cost of examination, it may be agreed upon to make a partial examination of the specimen by studying a reduced number of fields, distributed in accordance with a fixed scheme. Both the number of fields examined, and their distribution shall be arranged by prior agreement. In general, at least 100 fields are examined.

#### **8.2.4 General rules for methods A and B**

**8.2.4.1** Each field observed is compared with the chart images. If a field of inclusions falls between two chart images, it is rated following the image with the lower index *i*.

NOTE The presence of numerous elongated inclusions oriented in a consistently different direction from the presumed main deformation direction indicates a need to rotate the sample. The presence of numerous elongated inclusions oriented in various different directions indicates that the sample is not suitable for the standard.

**8.2.4.2** Individual inclusions that have a length greater than the field side length (0,710 mm) or a width or diameter greater than the thick class maximum (see [Table 3](#)) will be rated as oversized by length, width, or diameter. The oversized dimensions of the inclusion shall be noted separately. However, the total length of these inclusions shall be included in the overall rating of that field as specified in the assessment example of oversized inclusions in [Annex B, B.2](#).

Legacy processes of dealing with inclusions longer than the field side length are permitted but shall be declared in the report.

NOTE Custom methods of rating the severity of the oversized inclusions A, B, and C are a matter of agreement between the parties.

**8.2.4.3** Any inclusion intersecting the edge of the field of view shall be assigned to a field of view if the centre of gravity of the inclusion lies within the field for Method A. For Method B, it shall be assigned to a single field using a process that assigns all inclusions to exactly one field (e.g. centre of gravity, first found).

Legacy processes of assigning inclusions to fields are permitted but shall be declared in the report.

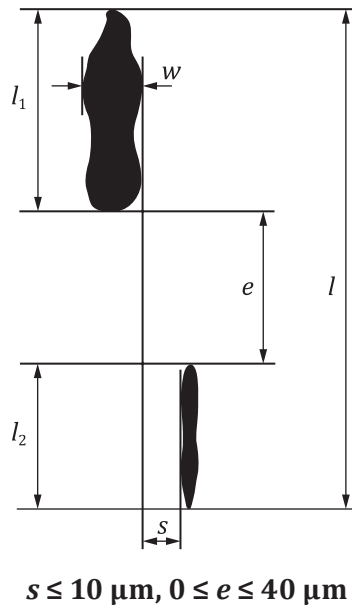
**8.2.4.4** All oversized type D inclusions shall be rated as D thick and shall also be rated as subgroup DS inclusions. For Method A, the DS rating of a specimen is the DS rating of the largest oversized type D inclusion. For Method B, all the oversized type D inclusions shall be individually tallied and rated, regardless of the proximity of other DS inclusions. An assessment example of oversized inclusions can be seen in [B.3](#) of [Annex B](#).

**8.2.4.5** The reproducibility of measurements is improved if actual measurements (inclusion lengths of A, B or C types, diameter of DS subgroup) and counts (D types) are made. Use a grid overlay or reticle, as shown in [Figure 10](#), the measurement limits in [Tables 2](#) and [3](#), and the morphological descriptions in [Clause 5](#), as illustrated in the chart.

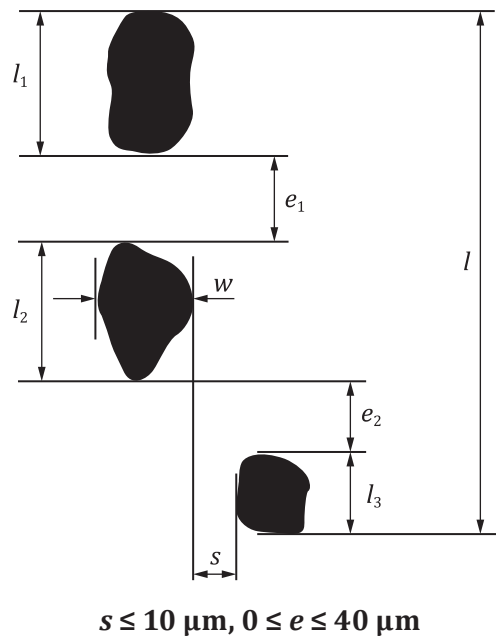
**8.2.4.6** Non-traditional inclusion types are rated according to the chart type and subgroup (A, B, C, D, DS) that best corresponds to their morphology. Compare the length, number, thickness, or diameter of the inclusions to each type shown in [Annex A](#) or determine their total length, number, thickness, or diameter, and use [Tables 2](#) and [3](#) to assign the appropriate index and class. Where necessary, a higher magnification is used to better discern the individual constituents of complex inclusions. An assessment example of complex inclusions can be seen in [Annex C](#).

**8.2.4.7** Stringers are formed from single particles of the same grey level category that meet the following conditions. For type A and C inclusions, two individual particles of lengths  $l_1$  and  $l_2$  are considered as one inclusion or stringer if the longitudinal distance  $e$  is lower than or equal to 40  $\mu\text{m}$  and if the distance  $s$  (the distance between facing tangent lines of particles) is lower than or equal to 10  $\mu\text{m}$  (see [Figure 11](#) and [D.3](#)). For type B inclusions, three individual particles of lengths  $l_1$ ,  $l_2$  and  $l_3$  are considered as one inclusion or stringer if the longitudinal distance  $e$  is lower than or equal to 40  $\mu\text{m}$  and if the distance  $s$ , (the distance between facing tangent lines of particles) is lower than or equal to 10  $\mu\text{m}$  (see [Figure 12](#) and [D.3](#)). The

distance between centreline and centreline of particles is allowed to be used as a legacy definition. It will gradually be phased out in future revisions. The use of legacy definitions shall be noted in the report.



**Figure 11 — Stringer for type A and C inclusions**



**Figure 12 — Stringer for type B inclusions**

**8.2.4.8** In the case of an inclusion with particles of different width, the width to be considered is the calliper width of the inclusion (see [Figures 11](#) and [12](#)) unless the largest particle width or another legacy definition is agreed on between the parties.

**8.2.4.9** Hybrid stringers composed of both globular and elongated black “oxide” particles are classified as type B or type C. If the number of particles with  $l/w < 3$  is less than 3, the inclusion is categorized as type C. If the number of particles with  $l/w < 3$  is three or larger, the inclusion is categorized as type B if the

total length of all individual particles with  $l/w \geq 3$  constitutes less than 50% of the total inclusion length; otherwise, the inclusion is categorized as type C.

NOTE [Figure C.2](#) of [Annex C](#) shows examples of how to categorize hybrid stringers when specific information on the chemistry is available.

## 9 Expression of results

### 9.1 General

Unless otherwise stated in the product standard or agreement in parties, the results may be expressed as described in [9.2](#) and [9.3](#) depending on the method used (method A or method B). Any subscripts used to identify non-traditional inclusion types shall be defined.

### 9.2 Case of method A

**9.2.1** For each specimen and each type and class of inclusions (see [Annex B](#)), the index  $i$  of the worst field shall be reported, with the presence of an oversized inclusion being indicated by the letter s. The dimension of the largest oversized inclusion shall be noted as well. For a single specimen, the notation may be made using an “e” to indicate the rating for the “thick” class. The specimen 1 in [Table E.1](#) would be noted A 2,0 / Ae 1,0 / B 2,0 / D 1,5 / Des 0,5 / DS 1,0.

**9.2.2** On the basis of the index numbers relating to each specimen, an arithmetic mean may be assessed per cast for each type and class. A typical result is given in [E.1](#) of [Annex E](#).

**9.2.3** If fewer than three specimens per cast are rated, or if the surveyed area differs significantly between specimens, the individual specimen ratings should be reported.

### 9.3 Case of method B

**9.3.1** The number of fields corresponding to each index  $i$ , per specimen and per group and subgroup, shall be reported along with the total number of fields observed ( $N$ ). It is recommended to formulate acceptance criteria for Method B as the maximum number of fields of a certain group per inspected area.

**9.3.2** The set of results from [9.3.1](#) may be used in special treatments for expressing results as global metrics, subject to agreement between the parties. Calculations and typical results are given in [Annex E](#).

## 10 Test report

The test report shall contain the following information, if available and applicable:

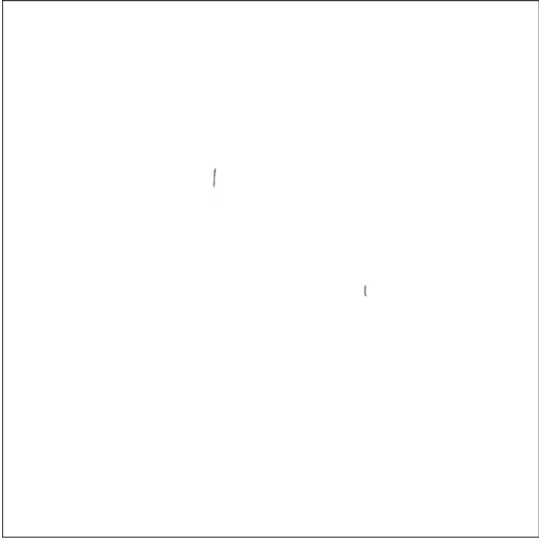
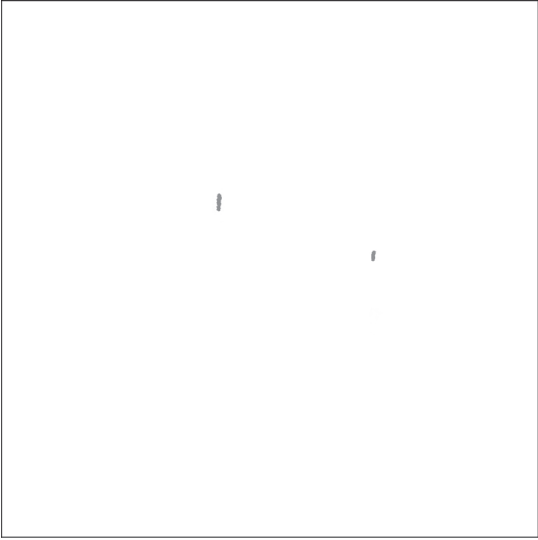
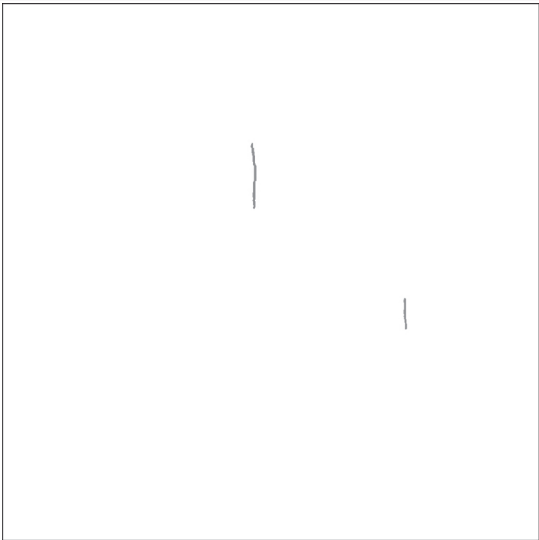
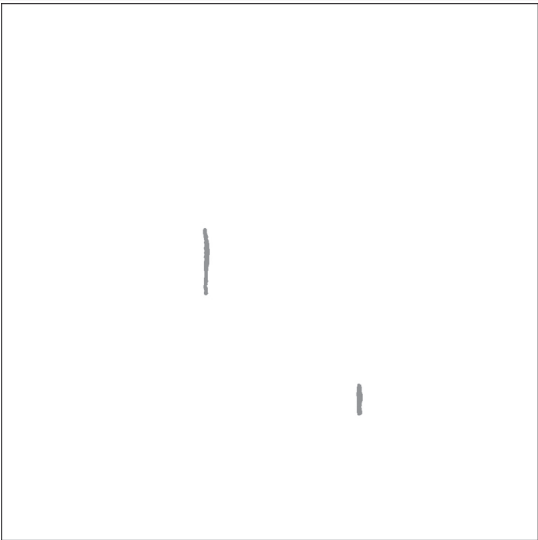
- a) a dated reference to this document and the method used, e.g. ISO 4967:2026 Method A;
- b) the use of legacy approaches or alternative definitions for
  - 1) width,
  - 2) proximity conditions,
  - 3) oversized inclusion length,
  - 4) assignation to field of view, and
  - 5) global metrics;
- c) the steel grade and the cast number;

- d) the nature (sheet, wire, rod, etc.) and dimensions of the product;
- e) the relevant sampling information;
- f) the magnification if greater than 100 ×, or the calibration factor for digital assessments;
- g) the number of observed fields or the total area examined;
- h) the results of the examination (including the number, size and type of oversized inclusions or stringers);
- i) statement of subscripts used to define any non-traditional inclusion type;
- j) unique report identification;
- k) name of operator or unique operator identification.

**Annex A**  
(normative)

**ISO chart images for inclusion types A, B, C, D and subgroup DS**

The standard reference chart images from index 0,5 to index 3,0 are given in [Figures A.1, A.2, A.3, A.4](#) and [A.5](#), for types A, B, C, D and subgroup DS, respectively. All images represent a 710 µm × 710 µm square field of view. The minimum total length of each index is given in [Table 2](#).

|                                                                                                                                                    |                                                                                                                                                                 |
|----------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                                                                  |                                                                              |
| <b>a) A 0,5 (<math>2\text{ }\mu\text{m} \leq w \leq 4\text{ }\mu\text{m}</math>, minimum total length <math>\geq 37\text{ }\mu\text{m}</math>)</b> | <b>b) Ae 0,5 (<math>4\text{ }\mu\text{m} &lt; \text{width} \leq 12\text{ }\mu\text{m}</math>, minimum total length <math>\geq 37\text{ }\mu\text{m}</math>)</b> |
|                                                                 |                                                                             |
| <b>c) A 1,0 (<math>2\text{ }\mu\text{m} \leq \text{width} \leq 4\text{ }\mu\text{m}</math>, minimum total length 127 µm)</b>                       | <b>d) Ae 1,0 (<math>4\text{ }\mu\text{m} &lt; \text{width} \leq 12\text{ }\mu\text{m}</math>, minimum total length 127 µm)</b>                                  |

**Figure A.1 — Standard reference chart images of A type (1 of 3)**

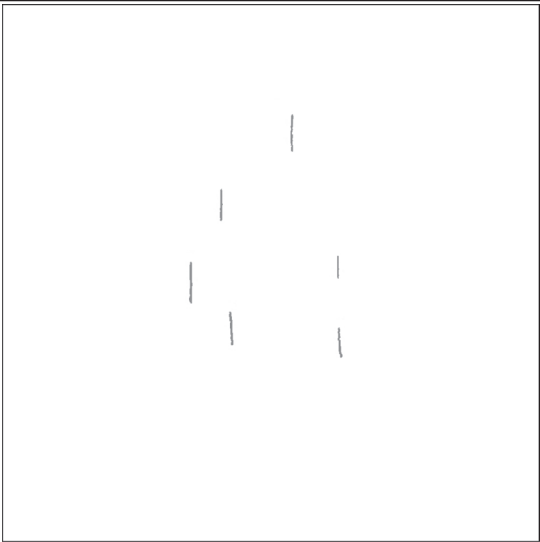
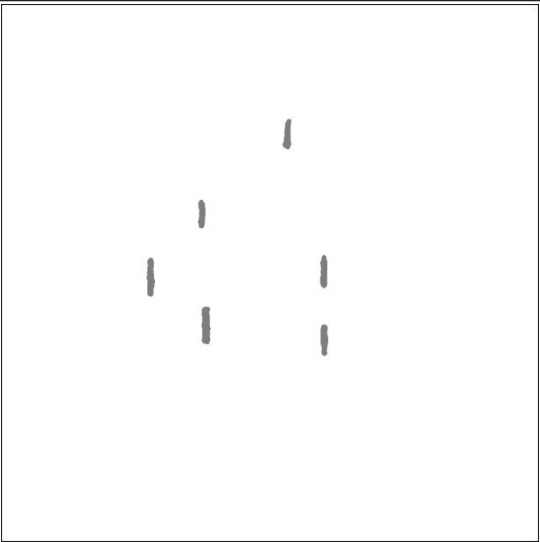
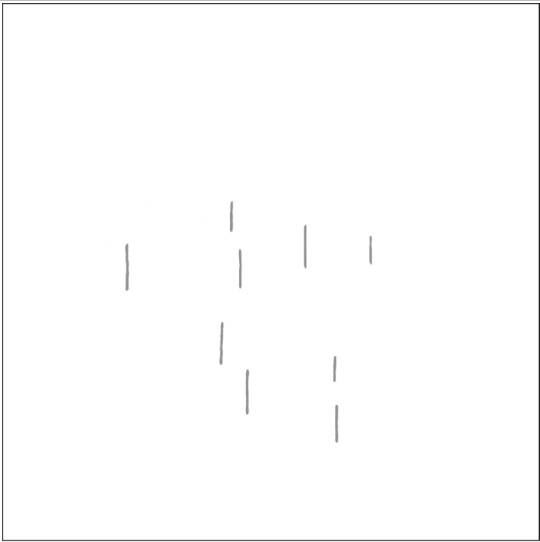
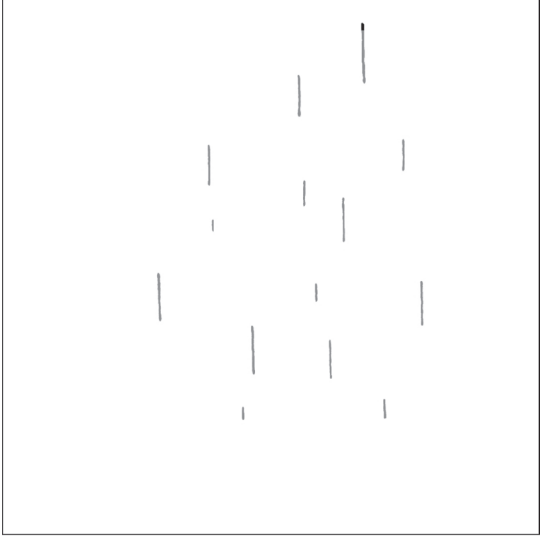
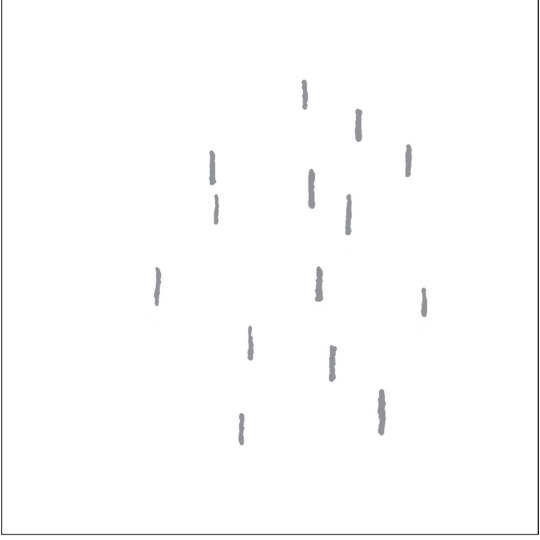
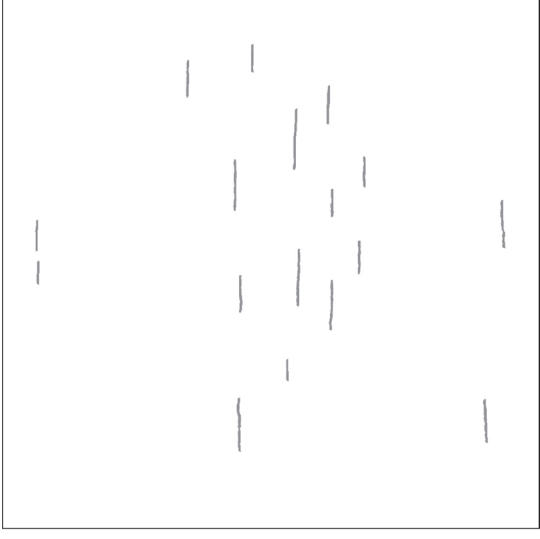
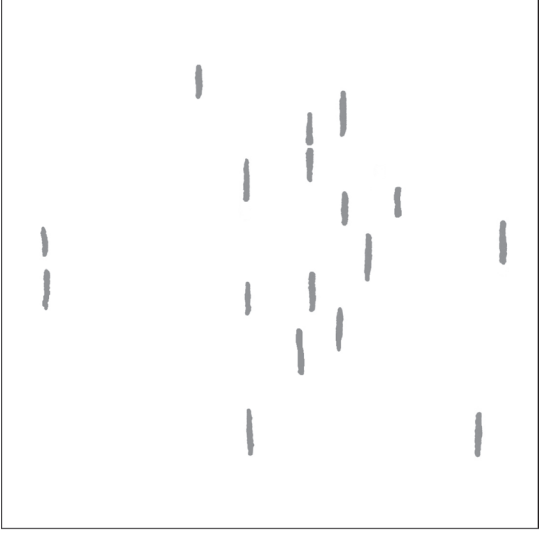
|                                                                                                                                                |                                                                                                                                                  |
|------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------|
|                                                               |                                                                |
| <b>e) A 1,5 (<math>2\text{ }\mu\text{m}\leq\text{width}\leq4\text{ }\mu\text{m}</math>, minimum total length 261 <math>\mu\text{m}</math>)</b> | <b>f) Ae 1,5 (<math>4\text{ }\mu\text{m}&lt;\text{width}\leq12\text{ }\mu\text{m}</math>, minimum total length 261 <math>\mu\text{m}</math>)</b> |
|                                                              |                                                               |
| <b>g) A 2,0 (<math>2\text{ }\mu\text{m}\leq\text{width}\leq4\text{ }\mu\text{m}</math>, minimum total length 436 <math>\mu\text{m}</math>)</b> | <b>h) Ae 2,0 (<math>4\text{ }\mu\text{m}&lt;\text{width}\leq12\text{ }\mu\text{m}</math>, minimum total length 436 <math>\mu\text{m}</math>)</b> |

Figure A.1 — Standard reference chart images of A type (2 of 3)

|                                                                                                                                               |                                                                                                                                                 |
|-----------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------|
|                                                              |                                                               |
| <p><b>i) A 2,5 (<math>2\ \mu\text{m} \leq \text{width} \leq 4\ \mu\text{m}</math>, minimum total length 649 <math>\mu\text{m}</math>)</b></p> | <p><b>j) Ae 2,5 (<math>4\ \mu\text{m} &lt; \text{width} \leq 12\ \mu\text{m}</math>, minimum total length 649 <math>\mu\text{m}</math>)</b></p> |
|                                                             |                                                              |
| <p><b>k) A 3,0 (<math>2\ \mu\text{m} \leq \text{width} \leq 4\ \mu\text{m}</math>, minimum total length 898 <math>\mu\text{m}</math>)</b></p> | <p><b>l) Ae 3,0 (<math>4\ \mu\text{m} &lt; \text{width} \leq 12\ \mu\text{m}</math>, minimum total length 898 <math>\mu\text{m}</math>)</b></p> |

**Figure A.1 — Standard reference chart images of A type (3 of 3)**

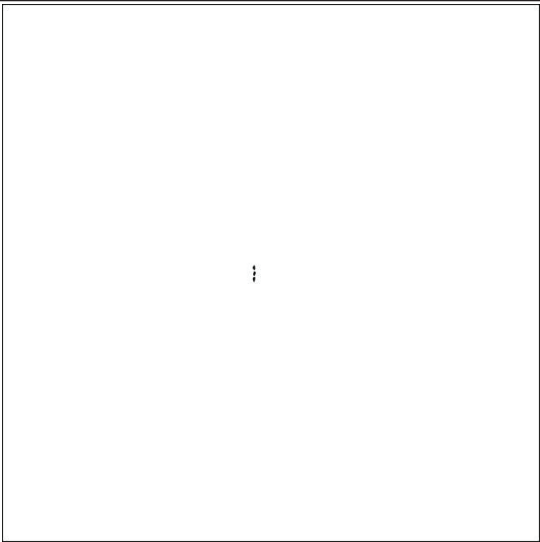
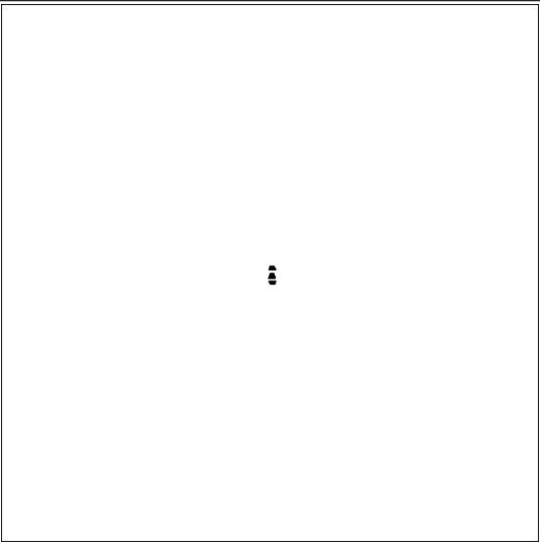
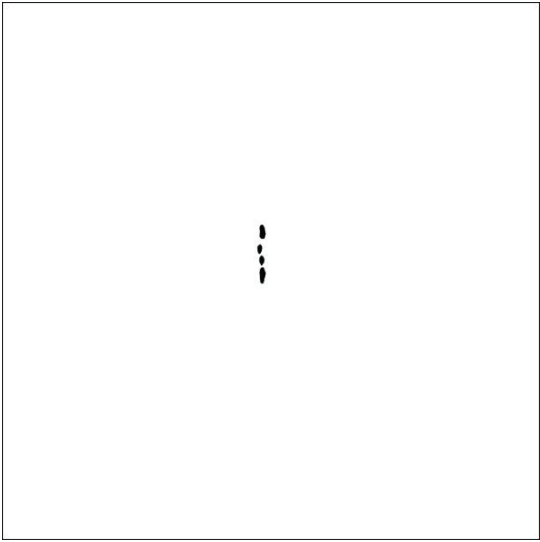
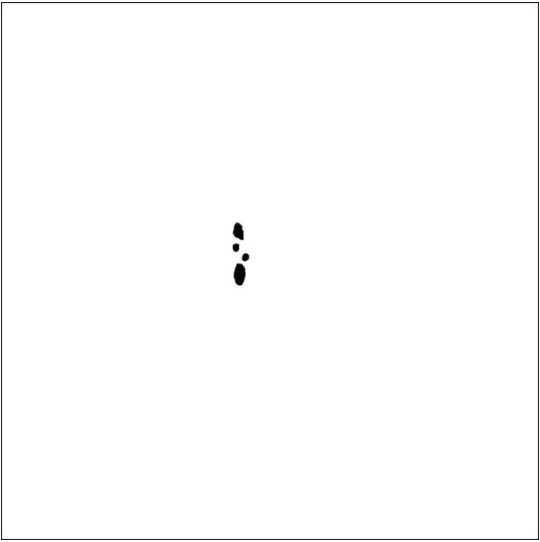
|                                                                                                                      |                                                                                                                     |
|----------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------|
|                                     |                                   |
| a) B 0,5 ( $2\text{ }\mu\text{m}\leq\text{width}\leq 9\text{ }\mu\text{m}$ , minimum total length 17 $\mu\text{m}$ ) | b) Be 0,5 ( $9\text{ }\mu\text{m}<\text{width}\leq 15\text{ }\mu\text{m}$ , minimum total length 17 $\mu\text{m}$ ) |
|                                    |                                  |
| c) B 1,0 ( $2\text{ }\mu\text{m}\leq\text{width}\leq 9\text{ }\mu\text{m}$ , minimum total length 77 $\mu\text{m}$ ) | d) Be 1,0 ( $9\text{ }\mu\text{m}<\text{width}\leq 15\text{ }\mu\text{m}$ , minimum total length 77 $\mu\text{m}$ ) |

Figure A.2 — Standard reference chart images of B type (1 of 3)

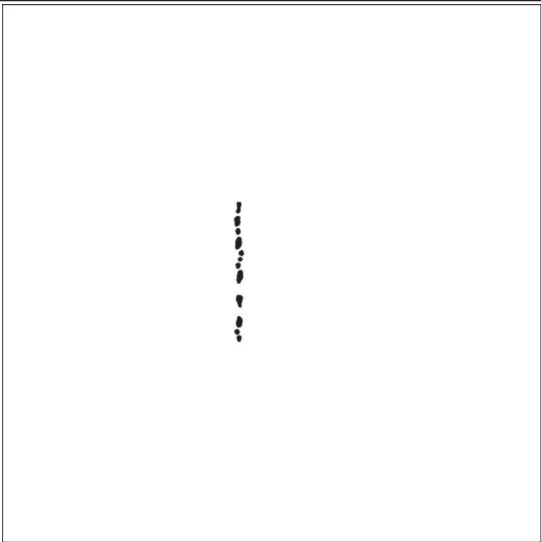
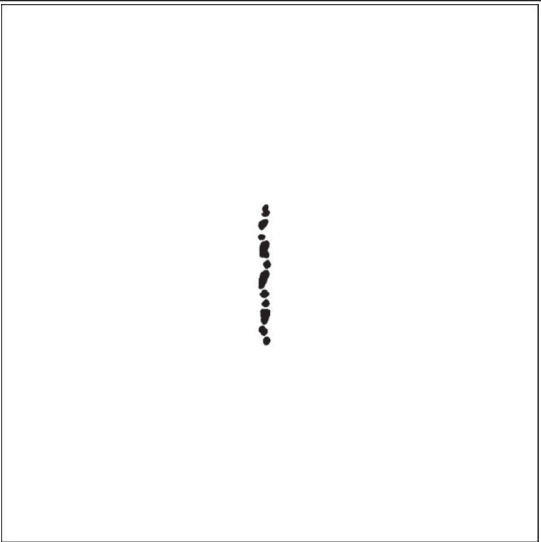
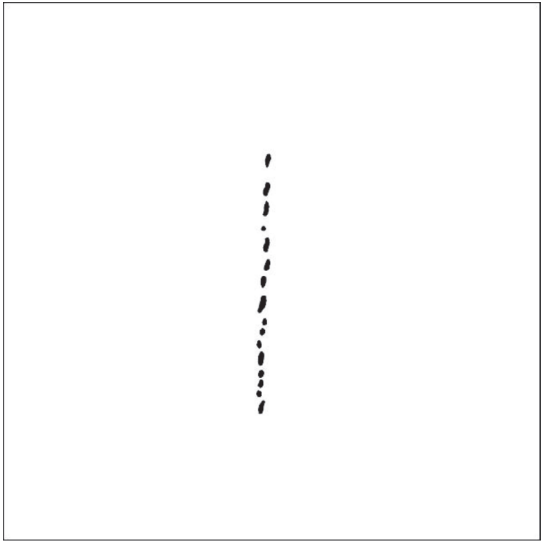
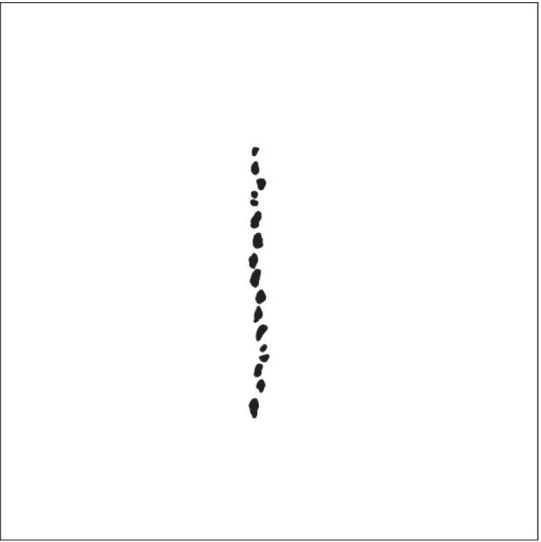
|                                                                                                                      |                                                                                                                     |
|----------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------|
|                                     |                                   |
| e) B 1,5 ( $2\text{ }\mu\text{m}\leq\text{width}\leq9\text{ }\mu\text{m}$ , minimum total length 184 $\mu\text{m}$ ) | f) Be 1,5 ( $9\text{ }\mu\text{m}<\text{width}\leq15\text{ }\mu\text{m}$ , minimum total length 184 $\mu\text{m}$ ) |
|                                    |                                  |
| g) B 2,0 ( $2\text{ }\mu\text{m}\leq\text{width}\leq9\text{ }\mu\text{m}$ , minimum total length 343 $\mu\text{m}$ ) | h) Be 2,0 ( $9\text{ }\mu\text{m}<\text{width}\leq15\text{ }\mu\text{m}$ , minimum total length 343 $\mu\text{m}$ ) |

Figure A.2 — Standard reference chart images of B type (2 of 3)

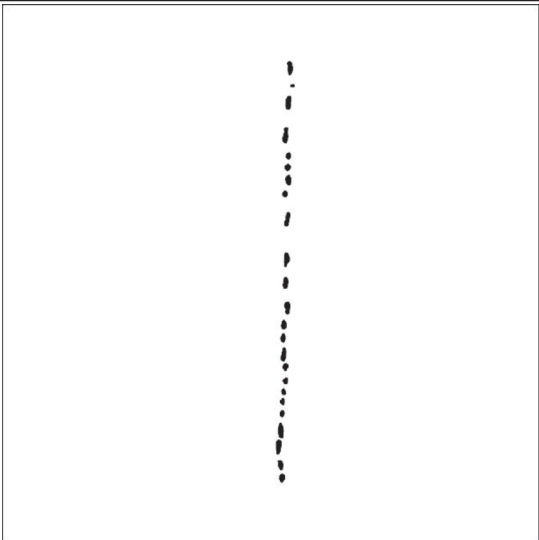
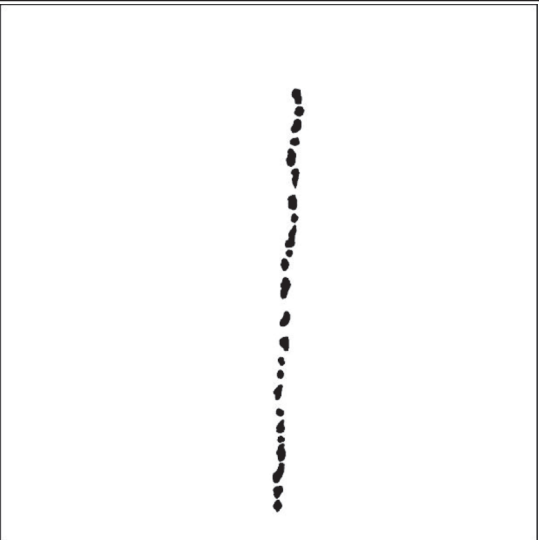
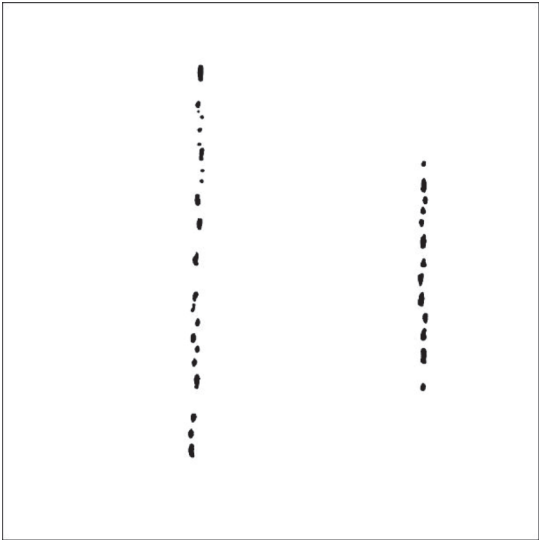
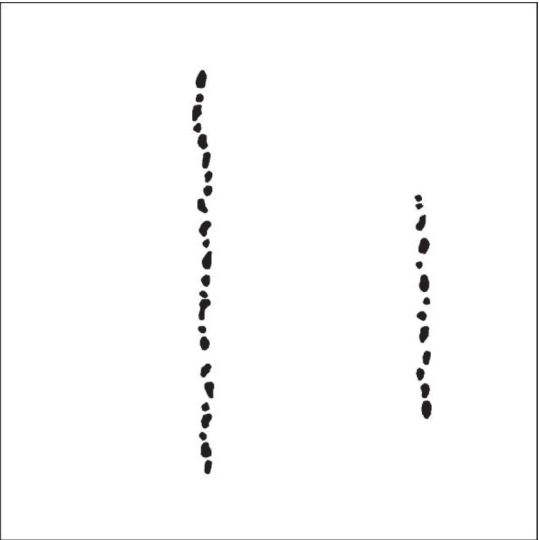
|                                                                                                                                                                  |                                                                                                                                                                    |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                                                                                 |                                                                                  |
| <p><b>i) B 2,5 (<math>2\text{ }\mu\text{m} \leq \text{width} \leq 9\text{ }\mu\text{m}</math>, minimum total length <math>555\text{ }\mu\text{m}</math>)</b></p> | <p><b>j) Be 2,5 (<math>9\text{ }\mu\text{m} &lt; \text{width} \leq 15\text{ }\mu\text{m}</math>, minimum total length <math>555\text{ }\mu\text{m}</math>)</b></p> |
|                                                                                |                                                                                 |
| <p><b>k) B 3,0 (<math>2\text{ }\mu\text{m} \leq \text{width} \leq 9\text{ }\mu\text{m}</math>, minimum total length <math>822\text{ }\mu\text{m}</math>)</b></p> | <p><b>l) Be 3,0 (<math>9\text{ }\mu\text{m} &lt; \text{width} \leq 15\text{ }\mu\text{m}</math>, minimum total length <math>822\text{ }\mu\text{m}</math>)</b></p> |

Figure A.2 — Standard reference chart images of B type (3 of 3)

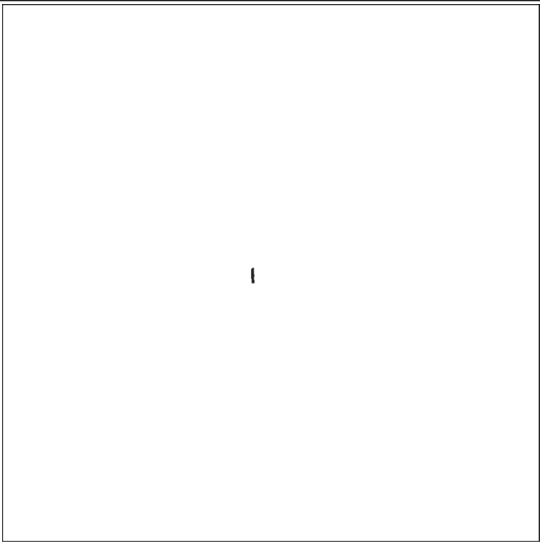
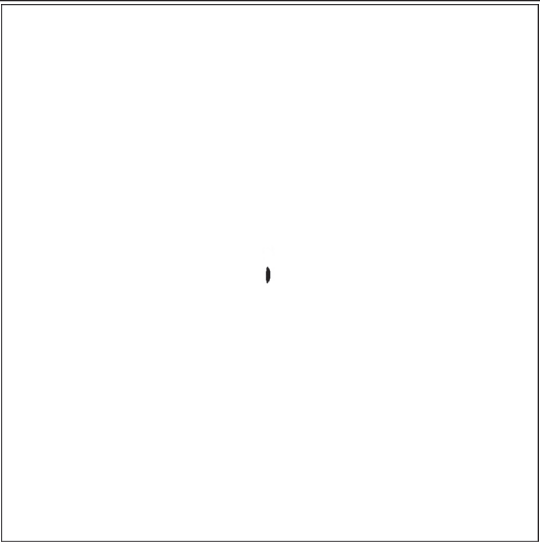
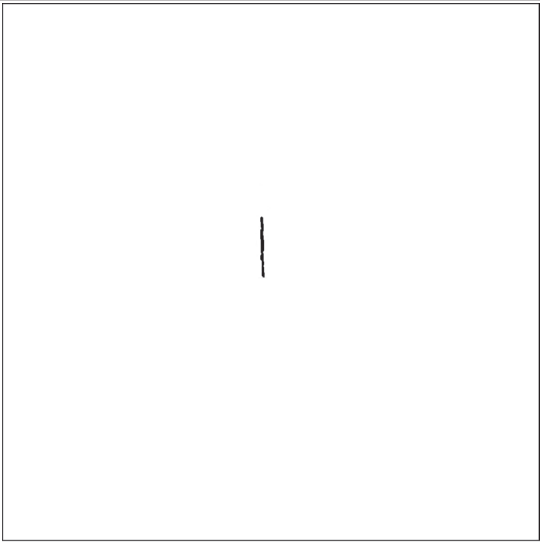
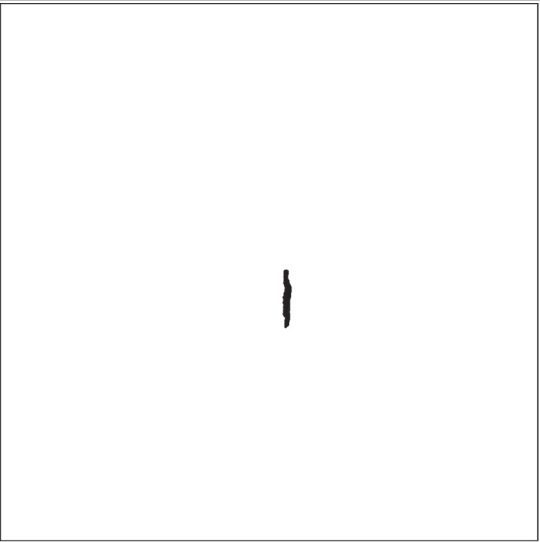
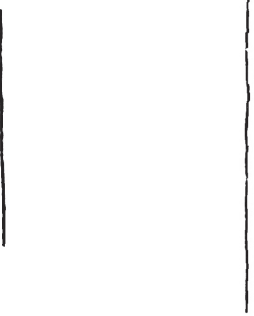
|                                                                                                                                                      |                                                                                                                                                        |
|------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------|
|                                                                     |                                                                      |
| <b>a) C 0,5 (<math>2\text{ }\mu\text{m}\leq\text{width}\leq5\text{ }\mu\text{m}</math>, minimum total length <math>18\text{ }\mu\text{m}</math>)</b> | <b>b) Ce 0,5 (<math>5\text{ }\mu\text{m}&lt;\text{width}\leq12\text{ }\mu\text{m}</math>, minimum total length <math>18\text{ }\mu\text{m}</math>)</b> |
|                                                                    |                                                                     |
| <b>c) C 1,0 (<math>2\text{ }\mu\text{m}\leq\text{width}\leq5\text{ }\mu\text{m}</math>, minimum total length <math>76\text{ }\mu\text{m}</math>)</b> | <b>d) Ce 1,0 (<math>5\text{ }\mu\text{m}&lt;\text{width}\leq12\text{ }\mu\text{m}</math>, minimum total length <math>76\text{ }\mu\text{m}</math>)</b> |

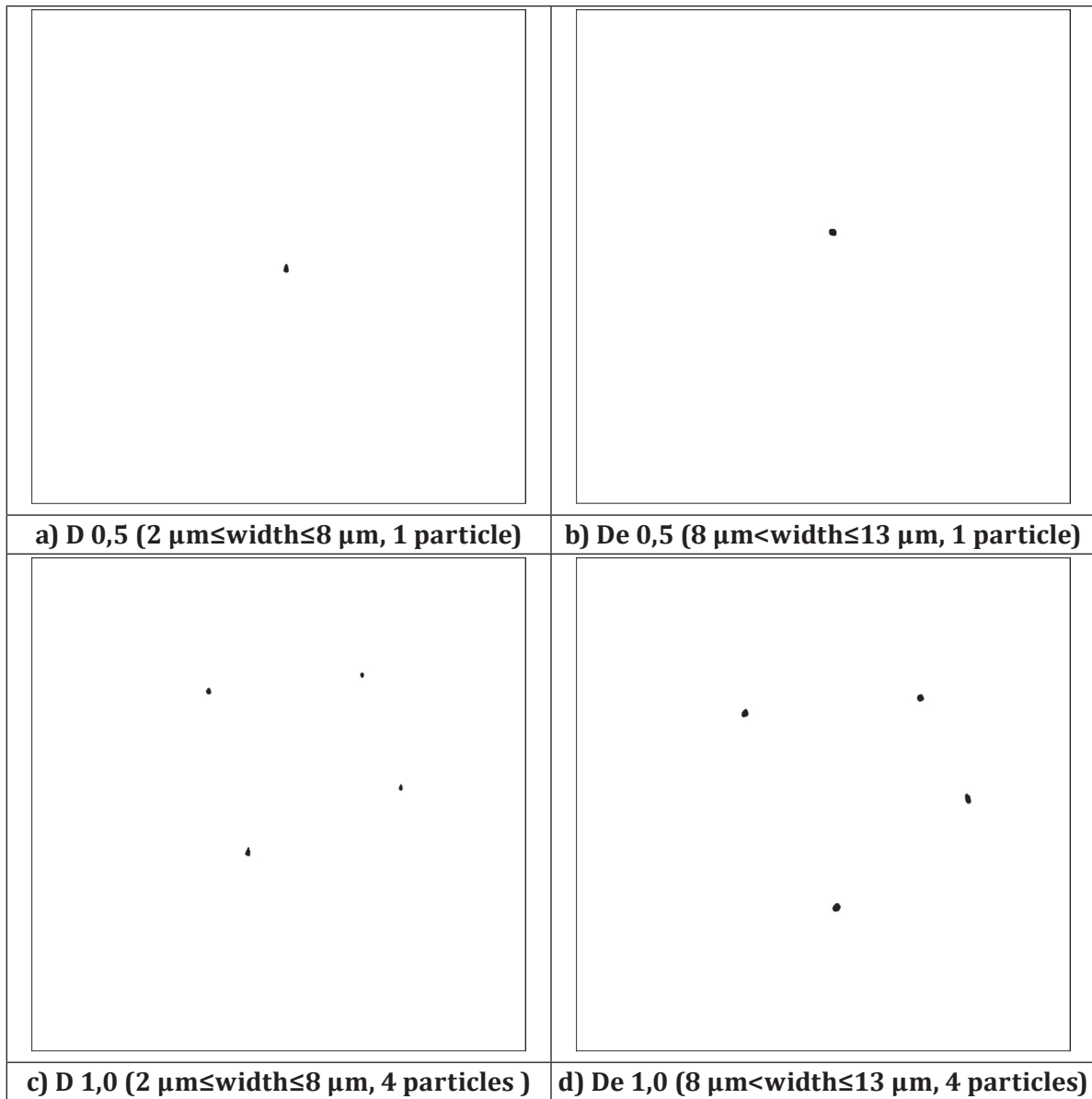
Figure A.3 — Standard reference chart images of C type (1 of 3)

|                                                                                                                                                           |                                                                                                                                                             |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                                                                          |                                                                          |
| <p><b>e) C 1,5 (<math>2\text{ }\mu\text{m} \leq \text{width} \leq 5\text{ }\mu\text{m}</math>, minimum total length 176 <math>\mu\text{m}</math>)</b></p> | <p><b>f) Ce 1,5 (<math>5\text{ }\mu\text{m} &lt; \text{width} \leq 12\text{ }\mu\text{m}</math>, minimum total length 176 <math>\mu\text{m}</math>)</b></p> |
|                                                                         |                                                                         |
| <p><b>g) C 2,0 (<math>2\text{ }\mu\text{m} \leq \text{width} \leq 5\text{ }\mu\text{m}</math>, minimum total length 320 <math>\mu\text{m}</math>)</b></p> | <p><b>h) Ce 2,0 (<math>5\text{ }\mu\text{m} &lt; \text{width} \leq 12\text{ }\mu\text{m}</math>, minimum total length 320 <math>\mu\text{m}</math>)</b></p> |

**Figure A.3 — Standard reference chart images of C type (2 of 3)**

|                                                                                                                                                                  |                                                                                                                                                                    |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                                                                                 |                                                                                 |
| <p><b>i) C 2,5 (<math>2\text{ }\mu\text{m} \leq \text{width} \leq 5\text{ }\mu\text{m}</math>, minimum total length <math>510\text{ }\mu\text{m}</math>)</b></p> | <p><b>j) Ce 2,5 (<math>5\text{ }\mu\text{m} &lt; \text{width} \leq 12\text{ }\mu\text{m}</math>, minimum total length <math>510\text{ }\mu\text{m}</math>)</b></p> |
|                                                                                |                                                                                 |
| <p><b>k) C 3,0 (<math>2\text{ }\mu\text{m} \leq \text{width} \leq 5\text{ }\mu\text{m}</math>, minimum total length <math>746\text{ }\mu\text{m}</math>)</b></p> | <p><b>l) Ce 3,0 (<math>5\text{ }\mu\text{m} &lt; \text{width} \leq 12\text{ }\mu\text{m}</math>, minimum total length <math>746\text{ }\mu\text{m}</math>)</b></p> |

**Figure A.3 — Standard reference chart images of C type (3 of 3)**



**Figure A.4 — Standard reference chart images of D type (1 of 3)**

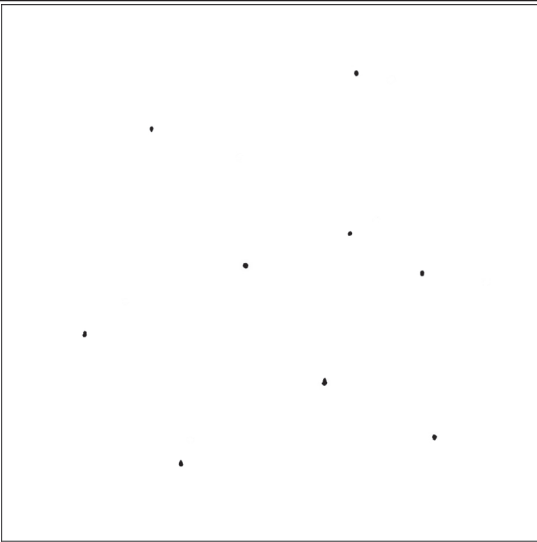
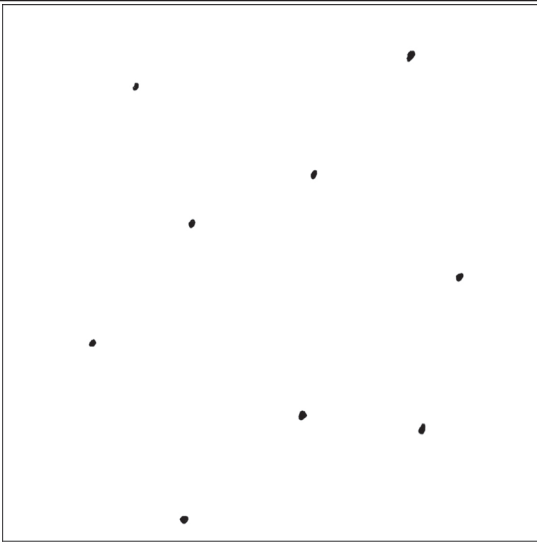
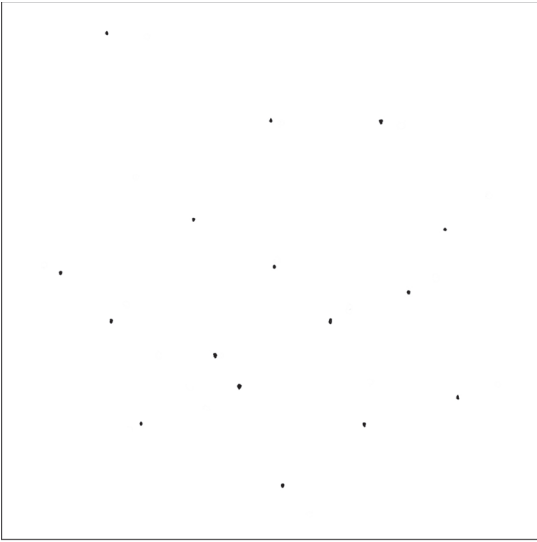
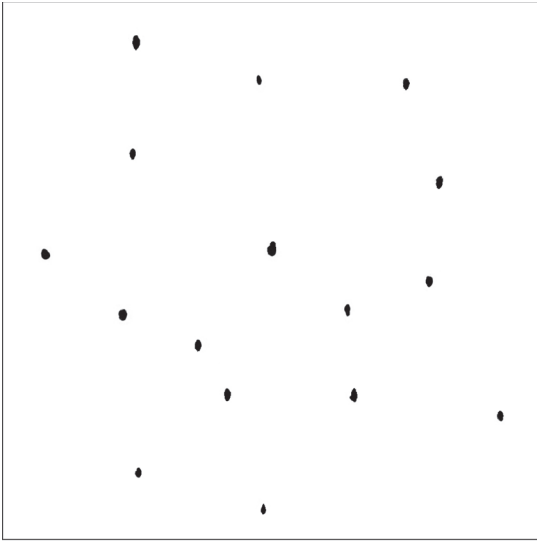
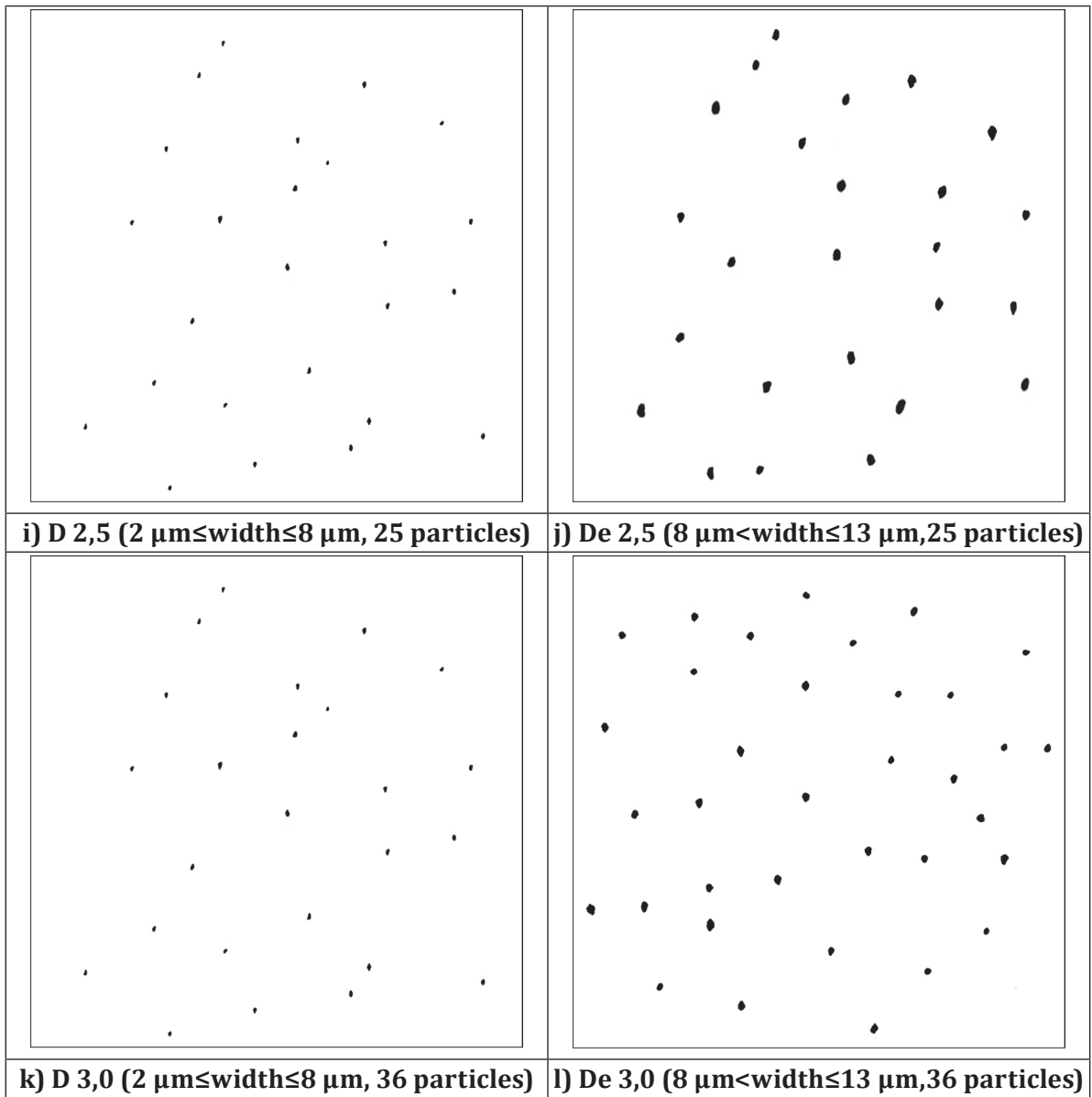
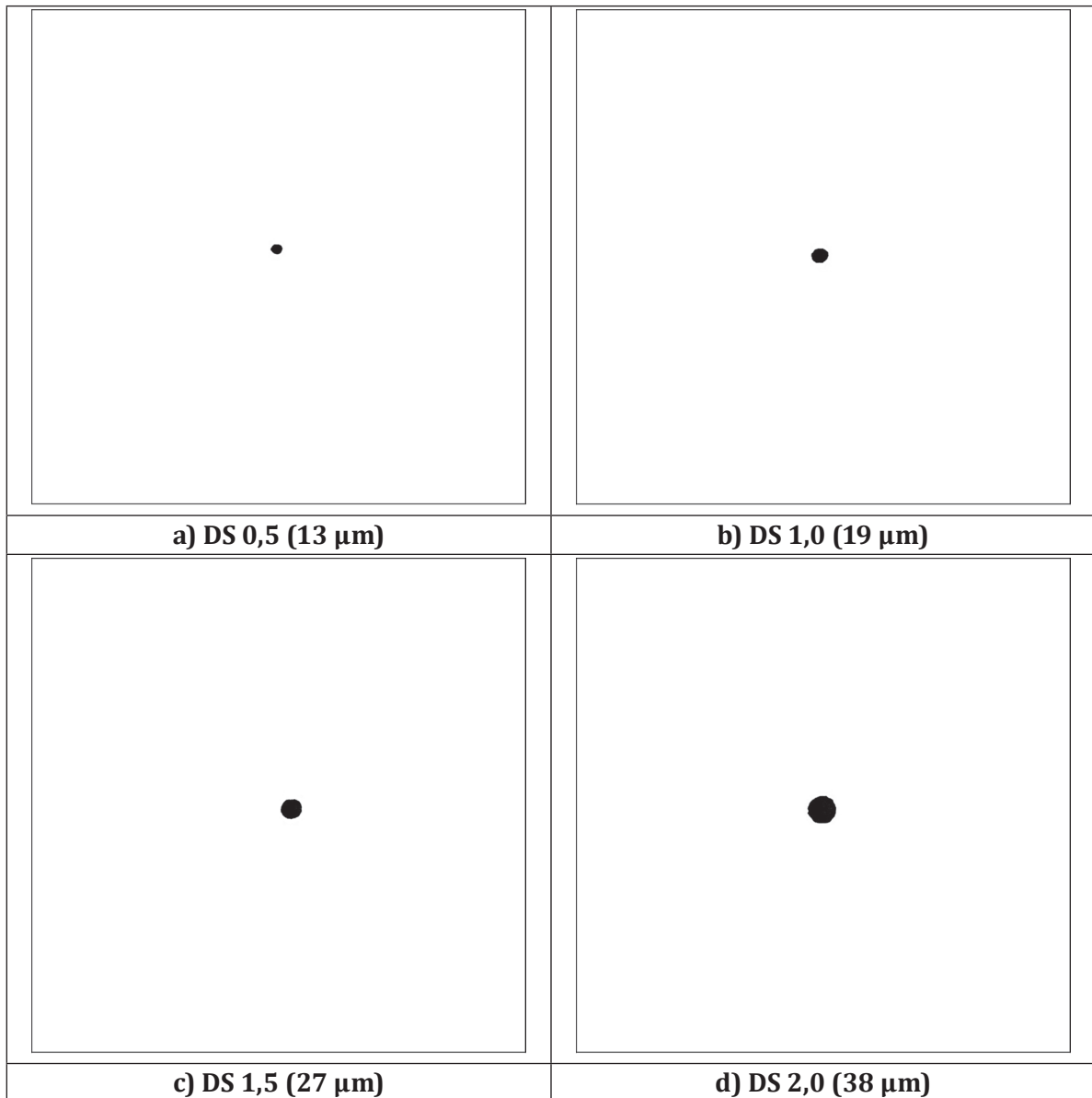
|                                                                                    |                                                                                     |
|------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------|
|   |   |
| e) D 1,5 (2 μm≤width≤8 μm, 9 particles)                                            | f) De 1,5 (8 μm<width≤13 μm, 9 particles)                                           |
|  |  |
| g) D 2,0 (2 μm≤width≤8 μm, 16 particles)                                           | h) De 2,0 (8 μm<width≤13 μm,16 particles)                                           |

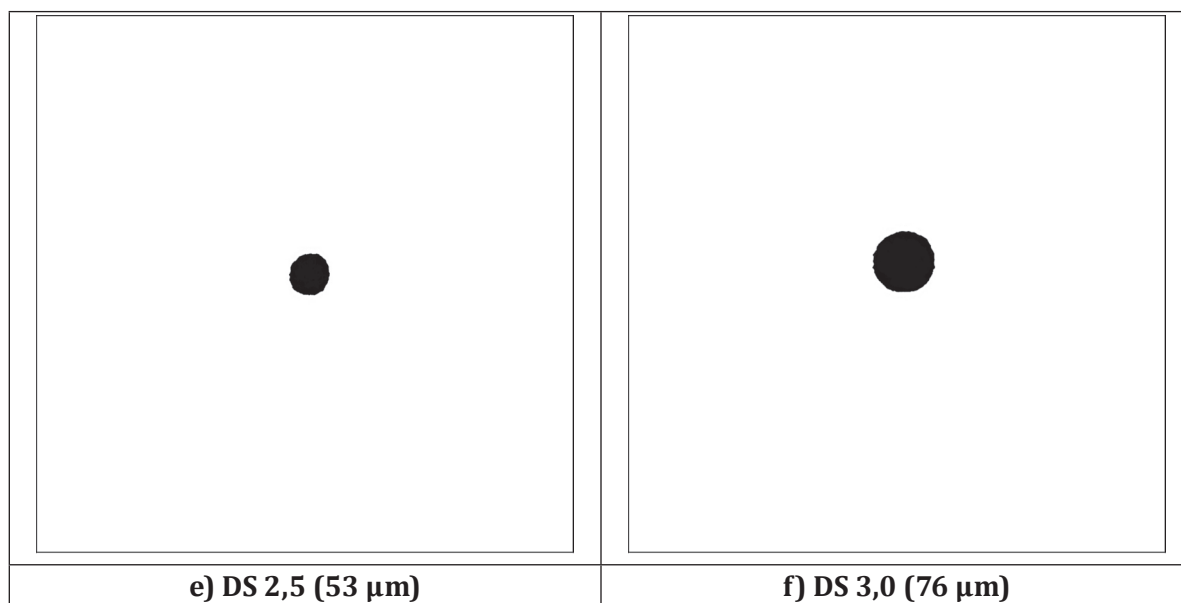
Figure A.4 — Standard reference chart images of D type (2 of 3)



**Figure A.4 — Standard reference chart images of D type (3 of 3)**



**Figure A.5 — Standard reference chart images of DS subgroup (1 of 2)**



**Figure A.5 — Standard reference chart images of DS subgroup (2 of 2)**

## **Annex B**

### **(normative)**

## **Examples of assessment of inclusions**

### **B.1 Example of assessment of a field**

[Figure B.1](#) a) shows a  $710\text{ }\mu\text{m} \times 710\text{ }\mu\text{m}$  field observed using a magnification of  $100\times$ , where three types of non-metallic inclusions are distinguished. Depending on their shape and distribution, these are categorized: type A, sulfide; type B, aluminate (fragment inclusions); type D (globular oxides).

The field observed is assessed by comparing it, for each inclusion group, with the nearest smaller standard reference chart image, ignoring other groups of inclusions. This gives the following indices: Ae 2,0 [see [Figure B.1](#) b)]; A 1,0 [see [Figure B.1](#) c)]; Be 2,0 [see [Figure B.1](#) d)]; De 0,5s ( $70\text{ }\mu\text{m}$ ) and DS 2,5 [see [Figure B.1](#) e)].

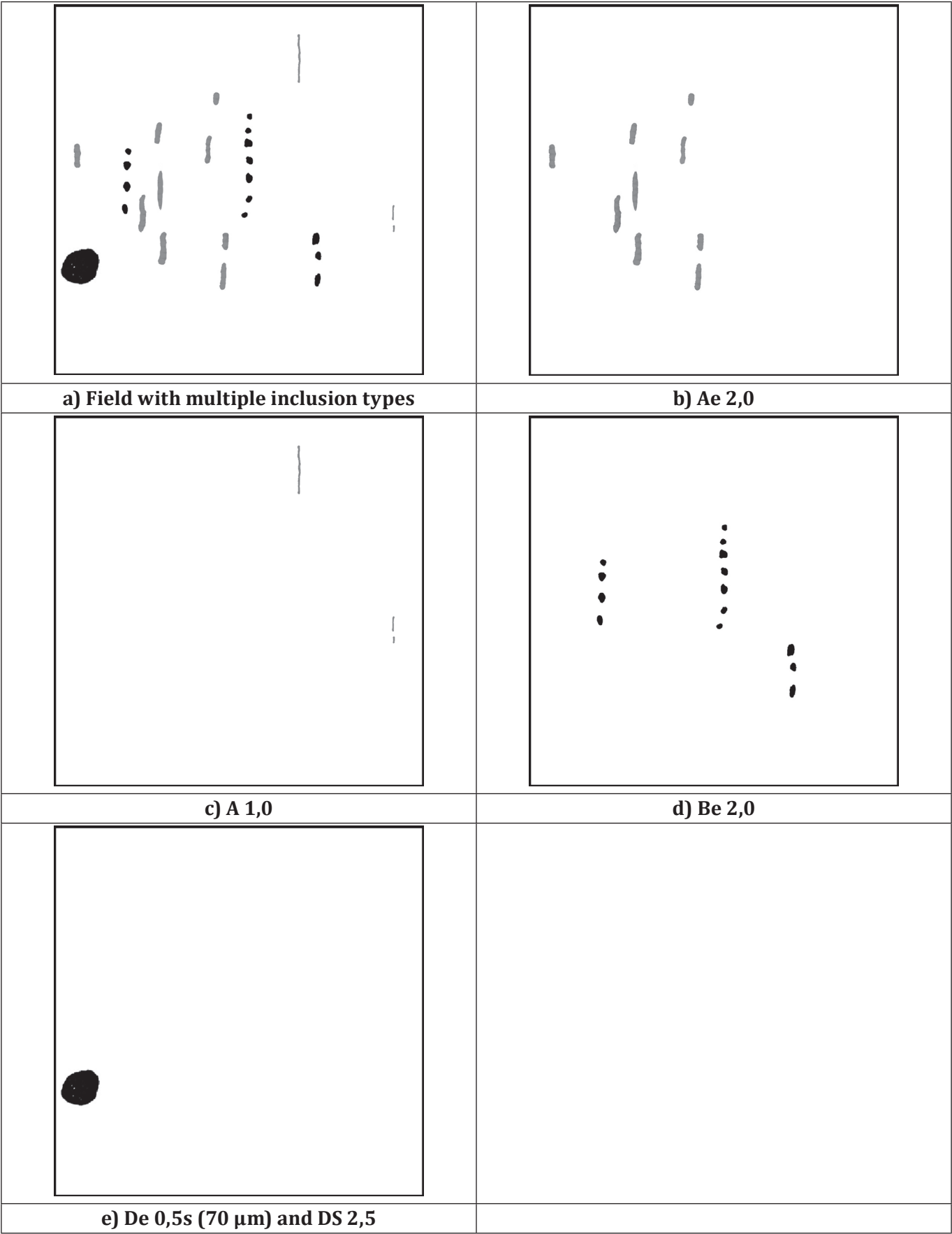


Figure B.1 — Example of field assessment

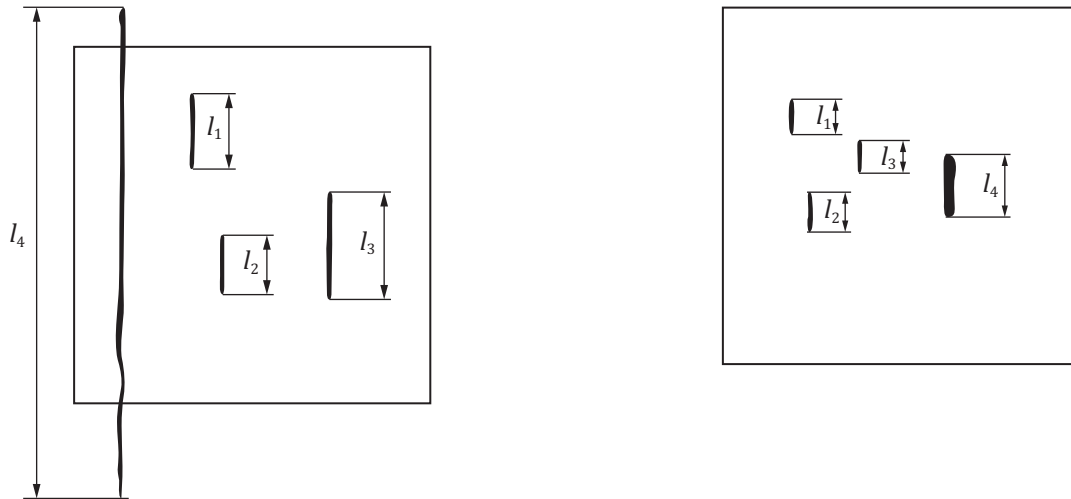
## B.2 Example of assessment of oversized inclusions for type A, B and C

If the inclusion is oversized by length only, the total length will be added to the length of any other inclusions of the same group in the same field [see [Figure B.2 a\)](#)].

If the inclusion is oversized by width (type A, B, and C inclusions), the inclusion shall be part of the thick class rating for that field [see [Figure B.2 b\)](#)].

The total length of all inclusions of the same group in a field is the sum of the length of each inclusion in that group.

For view fields that exceed the upper limits of [Table 2](#), the index can be calculated from the formula given in [Annex F](#).



a) For inclusions or stringers oversized by length    b) For inclusions or stringers oversized by width only

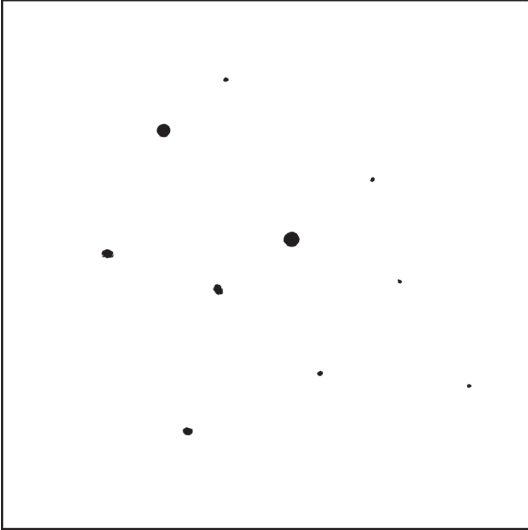
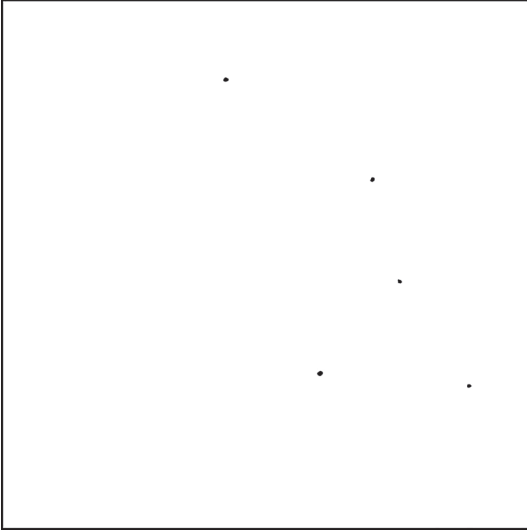
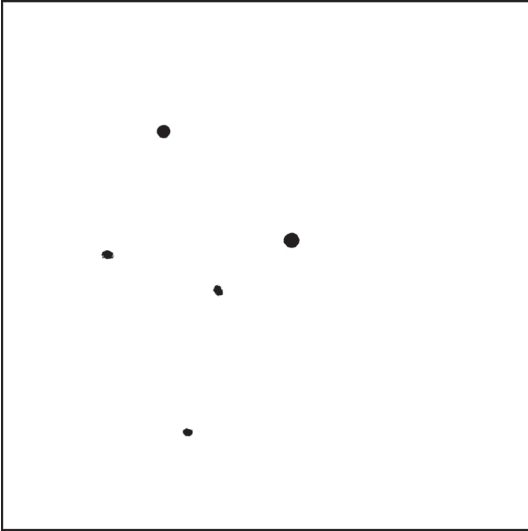
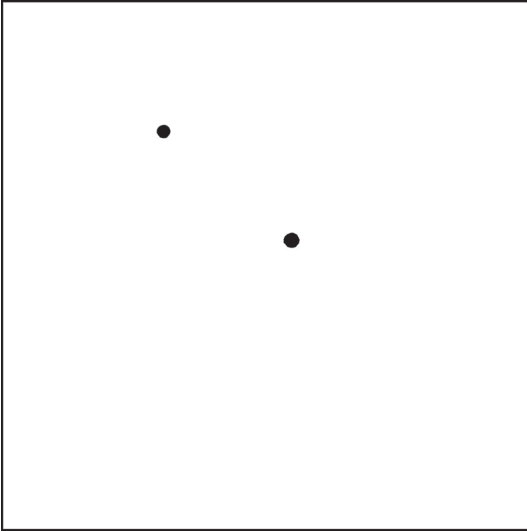
### Key

|       |                                                                                                 |
|-------|-------------------------------------------------------------------------------------------------|
| $l$   | the total length of all inclusions of the same group in a field ( $l = l_1 + l_2 + l_3 + l_4$ ) |
| $l_1$ | the length of inclusion 1                                                                       |
| $l_2$ | the length of inclusion 2                                                                       |
| $l_3$ | the length of inclusion 3                                                                       |
| $l_4$ | the length of inclusion 4                                                                       |

**Figure B.2 — Field assessment with oversized A, B and C types of inclusions**

## B.3 Example of assessment of oversized inclusions for type D

If the inclusion is oversized by diameter, it is rated as DS according to [8.2.4.4](#). Additionally, all the oversized inclusions will be included into the D thick group rating (see [Figure B.3](#)).

|                                                                                    |                                                                                     |
|------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------|
|   |   |
| <p><b>a) Field with multiple globular inclusions</b></p>                           | <p><b>b) D1,0</b></p>                                                               |
|  |  |
| <p><b>c) De1,0s (15 <math>\mu\text{m}</math>, 20 <math>\mu\text{m}</math>)</b></p> | <p><b>d) DS1,0 (Method B: DS 0,5; DS 1,0)</b></p>                                   |

**Figure B.3 — Field assessment (710  $\mu\text{m}$   $\times$  710  $\mu\text{m}$ ) with oversized D type inclusions**

## Annex C

### (informative)

### Examples of assessment of complex inclusions

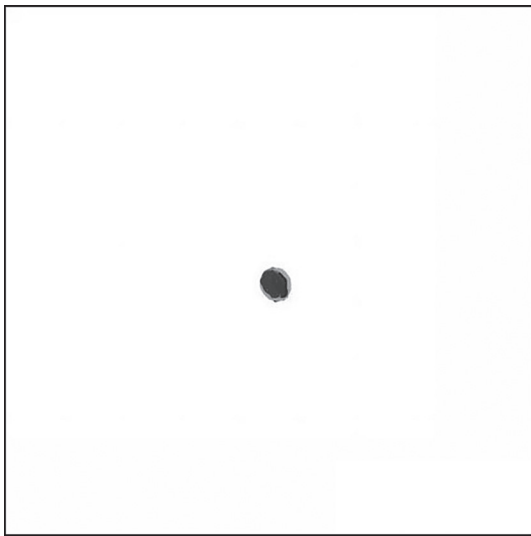
[Figure C.1](#) gives assessment examples of A and D types of complex inclusions. The globular particle, which may be rated as De 0,5 s (40  $\mu\text{m}$ ) and DS 2,0, is made up of inner aluminium oxide and outer calcium sulfide [see [Figure C.1](#) a)]. The area of aluminium oxide is bigger than that of calcium sulfide. Thus, this complex inclusion may be stated as  $\text{De}_{\text{Al}_2\text{O}_3+\text{CaS}} 0,5 \text{ s (40 } \mu\text{m)}$  and  $\text{DS}_{\text{Al}_2\text{O}_3+\text{CaS}} 2,0$ . The big portion of the inclusion in [Figure C.1](#) b) is made up of manganese sulfide thin film, in which a calcium aluminate is enfolded. This complex inclusion may be stated as  $\text{A}_{\text{MnS}+(\text{Al,Ca,Mg})\text{O}} 1,0$ . The chemical contents are determined by using EDS equipped on SEM.

[Figure C.2](#) gives examples of assessment of B and C types of complex inclusions. Where necessary, a higher magnification is used to better discern the individual constituents of the complex inclusion. In [Figures C.2](#) a) and b) more of the inclusion's length falls into B type: categorize it as B. It may be stated as  $\text{Be}_{(\text{Al,Mg,Si})\text{O}} 1,0$ . In [Figures C.2](#) c) and d) more of the inclusion's length falls into C type: categorize it as C. It may be stated as  $\text{Ce}_{(\text{Si,Al,Mg})\text{O}} 1,0$ .

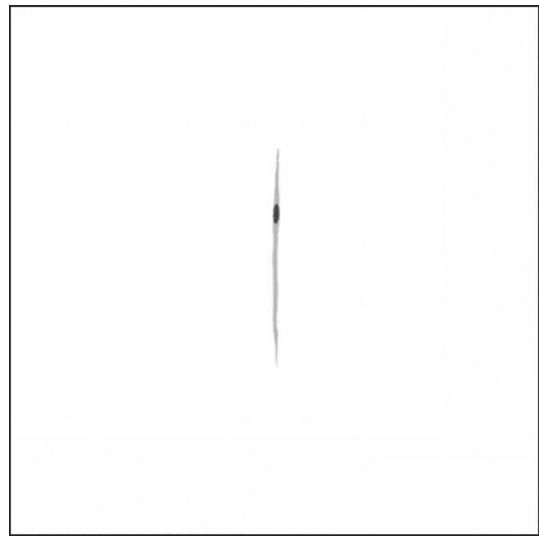
NOTE 1 [Figures C.2](#) a) and [C.2](#) b) are also examples of contiguous brittle type B inclusions that are often classified as type C, particularly by image analysis.

NOTE 2 As stated in [5.4](#), the treatment of complex inclusions is a matter of agreement between the parties.

NOTE 3 All images represent a 710  $\mu\text{m} \times 710 \mu\text{m}$  square field of view.

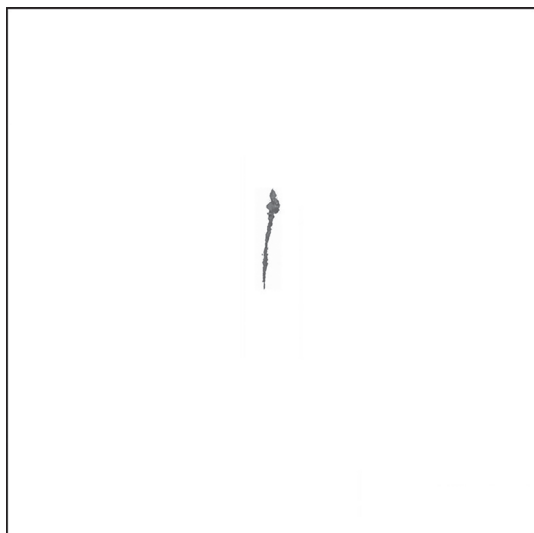


**a)**  $\text{De}_{\text{Al}_2\text{O}_3+\text{CaS}} 0,5 \text{ s (40 } \mu\text{m)}$  /  $\text{DS}_{\text{Al}_2\text{O}_3+\text{CaS}} 2,0$  100  $\times$

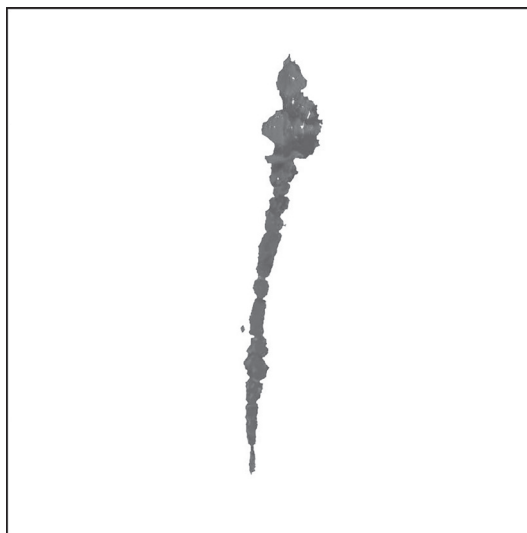


**b)**  $\text{A}_{\text{MnS}+(\text{Al,Ca,Mg})\text{O}} 1,0$  100  $\times$

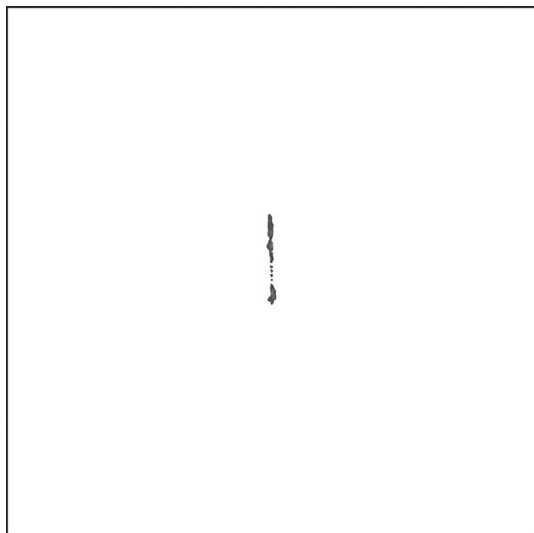
**Figure C.1 — Field assessment with complex A and D types of inclusions**



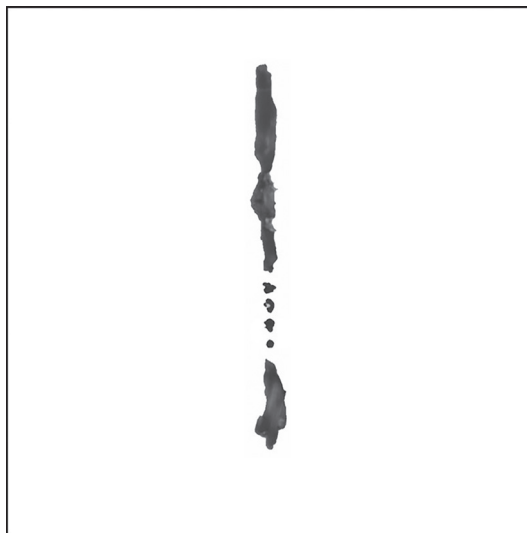
**a)**  $\text{Be}_{(\text{Al,Mg,Si})}\text{O}$  1,0 100 ×



**b)**  $\text{Be}_{(\text{Al,Mg,Si})}\text{O}$  1,0 500 ×



**c)**  $\text{Ce}_{(\text{Si,Al,Mg})}\text{O}$  1,0 100 ×



**d)**  $\text{Ce}_{(\text{Si,Al,Mg})}\text{O}$  1,0 500 ×

**Figure C.2 — Field assessment with complex B and C types of inclusions**

Annex D  
(informative)

Illustration of the width definitions

D.1 General

The calliper width is illustrated for a single particle in 3.5. It was chosen because it reliably returns a width closely representative of the internal flaw. This Annex expands on the illustration in 3.5 for several less obvious cases and in particular contrasts the calliper width with the largest particle width and other width definitions for multi-particle inclusions with overlapping particles.

D.2 Single particles and in-line stringers

Figure 11 and Figure 12 show two examples of in-line stringers and the assigned calliper width: the width in this case corresponds to the calliper width of the widest particle. Figure D.1 contrasts the calliper width to other width definitions.

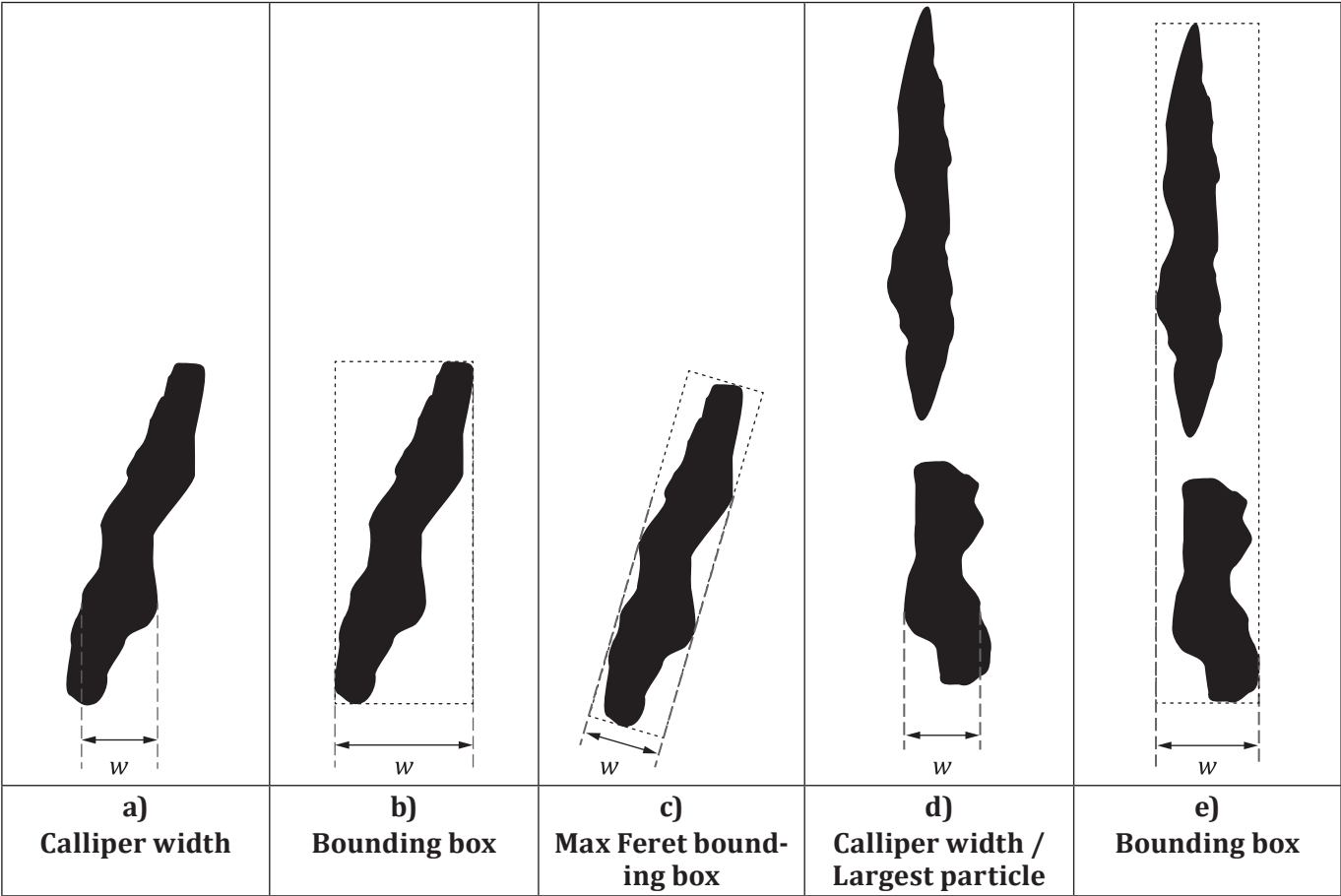
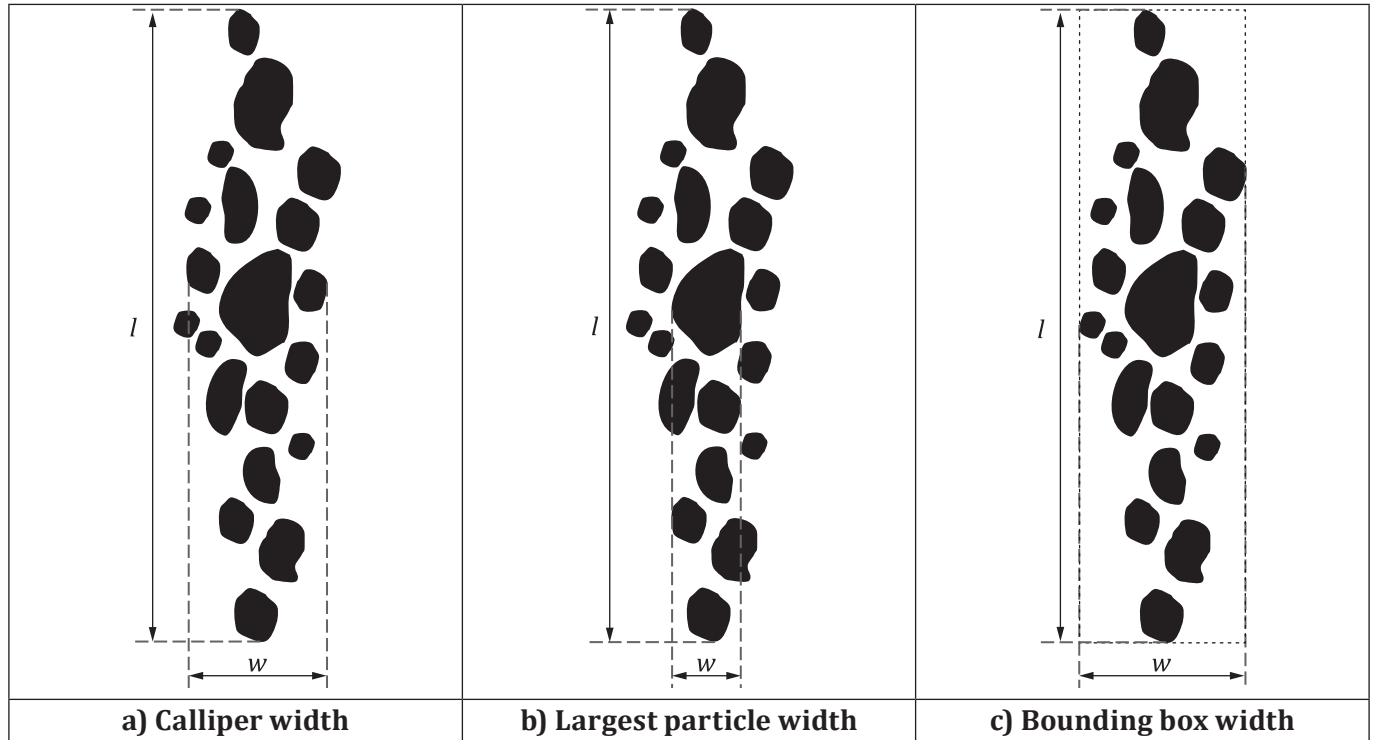


Figure D.1 — Comparison of the calliper width to alternate width definitions

### D.3 Stringers with particles overlapping in the main deformation direction

When multiple particles fulfil the proximity conditions ( $s \leq 10 \mu\text{m}$ ,  $e \leq 40 \mu\text{m}$ ) to combine into a single inclusion, overlap in the main deformation direction can occur between particles (i. e.  $e < 0 \mu\text{m}$ ). This adds further nuance to the width definition. [Figure D.2](#) illustrates the difference between the calliper width and two frequently used alternatives, a “largest particle” width and a “bounding box” width.

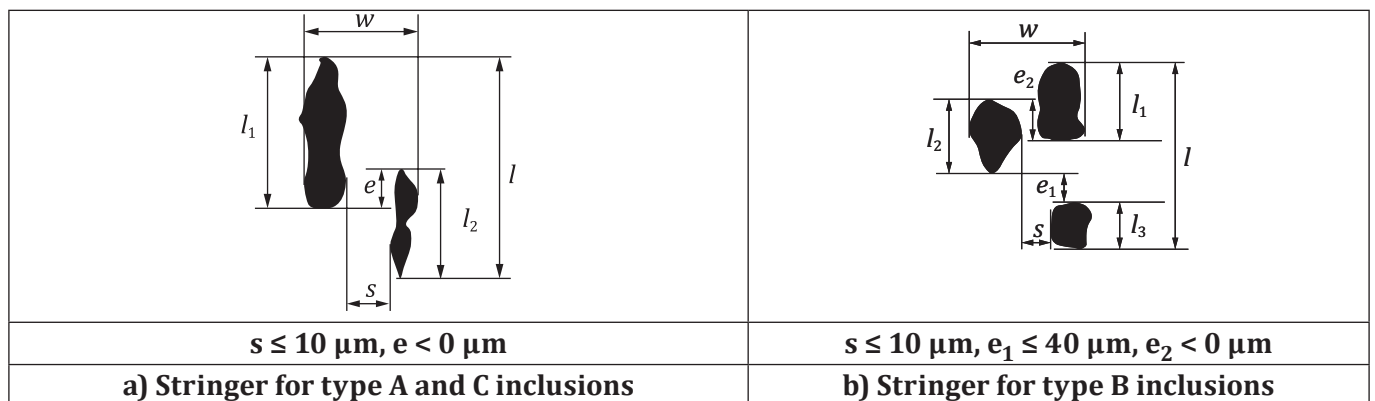


**Figure D.2 — Comparison of width definitions for multi-particle inclusions with overlap**

Because legacy approaches to width definition can lead to different ratings [e. g. [Figure D.1](#) a) and b) or [Figure D.2](#) a) and b)], they shall be stated in the reporting of the results, as must measures taken to compensate for under- or over-estimating the width.

The computation of global indices in [Annex E](#) relies on the use of the calliper width and the projected length in the main deformation direction to characterize inclusions.

[Figure D.2](#) shows a Type B inclusion. The approach is identical for inclusions consisting of elongated particles overlapping in the main deformation direction, as shown in [Figure D.3](#).



**Figure D.3 — Calliper width for different types of multi-particle inclusions with overlap**

## Annex E

### (informative)

## Assessment result examples and global inclusion content metrics

### E.1 Typical example of results for method A

[Table E.1](#) gives an example of the result of an assessment of six specimens in one heat using method A.

**Table E.1 — Assessment result of six specimens for method A**

| Specimen | Inclusion Group / Subgroup |       |      |       |      |       |      |       |     |
|----------|----------------------------|-------|------|-------|------|-------|------|-------|-----|
|          | A                          |       | B    |       | C    |       | D    |       | DS  |
|          | fine                       | thick | fine | thick | fine | thick | fine | thick |     |
| 1        | 2,0                        | 1,0   | 2,0  | 0,0   | 0,0  | 0,0   | 1,5  | 0,5 s | 1,0 |
| 2        | 1,5                        | 1,0   | 1,0  | 1,5   | 0,0  | 0,0   | 1,0  | 1,0 s | 0,5 |
| 3        | 1,5                        | 1,0   | 1,5  | 0,0   | 0,0  | 0,0   | 1,5  | 1,0 s | 1,5 |
| 4        | 1,0                        | 1,0   | 1,0  | 0,5 s | 0,0  | 0,0   | 1,0  | 1,0 s | 1,0 |
| 5        | 1,5                        | 1,5   | 1,0  | 0,5   | 0,5  | 0,0   | 1,5  | 1,0 s | 1,5 |
| 6        | 1,0                        | 1,0   | 2,0  | 1,0 s | 0,0  | 1,5 s | 1,5  | 1,0 s | 0,5 |
| Average  | 1,4                        | 1,1   | 1,4  | 0,6   | 0,1  | 0,3   | 1,3  | 0,9   | 1,0 |

Oversized inclusions: Be 19 µm max, Ce 18 µm max, DS as reported in [Table E.1](#).

### E.2 Global metrics for the inclusion content of a steel, derived from method B

#### E.2.1 General

Method B is a field frequency method. As such it includes a record of all relevant inclusion instances across a sample surface. This record can be used to expand on the description of the inclusion population in more relatable and physically relevant terms.

These global metrics include:

- area fraction per type (A, B, C, D, DS), class (fine, thick), group, apparent chemistry (sulfide/oxide/nitride) and as a total;
- relative area fraction of inclusions, e.g., the ratio between inclusion types, classes, apparent chemistries, and total;
- inclusion density (number per unit area), per type, class, apparent chemistry and as a total;
- inclusion interdistance, i.e. the average distance between inclusions in a surveyed surface, per type, class, apparent chemistry and as a total;
- global severity ratings based on normalized inclusion area per index, type and class.

As described extensively elsewhere<sup>[4][5]</sup>, it is also recognized that extreme value analysis of large inclusions (DS and oversized) is a viable option.

## E.2.2 Assessment rule basics

### E.2.2.1 General

For the treatment in this annex, it is required that the following input parameters are used.

All inclusion widths adhere to the new calliper definition (see 3.5). This is essential to the calculation of the inclusion area as an internal flaw.

For stringers, the transverse proximity is defined by facing tangents (see 8.2.4.7). This is central because it has been shown that the old centreline-to-centreline definition on occasion, and especially for image analysis systems, breaks down and dissociates obvious stringers into shorter segments and individual particles, thereby underestimating the severity of the inclusion content. For manual analyses this has been less of a problem since the human operator promptly will identify a stringer when it occurs, essentially overriding the inherent flaw of the centreline-to-centreline definition.

Single inclusions are assessed by their full lengths (see 8.2.4.2) and indexed as such while assigned to one field only. This is important because it has been shown that capping of the inclusion lengths at the field border makes method B dependent on where the field grid is positioned on the polished surface, hence introducing a random bias. The full-length indexing is therefore a requirement for repeatability, but also for the calculation of the inclusion area.

All DS inclusions are accounted for separately, by index or by their true size ( $d$ ), and all oversized type A, B, C inclusions are recorded by their true size ( $l \times w$ ). This is necessary to be able to calculate the inclusion area they add to the analysis, apart from their respective contributions to the thick indices. This contribution is referred to as the excess area.

For further treatment, all inclusions are ascribed an ellipsis shape, with the circle as a special case for types D and DS. It is also assumed that the size distribution of any endogenous inclusion population reasonably follows a log-normal relationship, and hence the use of geometrical averages.

Based on the upper and lower limits, each index for each type (A, B, C, D, DS) and class (fine, thick) can be assigned an average length and width (A, B, C), or number (D) and diameter (D, DS). From these metrics, index specific areas can be calculated.

NOTE Attempts to re-calculate the value tables frequently lead to deviations due to rounding effects.

### E.2.2.2 Types A, B, C

The geometric index length for type A, B, and C inclusions is given by [Formula \(E.1\)](#)

$$\bar{l}^i = \sqrt{l_{\min}^i \times l_{\max}^i} \quad (\text{E.1})$$

The geometric class width for type A, B, and C inclusions is given by [Formula \(E.2\)](#)

$$\bar{w}^c = \sqrt{w_{\min}^c \times w_{\max}^c} \quad (\text{E.2})$$

The geometric index area for type A, B, and C inclusions is given by [Formula \(E.3\)](#).

$$\bar{A}_{ABC}^{i,c} = \frac{\pi}{4} (\bar{w}^c \times \bar{l}^i) \quad (\text{E.3})$$

### E.2.2.3 Type D

The geometric index number for type D inclusion is given by [Formula \(E.4\)](#).

$$\bar{n}^i = \sqrt{n_{\min}^i \times (n_{\min}^{i+0,5} - 1)} \quad (\text{E.4})$$

NOTE Since the number of inclusions is in whole integers, the upper count of each index is one less than the minimum count for the next index. “ $n_{\min}^{i+0,5} - 1$ ” therefore is 3, 8, 15, 24, and so on, for indices 0,5; 1,0; 1,5; 2,0, etc., respectively.

The geometric class diameter for type D is given by [Formula \(E.5\)](#).

$$\bar{d}^c = \sqrt{d_{\min}^c \times d_{\max}^c} \quad (\text{E.5})$$

The geometric index area for type D is given by [Formula \(E.6\)](#).

$$\bar{A}_D^i = \frac{\pi (\bar{d}^c)^2}{4} \times \bar{n}^i \quad (\text{E.6})$$

#### E.2.2.4 Type DS

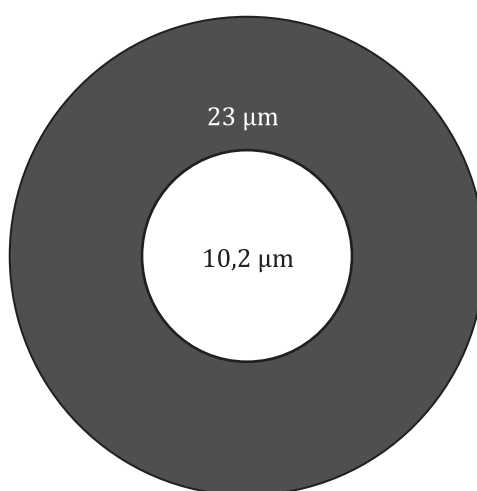
The geometric index diameter for type DS is given by [Formula \(E.7\)](#).

$$\bar{d}^i = \sqrt{d_{\min}^i \times d_{\max}^i} \quad (\text{E.7})$$

The geometric index area for type DS is given by [Formula \(E.8\)](#).

$$\bar{A}_{DS}^i = \frac{\pi (d^i)^2}{4} \quad (\text{E.8})$$

Since DS is included in the D thick count, the excess DS area shall be calculated. The excess DS area is the difference between the index geometric DS area and the area of a nominal D thick inclusion, see [Table E.4](#), and [Figure E.1](#).



NOTE The nominal area of a D thick (10,2 μm diameter) is subtracted from a DS, i=1,0, with the nominal diameter of 23 μm.

**Figure E.1 — Excess area of a DS inclusion illustrated by the annulus**

The general DS formula becomes:

$$\bar{A}_{DS}^{\text{excess}} = \sum \left[ \bar{A}_{DS}^i - \frac{\bar{A}_{D \text{ thick}}^i}{\bar{n}^i} \right] = \sum \left[ \frac{\pi (\bar{d}_{DS}^i)^2}{4} - \frac{\pi (\bar{d}_{D \text{ thick}}^i)^2}{4} \right] = \frac{\pi}{4} \sum \left[ (\bar{d}_{DS}^i)^2 - 10,2^2 \right] \quad (\text{E.9})$$

Formula (E.9) is used for all DS instances in the analysis.

## E.2.3 Tabled values

### E.2.3.1 General

In Table E.2, the minimum, maximum and geometric average of the indexable metrics—length, number, and diameter—are presented.

**Table E.2 — Inclusion minimum, maximum and geometric average length [μm] (A, B, C), number (D) and diameter [μm] (DS)**

| Index<br><i>i</i> | Length [μm] |       |           |       |       |           |       |       |           | Number |     |           | Diameter [μm] |     |           |
|-------------------|-------------|-------|-----------|-------|-------|-----------|-------|-------|-----------|--------|-----|-----------|---------------|-----|-----------|
|                   | A           |       |           | B     |       |           | C     |       |           | D      |     |           | DS            |     |           |
|                   | Min         | Max   | Geo. Ave. | Min   | Max   | Geo. Ave. | Min   | Max   | Geo. Ave. | Min    | Max | Geo. Ave. | Min           | Max | Geo. Ave. |
| 0,5               | 37          | 127   | 69        | 17    | 77    | 36        | 18    | 76    | 37        | 1      | 3   | 1,7       | 13            | 19  | 15,7      |
| 1                 | 127         | 261   | 182       | 77    | 184   | 119       | 76    | 176   | 116       | 4      | 8   | 5,7       | 19            | 27  | 22,6      |
| 1,5               | 261         | 436   | 337       | 184   | 343   | 251       | 176   | 320   | 237       | 9      | 15  | 11,6      | 27            | 38  | 32,0      |
| 2                 | 436         | 649   | 532       | 343   | 555   | 436       | 320   | 510   | 404       | 16     | 24  | 19,6      | 38            | 53  | 44,9      |
| 2,5               | 649         | 898   | 763       | 555   | 822   | 675       | 510   | 746   | 617       | 25     | 35  | 29,6      | 53            | 76  | 63        |
| 3                 | 898         | 1 181 | 1 030     | 822   | 1 147 | 971       | 746   | 1 029 | 876       | 36     | 48  | 41,6      | 76            | 107 | 90        |
| 3,5               | 1 181       | 1 498 | 1 330     | 1 147 | 1 530 | 1 325     | 1 029 | 1 359 | 1 183     | 49     | 63  | 55,6      | 107           | 151 | 128       |
| 4                 | 1 498       | 1 848 | 1 664     | 1 530 | 1 973 | 1 737     | 1 359 | 1 737 | 1 536     | 64     | 80  | 71,6      | 151           | 214 | 181       |
| 4,5               | 1 848       | 2 230 | 2 030     | 1 973 | 2 476 | 2 210     | 1 737 | 2 163 | 1 938     | 81     | 99  | 89,5      | 214           | 303 | 256       |
| 5                 | 2 230       | 2 643 | 2 428     | 2 476 | 3 039 | 2 743     | 2 163 | 2 640 | 2 390     | 100    | 120 | 110       | 303           | 430 | 361       |
| ⋮                 | ⋮           | ⋮     | ⋮         | ⋮     | ⋮     | ⋮         | ⋮     | ⋮     | ⋮         | ⋮      | ⋮   | ⋮         | ⋮             | ⋮   | ⋮         |

In Table E.3, the minimum, maximum and geometric average widths (A, B, C) and diameters (D), for each class (fine, thick) are presented.

**Table E.3 — Geometric averages calculated from max and min width and diameter limits**

| Type | Fine |     |           | Thick |     |           |
|------|------|-----|-----------|-------|-----|-----------|
|      | Min  | Max | Geo. Ave. | Min   | Max | Geo. Ave. |
| A    | 2    | 4   | 2,8       | 4     | 12  | 6,9       |
| B    | 2    | 9   | 4,2       | 9     | 15  | 11,6      |
| C    | 2    | 5   | 3,2       | 5     | 12  | 7,7       |
| D    | 2    | 8   | 4,0       | 8     | 13  | 10,2      |

In accordance with Formulae (E.3), (E.6), (E.8), and (E.9), the geometric and excess (DS) areas now can be calculated, see Table E.4.

Table E.4 — Index area per type and class in  $\mu\text{m}^2$

| Index, $i$ | A     |        | B     |        | C     |        | D     |       | DS      |         |
|------------|-------|--------|-------|--------|-------|--------|-------|-------|---------|---------|
|            | Fine  | Thick  | Fine  | Thick  | Fine  | Thick  | Fine  | Thick | Nominal | Excess  |
| 0,5        | 151   | 371    | 119   | 330    | 93    | 224    | 22    | 142   | 194     | 112     |
| 1          | 400   | 987    | 393   | 1 084  | 291   | 699    | 71    | 462   | 403     | 321     |
| 1,5        | 742   | 1 828  | 829   | 2 289  | 596   | 1 435  | 146   | 949   | 806     | 724     |
| 2          | 1 170 | 2 883  | 1 439 | 3 975  | 1 015 | 2 443  | 246   | 1 601 | 1 582   | 1 500   |
| 2,5        | 1 679 | 4 137  | 2 228 | 6 154  | 1 550 | 3 730  | 372   | 2 416 | 3 164   | 3 082   |
| 3          | 2 265 | 5 581  | 3 203 | 8 846  | 2 202 | 5 299  | 522   | 3 395 | 6 387   | 6 305   |
| 3,5        | 2 925 | 7 208  | 4 370 | 12 069 | 2 972 | 7 152  | 698   | 4 540 | 12 690  | 12 608  |
| 4          | 3 659 | 9 017  | 5 731 | 15 829 | 3 884 | 9 345  | 899   | 5 847 | 25 379  | 25 298  |
| 4,5        | 4 464 | 11 001 | 7 291 | 20 137 | 4 900 | 11 789 | 1 125 | 7 317 | 50 927  | 50 845  |
| 5          | 5 340 | 13 158 | 9 046 | 24 984 | 6 008 | 14 456 | 1 376 | 8 950 | 102 445 | 102 363 |
| ⋮          | ⋮     | ⋮      | ⋮     | ⋮      | ⋮     | ⋮      | ⋮     | ⋮     | ⋮       | ⋮       |

### E.2.3.2 Treatment of oversized A, B, C, inclusions

For the case that an oversized inclusion,  $l \times w$ , is encountered, its contribution to the length is accounted for in the thick index. The oversized *width* however makes it necessary to calculate the excess area the oversized inclusion adds to the analysis.

The excess area is defined as the ascribed elliptical area of the oversized inclusion minus the elliptical area of a nominally thick inclusion of the same length, of the specific inclusion type, illustrated in [Figure E.2](#). The calculation of the excess area is given in [Formula \(E.10\)](#).

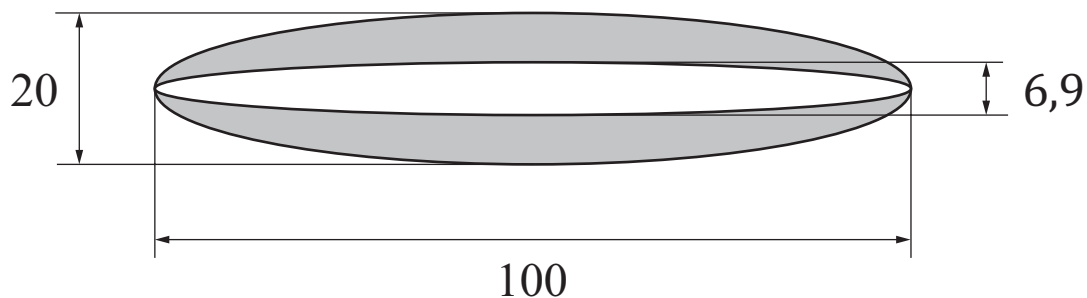


Figure E.2 — Difference (grey) in area between an oversized inclusion ( $100 \mu\text{m} \times 20 \mu\text{m}$ ) and a thick inclusion ( $100 \mu\text{m} \times 6,9 \mu\text{m}$ )

$$A_{A+}^{\text{excess}} = A_{A+} - A_{A \text{ thick}} = \frac{\pi}{4} (l_{A+} \cdot w_{A+}) - \frac{\pi}{4} (l_{A+} \cdot w_{A \text{ thick}}) \quad (\text{E.10})$$

The excess area is added to the area for type, and consequently the total inclusion area.

NOTE It is not necessary to know the exact field where the oversized or DS inclusion was recorded to perform the excess area calculations.

## E.2.4 Total analysis example

### E.2.4.1 General

The field count [Table E.5](#) represents the result from a method B assessment. The total surveyed sample area in the analysis is  $200 \text{ mm}^2$  ( $400 \text{ fields} \times 0,5 \text{ mm}^2$ ). For this example, it is assumed that every DS index represents one individual inclusion per count, meaning that in this case two or more DS inclusions were never encountered within the same field.

**Table E.5 — Number of fields per index, type, and class (Method B assessment)**

| Index | A    |       | B    |       | C    |       | D    |       | DS |
|-------|------|-------|------|-------|------|-------|------|-------|----|
|       | Fine | Thick | Fine | Thick | Fine | Thick | Fine | Thick |    |
| 0,5   | 95   | 23    | 17   | 5     | 13   | 7     | 63   | 33    | 31 |
| 1     | 48   | 7     | 7    | 2     | 4    | 1     | 52   | 7     | 12 |
| 1,5   | 5    |       | 2    |       | 3    | 1     | 11   | 5     | 3  |
| 2     | 1    | 1     |      |       |      |       | 2    |       | 1  |
| 2,5   | 1    |       |      |       |      |       |      |       |    |
| 3     |      |       |      |       |      |       |      |       |    |

To create a more comprehensive example, it is also assumed that the oversized type A inclusion, 100×20 µm, used in the example in [Figure E.2](#), also was encountered during the assessment. It is thereby already included by length in one of the field indices, but will add to the area due to its oversized width.

For A thick, the nominal width,  $w_n$ , is 6,9 µm (see [Table E.3](#)). The excess area then becomes:

$$A^{\text{excess}} \approx \frac{\pi}{4} (100 \cdot 20) - \frac{\pi}{4} (100 \cdot 6,9) \approx 1\,029 \mu\text{m}^2$$

This is the difference illustrated in [Figure E.2](#). Using the index area, [table E.4](#), the inclusion area of the analysis can be calculated, per, class, type, apparent chemistry (oxide/sulfide) and as a total ([Table E.6](#)).

**Table E.6 — Inclusion area per class, type, apparent chemistry, and as a total [µm²]**

| Index                                                                                      | Sulfide |        | Oxide  |       |       |       |        |        |         |                     |
|--------------------------------------------------------------------------------------------|---------|--------|--------|-------|-------|-------|--------|--------|---------|---------------------|
|                                                                                            | A       |        | B      |       | C     |       | D      |        | DS      |                     |
|                                                                                            | Fine    | Thick  | Fine   | Thick | Fine  | Thick | Fine   | Thick  | Nominal | Excess <sup>a</sup> |
| 0,5                                                                                        | 14 321  | 8 544  | 2 029  | 1 648 | 1 208 | 1 566 | 1 371  | 4 671  | 6 014   | 3 481               |
| 1                                                                                          | 19 218  | 6 907  | 2 748  | 2 169 | 1 163 | 699   | 3 696  | 3 236  | 4 835   | 3 854               |
| 1,5                                                                                        | 3 709   |        | 1 657  |       | 1 789 | 1 435 | 1 606  | 4 747  | 2 417   | 2 172               |
| 2                                                                                          | 1 170   | 2 883  |        |       |       |       | 492    |        | 1 582   | 1 500               |
| 2,5                                                                                        | 1 679   |        |        |       |       |       |        |        |         |                     |
| 3                                                                                          |         |        |        |       |       |       |        |        |         |                     |
| Area per group                                                                             | 40 097  | 18 333 | 6 435  | 3 817 | 4 160 | 3 700 | 7 166  | 12 653 | 14 848  |                     |
| Excess area                                                                                | 1 029   |        |        |       |       |       |        |        | 11 007  |                     |
| Area per type                                                                              | 59 459  |        | 10 252 |       | 7 861 |       | 19 820 |        | 11 007  |                     |
|                                                                                            |         |        |        |       |       |       | 30 827 |        |         |                     |
| Area per chem.                                                                             | 59 459  |        | 48 940 |       |       |       |        |        |         |                     |
| Total inclusion area                                                                       | 108 399 |        |        |       |       |       |        |        |         |                     |
| a The difference between the nominal D thick inclusion area and the nominal DS index area. |         |        |        |       |       |       |        |        |         |                     |

<sup>a</sup> The difference between the nominal D thick inclusion area and the nominal DS index area.

#### E.2.4.2 Calculating area fractions

The inclusion content can now be expressed as area fractions,  $f$ . The total surveyed area,  $A_s$ , is 200 mm² (200×10⁶ µm²).

The area fraction of all inclusions is calculated by [Formula \(E.11\)](#)

$$f_{\text{tot}} = \frac{A_{\text{tot}}}{A_s} \quad (\text{E.11})$$

$$f_{\text{tot}} \approx \frac{108\,399}{200 \cdot 10^6} \approx 0,000\,54 \approx 0,054 \%$$

The area fraction of all “oxidic” (B+C+D+DS) inclusions is calculated by [Formula \(E.12\)](#)

$$f_{\text{ox}} = \frac{A_{\text{ox}}}{A_s} \quad (\text{E.12})$$

$$f_{\text{ox}} \approx \frac{48\,940}{200 \cdot 10^6} \approx 0,000\,24 \approx 0,024 \%$$

The area fraction of globular (D+DS) inclusions is calculated by [Formula \(E.13\)](#)

$$f_{\text{glob}} = \frac{A_{\text{glob}}}{A_s} \quad (\text{E.13})$$

$$f_{\text{glob}} \approx \frac{30\,827}{200 \cdot 10^6} \approx 0,000\,15 \approx 0,015 \%$$

And so on.

#### E.2.4.3 Calculating relative fractions

Sometimes the ratio,  $R$ , between types, between classes, between sulfides and oxides, etc., is of interest. For example, the ratio between types B and C is calculated by [Formula \(E.14\)](#)

$$R_{\text{B:C}} = \frac{A_{\text{B}}}{A_{\text{C}}} \quad (\text{E.14})$$

$$R_{\text{B:C}} \approx \frac{10\,252}{7\,861} \approx 1,30$$

The ratio between classes fine and thick, including oversized, for type A is calculated by [Formula \(E.15\)](#)

$$R_{\text{f:t}}^{\text{A}} = \frac{A_{\text{A fine}}}{A_{\text{A thick}}} \quad (\text{E.15})$$

$$R_{\text{f:t}}^{\text{A}} \approx \frac{40\,097}{18\,333 + 1\,029} \approx 2,07$$

The ratio between globular and non-globular oxides is calculated by [Formula \(E.16\)](#)

$$R_{\text{G:nG}}^{\text{oxide}} = \frac{A_{\text{D+DS}}}{A_{\text{B+C}}} \quad (\text{E.16})$$

$$R_{\text{G:nG}}^{\text{oxide}} \approx \frac{30\,827}{10\,252 + 7\,861} \approx 1,70$$

And so on.

## E.2.5 Calculating the number density of inclusions and the inclusion interdistance

### E.2.5.1 Type D

The density of type D inclusions expressed as number per unit area can be determined directly from the nominal number of inclusions per index and the number of index instances.

For type D, each index represents a geometric average number of inclusions (see [Table E.2](#)), which for D thick also includes all DS inclusions. The total number of inclusions is defined as the sum of all number of indices multiplied with the geometric average number of inclusions for each index.

Using the data from [Tables E.2](#) and [E.5](#) for type D, [Tables E.7](#) and [E.8](#) are achieved.

**Table E.7 — Minimum, maximum and geometric average number of type D inclusions per index**

| Index        | 0,5 | 1,0 | 1,5  | 2,0  | 2,5  | 3,0  |
|--------------|-----|-----|------|------|------|------|
| Min          | 1   | 4   | 9    | 16   | 25   | 36   |
| Max          | 3   | 8   | 15   | 24   | 35   | 48   |
| Geo. average | 1,7 | 5,7 | 11,6 | 19,6 | 29,6 | 41,6 |

**Table E.8 — Type D index count**

| Index          | 0,5   | 1,0   | 1,5  | 2,0  | 2,5 | 3,0 |
|----------------|-------|-------|------|------|-----|-----|
| D fine         | 63    | 52    | 11   | 2    |     |     |
| D thick        | 33    | 7     | 5    |      |     |     |
| D total        | 96    | 59    | 16   | 2    |     |     |
| Per index      | 163,2 | 336,3 | 27,6 | 39,2 |     |     |
| Sum total, $n$ | 724,3 |       |      |      |     |     |

The number frequency for type D can be calculated by [Formula \(E.17\)](#)

$$f_{\text{number}}^D = \frac{n}{A_s} \quad (\text{E.17})$$

For type D the number frequency becomes

$$f_{\text{number}}^D = \frac{724,3}{200} \approx \frac{3,62}{\text{mm}^2}$$

The inclusion interdistance is defined as the average distance between inclusions on the premise that they are evenly distributed across the surveyed area. The inclusion interdistance can be calculated by [Formula \(E.18\)](#).

$$x = \sqrt{\frac{1}{f_{\text{number}}}} = \sqrt{\frac{A_s}{n}} \quad (\text{E.18})$$

For type D the inclusion interdistance becomes

$$x = \sqrt{\frac{200}{724,3}} \approx 0,525 \text{ mm} \approx 525 \text{ } \mu\text{m}$$

In theory it is possible to compensate for the inclusion area by subtraction from the surveyed area. Thus the inclusion interdistance for type D can also be calculated by [Formula \(E.19\)](#).

$$x = \sqrt{\frac{A_s - A_{D+DS}}{n}} \quad (\text{E.19})$$

For type D the inclusion interdistance becomes

$$x = \sqrt{\frac{200 \cdot 10^6 - 30\,827}{724,3}} \approx 525 \, \mu\text{m}$$

However, given the substantial difference in magnitude between the areas, even if all inclusions are accounted for, this compensation is irrelevant for clean steel.

### E.2.5.2 Types A, B, C

Individual lengths and thereby the number of elongated inclusions is usually not recorded in a method B analysis. Therefore, some predictions and assumptions must be made.

For free cutting steel, where sulfides are intentional, an increase in field index is related to an increase in number of inclusions rather than an increase in individual inclusion lengths. Assuming the average inclusion length stays roughly the same, an increase in number therefore can be hypothesized.

One approach is that each index step corresponds to a doubling of the number of inclusions, where  $i=0,5$  represents one inclusion,  $i=1,0$  represents two,  $i=1,5$  is four, and so on.

**Table E.9 — Type A index count**

| Index                | 0,5 | 1   | 1,5 | 2  | 2,5 | 3  |
|----------------------|-----|-----|-----|----|-----|----|
| Inclusions per index | 1   | 2   | 4   | 8  | 16  | 32 |
| A fine               | 95  | 48  | 5   | 1  | 1   |    |
| A thick              | 23  | 7   |     | 1  |     |    |
| A total              | 118 | 55  | 5   | 2  | 1   |    |
| Per index            | 118 | 110 | 20  | 16 | 16  |    |
| Sum total, $n$       | 280 |     |     |    |     |    |

Again, the number frequency for type A becomes, adapting [Formula \(E.17\)](#):

$$f_{\text{number}}^A = \frac{280}{200} = \frac{1,4}{\text{mm}^2}$$

The subsequent inclusion interdistance for type A becomes, adapting [Formula \(E.18\)](#):

$$x = \sqrt{\frac{200}{280}} \approx 0,845 \, \text{mm} = 845 \, \mu\text{m}$$

A similar approach can be used for types B and C. In this case however, it is recommended to investigate the relationship between number and length further.

If a relationship can be established empirically, it gives the user the option to use custom formulas to fit the average lengths to the specific sample.

For cases where the number of any elongated inclusions is very small, for instance in hot rolled Calcium-treated steel, they can be disregarded from the total count, allowing the type D count to be a reasonable average for all inclusions.

Another option to calculate the inclusion density is presented by most fully automated systems, SEM or LOM, in raw data form.

When all features have been recorded and after the preparation artifacts have been removed, but before going through sorting, thus ignoring type and chemistry, the total number of separate particle instances can be used to calculate an inclusion density and interdistance. This will however treat the particles of all stringers as several separate, evenly dispersed individual inclusions.

## E.2.6 Normalized inclusion area as basis for a weighted, global severity rating

In essence, [Table E.4](#) also represents a relative severity between types and classes, for any given index. Using D fine 0,5 as reference with the relative area 1 (arbitrary unit), the relative area (dimensionless) per type, class and index is presented in [Table E.10](#).

**Table E.10 — Relative index area per type, class, and index**

| Index | A     |       | B     |         | C     |       | D    |       | DS excess |
|-------|-------|-------|-------|---------|-------|-------|------|-------|-----------|
|       | fine  | thick | fine  | thick   | fine  | thick | fine | Thick |           |
| 0,5   | 6,9   | 17,1  | 5,5   | 15,1    | 4,3   | 10,3  | 1    | 6,5   | 5,2       |
| 1,0   | 18,4  | 45,3  | 18,0  | 49,8    | 13,4  | 32,1  | 3,3  | 21,2  | 14,5      |
| 1,5   | 34,1  | 84,0  | 38,1  | 105,2   | 27,4  | 65,9  | 6,7  | 43,6  | 33,3      |
| 2,0   | 53,7  | 132,4 | 66,1  | 182,6   | 46,6  | 112,2 | 11,3 | 73,6  | 68,9      |
| 2,5   | 77,1  | 190,1 | 102,4 | 282,7   | 71,2  | 171,4 | 17,1 | 111,1 | 141,6     |
| 3,0   | 104,0 | 256,4 | 147,2 | 406,4   | 101,2 | 243,4 | 24,0 | 156,1 | 289,7     |
| 3,5   | 134,4 | 331,2 | 200,8 | 554,5   | 136,5 | 328,6 | 32,1 | 208,6 | 579,4     |
| 4,0   | 168,1 | 414,3 | 263,3 | 727,3   | 177,4 | 426,9 | 41,3 | 268,6 | 1 162,5   |
| 4,5   | 205,1 | 505,4 | 335,0 | 925,2   | 223,8 | 538,6 | 51,7 | 336,2 | 2 336,4   |
| 5,0   | 245,3 | 604,5 | 415,8 | 1 148,3 | 275,9 | 664,0 | 63,2 | 411,3 | 4 698,4   |

[Table E.10](#) can then be used to calculate global indices per type, class, chemistry, and as a total.

The general formula for the global index is given in [Formula \(E.20\)](#). Except for  $A_s$ , areas in [Formula \(E.20\)](#) are relative index areas from [Table E.10](#).

$$C_i = \frac{1}{A_s} \left( \sum_{i=0,5} \left[ \sum_{\text{Type}} \left[ \sum_{\text{Class}}^{\text{fine/thick}} \left[ i \cdot n_i \cdot A_i^{\text{Group}} \right] \right] \right] + \sum_{i_{\text{DS}}=0,5} \left[ i \cdot n_i \cdot A_i^{\text{excess}} \right] \right) \quad (\text{E.20})$$

For the example in [E.2.4.1](#) and in [Table E.5](#), the global inclusion index for type A becomes

$$C_i^A = \frac{1}{A_s} \sum_{i=0,5}^{3,0} \left[ \sum_A^{\text{fine/thick}} \left[ i \cdot n_i \cdot A_i^{\text{Group}} \right] \right]$$

$$\approx \frac{1}{200} \left\{ \begin{array}{l} \left[ 0,5 \cdot (95 \cdot 6,9 + 23 \cdot 17,1) \right] + \\ \left[ 1,0 \cdot (48 \cdot 18,4 + 7 \cdot 45,3) \right] + \\ \left[ 1,5 \cdot (5 \cdot 34,1) \right] + \\ \left[ 2,0 \cdot (1 \cdot 53,7 + 1 \cdot 132,4) \right] + \\ \left[ 2,5 \cdot (1 \cdot 77,1) \right] \end{array} \right\} \approx 16,98$$

For type B:

$$C_i^B = \frac{1}{A_s} \sum_{i=0,5}^{3,0} \left[ \sum_B^{\text{fine/thick}} \left[ i \cdot n_i \cdot A_i^{\text{Group}} \right] \right]$$

$$\approx \frac{1}{200} \left\{ \begin{array}{l} [0,5 \cdot (17 \cdot 5,5 + 5 \cdot 15,1)] + \\ [1,0 \cdot (7 \cdot 18 + 1 \cdot 49,8)] + \\ [1,5 \cdot (2 \cdot 38,1)] \end{array} \right\} \approx 2,83$$

For type C:

$$C_i^C = \frac{1}{A_s} \sum_{i=0,5}^{3,0} \left[ \sum_C^{\text{fine/thick}} [i \cdot n_i \cdot A_i^{\text{Group}}] \right]$$

$$\approx \frac{1}{200} \left\{ \begin{array}{l} [0,5 \cdot (13 \cdot 4,3 + 7 \cdot 10,3)] + \\ [1,0 \cdot (4 \cdot 13,4 + 1 \cdot 32,1)] + \\ [1,5 \cdot (3 \cdot 27,4 + 1 \cdot 65,9)] \end{array} \right\} \approx 2,48$$

For type D:

$$C_i^D = \frac{1}{A_s} \sum_{i=0,5}^{3,0} \left[ \sum_D^{\text{fine/thick}} [i \cdot n_i \cdot A_i^{\text{Group}}] \right]$$

$$\approx \frac{1}{200} \left\{ \begin{array}{l} [0,5 \cdot (63 \cdot 1 + 33 \cdot 6,5)] + \\ [1,0 \cdot (52 \cdot 3,3 + 7 \cdot 21,2)] + \\ [1,5 \cdot (11 \cdot 6,7 + 5 \cdot 43,6)] + \\ [2,0 \cdot (2 \cdot 11,3)] \end{array} \right\} \approx 6,27$$

For type DS:

$$C_i^{DS} = \frac{1}{A_s} \sum_{i=0,5}^{3,0} \left[ \sum_{DS}^{\text{fine/thick}} [i \cdot n_i \cdot A_i^{\text{excess}}] \right]$$

$$\approx \frac{1}{200} \left\{ \begin{array}{l} [0,5 \cdot (31 \cdot 5,2)] + \\ [1,0 \cdot (12 \cdot 14,8)] + \\ [1,5 \cdot (3 \cdot 33,3)] + \\ [2,0 \cdot (1 \cdot 68,9)] \end{array} \right\} \approx 3,63$$

For the oversized inclusion, the contribution to the global index, in this case type A, is calculated by [Formula \(E.21\)](#).

$$C_i^{A+} = \frac{1}{A_s} \cdot \frac{1}{A_{i=0,5}^{D \text{ fine}}} \cdot \frac{\pi}{4} [l \cdot (w - w_{A \text{ thick}})] \quad (\text{E.21})$$

NOTE The nominal area for D fine, i=0,5 is the reference for all types and classes.

$$C_i^{A+} = \frac{1}{200} \cdot \frac{1}{22} \cdot \frac{\pi}{4} [100 \cdot (20 - 6,9)] \approx 0,31$$

The total global inclusion index for the analysis,  $C_i^{\text{tot}}$ , is calculated by [Formula \(E.22\)](#).

$$C_i^{\text{tot}} = C_i^A + C_i^{A+} + C_i^B + C_i^C + C_i^D + C_i^{DS} \quad (\text{E.22})$$

$$C_i^{\text{tot}} \approx 16,98 + 0,31 + 2,83 + 2,48 + 6,27 + 3,63 \approx 32,18$$

NOTE The unit for  $C_i$  technically is /mm<sup>2</sup>, but it should not be misinterpreted as number per unit area.

The relationship between global indices for types can be used to e.g., track the success of a calcium treatment, by comparing the combined indices for B and C with the indices for D and DS.

$$\frac{C_i^D + C_i^{DS}}{C_i^B + C_i^C} = \frac{6,27 + 3,63}{2,83 + 2,48} = 1,86$$

Unlike the relative area fraction,  $R$ , in [E.2.4.2](#), the global indices are weighted by field index: This means that if a certain inclusion area is clustered to a few high index fields rather than distributed between several fields of lower indices, the global index will be higher in the first instance.

### E.3 Tabulation and legacy computation example for method B

[Table E.11](#) shows a tabulation identical to [Table E.5](#) and the resulting legacy global index computation examples for one specimen with  $N = 400$  observed fields. For types A, B, C, and D the field ratings are tallied, while for the subgroup DS the individual inclusion ratings are tallied. Because not all fields are rated with an index  $> 0$ , the total number of ratings per type A, B, C, and D is  $\leq N$ . For DS, the total number of rated inclusions bears no relation to  $N$  and can exceed  $N$ . This legacy approach treats inclusions of different average sizes equally, e. g. a D fine inclusion is weighted no differently from a C thick inclusion.

**Table E.11 — Total number of fields (A, B, C, and D) and inclusions (DS)  $n_i$**

| Number of rated fields<br>$N$ | Inclusion group |       |      |       |      |       |      |       |      | Specimen area $S$   |       |
|-------------------------------|-----------------|-------|------|-------|------|-------|------|-------|------|---------------------|-------|
| 400                           | A               |       | B    |       | C    |       | D    |       | DS   | 200 mm <sup>2</sup> |       |
| Index                         | fine            | thick | fine | thick | fine | thick | fine | thick |      | Sum                 | $F_i$ |
| 0,5                           | 95              | 23    | 17   | 5     | 13   | 7     | 63   | 33    | 31   | 287                 | 0,05  |
| 1                             | 48              | 7     | 7    | 2     | 4    | 1     | 52   | 7     | 12   | 140                 | 0,1   |
| 1,5                           | 5               | 0     | 2    | 0     | 3    | 1     | 11   | 5     | 3    | 30                  | 0,2   |
| 2                             | 1               | 1     | 0    | 0     | 0    | 0     | 2    | 0     | 1    | 5                   | 0,5   |
| 2,5                           | 1               | 0     | 0    | 0     | 0    | 0     | 0    | 0     | 0    | 1                   | 1     |
| 3                             | 0               | 0     | 0    | 0     | 0    | 0     | 0    | 0     | 0    | 0                   | 2     |
| $i_{\text{tot}}$              | 107,5           | 20,5  | 18,5 | 4,5   | 15   | 6     | 104  | 31    | 34   | $C_t$               | 189,3 |
| $i_{\text{moy}}$              | 0,27            | 0,05  | 0,05 | 0,01  | 0,04 | 0,02  | 0,26 | 0,08  | 0,09 |                     |       |

Inclusions having a length greater than the dimension of the field, or a width or a diameter greater than indicated in [Table 3](#) shall be rated using the standard diagrams and reported separately in the test report. The [Table E.2](#) shall be expanded for larger indices if fields or inclusions are rated with an index greater than 3. Multiple specimens can be tallied in the same table or separated for traceability.

The indices reported above are calculated as follows. For each group,  $i_{tot}$  is the sum of the products of  $i$  and  $n_i$  as shown in [Formula \(E.23\)](#).

$$i_{tot} = \sum_{i=0} i \times n_i \quad (E.23)$$

To illustrate, for  $A_{fine}$ :

$$i_{tot} = 95 \times 0,5 + 48 \times 1 + 5 \times 1,5 + 1 \times 2 + 1 \times 2,5 = 107,5$$

The index  $i_{moy}$  is  $i_{tot}$  divided by the number of rated fields  $N$ , as shown in [Formula \(E.24\)](#).

$$i_{moy} = \frac{i_{tot}}{N} \quad (E.24)$$

To illustrate, for  $A_{fine}$ :

$$i_{moy} = \frac{107,5}{400} \approx 0,27$$

The cleanness index  $C_t$  is calculated by [Formula \(E.25\)](#) using weighting factors  $F_i$  as shown in [Table E.11](#). Similarly to  $i_{tot}$ , it is calculated as the sum of the products of  $F_i$  and  $n_{i,tot}$ , where  $n_{i,tot}$  is the total number of fields with the index  $i$  across all groups, and then normalized to an observed area of 1 000 mm<sup>2</sup>:

$$C_t = \left( \sum_{i=0} n_{i,tot} \times F_i \right) \times \frac{1\,000}{S} \quad (E.25)$$

$$C_t = (287 \times 0,05 + 140 \times 0,1 + 30 \times 0,2 + 5 \times 0,5 + 1 \times 1) \times 1\,000/200 \cong 189,3$$

By analogy, cleanness indices can be calculated for each group separately.

## Annex F (informative)

### Relationship between indices and inclusion measurements

#### F.1 General

The relationships between the chart diagram indices and the inclusion measurements (length or diameter in  $\mu\text{m}$ , or number per field) for inclusion types A, B, C, D and subgroup DS are shown on the following graphs. The following equations can be used to calculate either the index from the measurement, or the inclusion measurement from the index, for example, if there is a need to work to chart picture numbers above 3.

#### F.2 Calculation of indices from inclusion measurements

For type A sulfides, length in  $\mu\text{m}$  ( $l$ ):

$$i = 0,065\ 8 \times l^{0,561\ 7} \quad (\text{F.1})$$

For type B aluminates, length in  $\mu\text{m}$  ( $l$ ):

$$i = 0,133\ 8 \times l^{0,463\ 3} \quad (\text{F.2})$$

For type C silicates, length in  $\mu\text{m}$  ( $l$ ):

$$i = 0,125\ 5 \times l^{0,479\ 8} \quad (\text{F.3})$$

For type D globular oxide type, number per field ( $n$ ):

$$i = \frac{\sqrt{n}}{2} \quad (\text{F.4})$$

For subgroup DS single globular oxide, diameter in  $\mu\text{m}$  ( $D$ ):

$$i = \log_2 D - 3,248 \quad (\text{F.5})$$

#### F.3 Calculation of the inclusion measurement from an index

For type A sulfides, length in  $\mu\text{m}$  ( $l$ ):

$$l = 126,999 \times i^{1,780\ 2} \quad (\text{F.6})$$

For type B aluminates, length in  $\mu\text{m}$  ( $l$ ):

$$l = 76,775 \times i^{2,158\ 3}$$

(F.7)

For type C silicates, length in µm (*l*):

$$l = 75,596 \times i^{2,084\ 0}$$

(F.8)

For type D globular oxides, number per field (*n*):

$$n = 4 \times i^2$$

(F.9)

For subgroup DS single globular oxide, diameter in µm (*D*):

$$D = 9,455 \times 2^i$$

(F.10)

For the above linear regression equations, the *R*<sup>2</sup> values are all above 0,999 9.

See [Figures F.1](#) to [F.5](#) for a visualisation of the above equations.

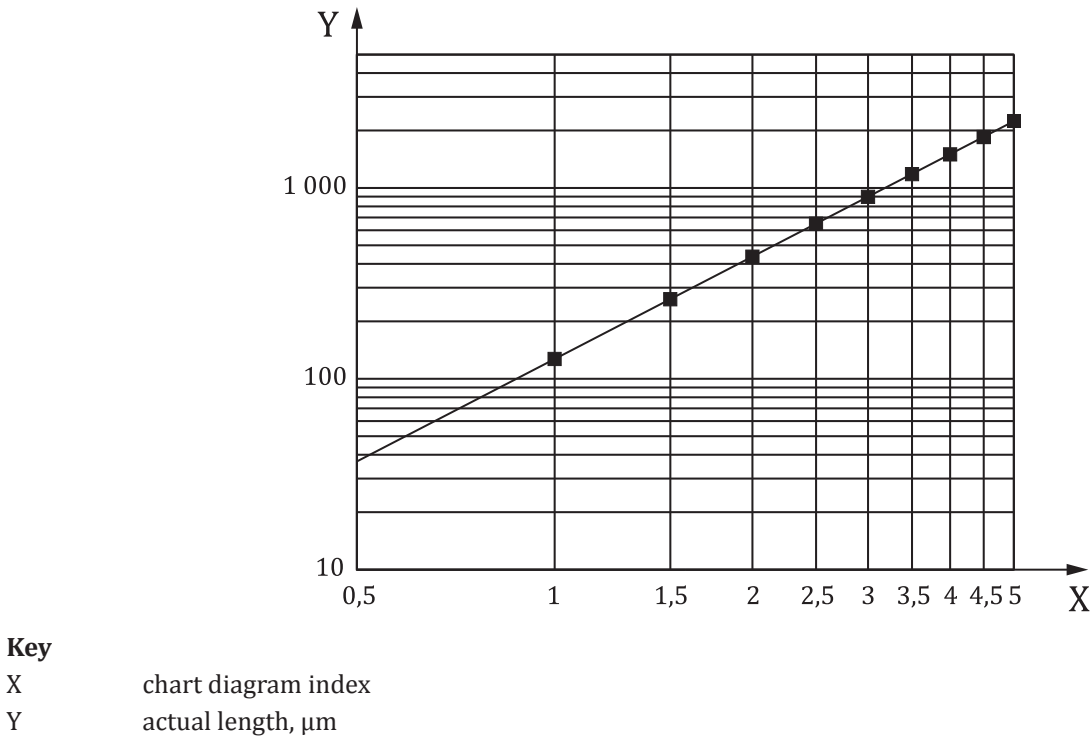
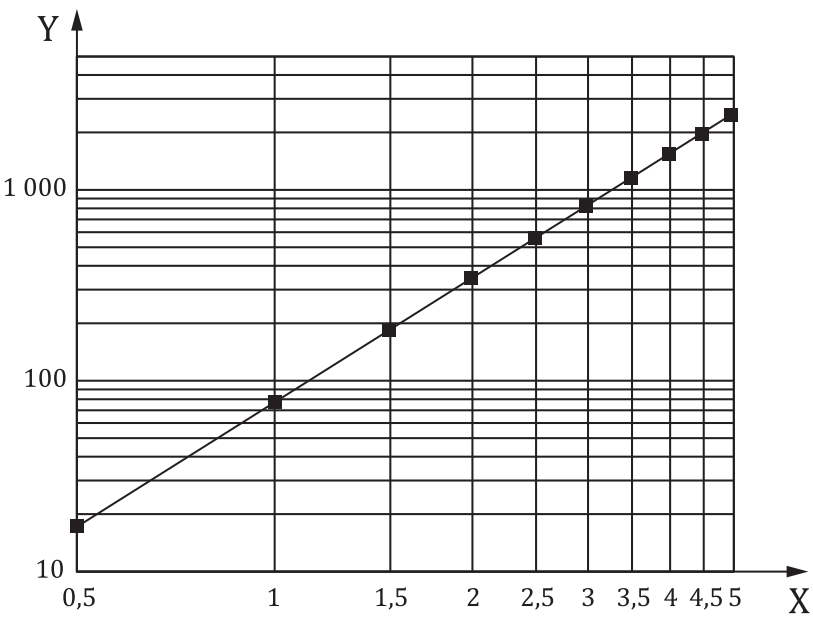
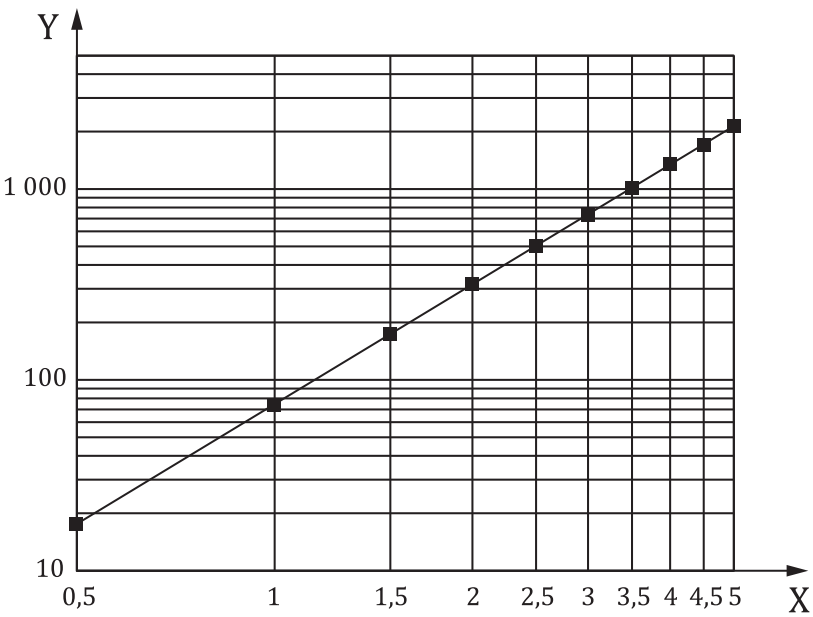


Figure F.1 — Type A: sulfide type



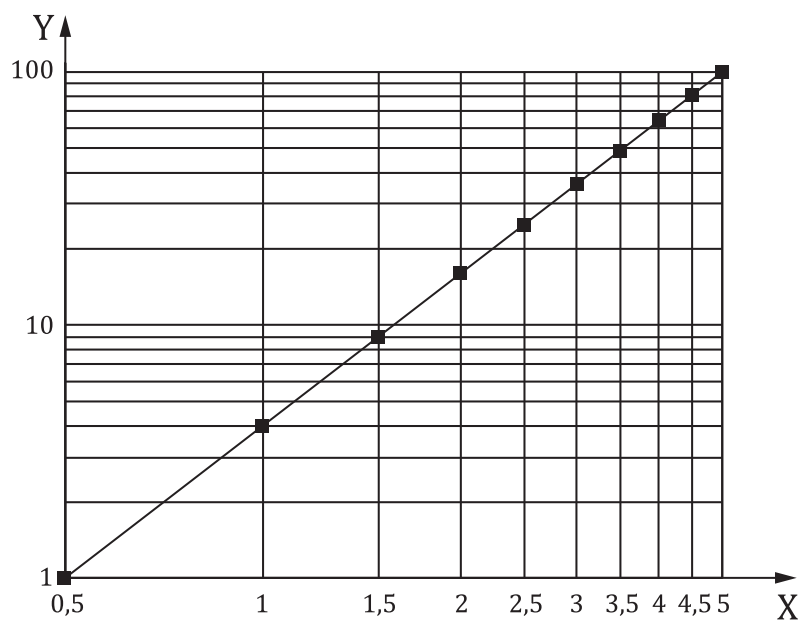
**Key**  
X chart diagram index  
Y actual length,  $\mu\text{m}$

Figure F.2 — Type B: aluminate



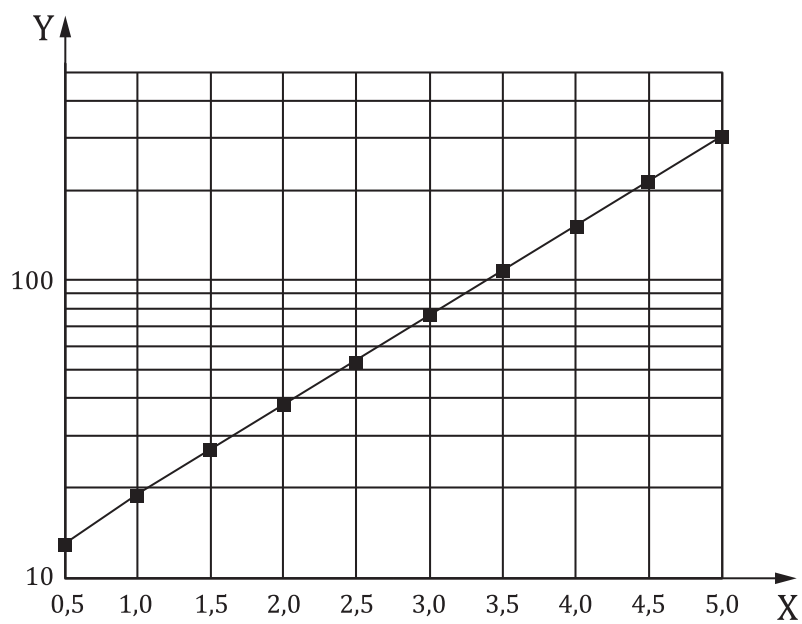
**Key**  
X chart diagram index  
Y actual length,  $\mu\text{m}$

Figure F.3 — Type C: silicate type



**Key**  
X chart diagram index  
Y number/field

Figure F.4 — Type D: globular oxide



**Key**  
X chart diagram index  
Y actual diameter,  $\mu\text{m}$

Figure F.5 — Subgroup DS: single oversized type D

## Bibliography

- [1] EN 10247:2017, *Micrographic examination of the non-metallic inclusion of steels using standard pictures*
- [2] ASTM E45a – 25, *Standard Test Methods for Determining the Inclusion Content of Steel*
- [3] SS 111116:2019, *Jernkontoret's inclusion chart II for quantitative assessment of the content of non-metallic inclusions in metals and alloys*
- [4] SEP 1571:2017, *Evaluation of inclusions in special steels based on their surface areas*
- [5] ASTM E2283 – 08, (Reapproved 2019), *Standard Practice for Extreme Value Analysis of Nonmetallic Inclusions in Steel and Other Microstructural Features*





**ICS 77.040.99**  
Price based on 56 pages

© ISO 2026  
All rights reserved