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# Microstructure of cast irons —

## Part 4: Test method for evaluating nodularity in spheroidal graphite cast irons

*Microstructure des fontes —*

*Partie 4: Méthode d'essai pour l'évaluation de la nodularité des fontes à graphite sphéroïdal*



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# Foreword

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This document was prepared by Technical Committee ISO/TC 25, *Cast irons and pig irons*.

A list of all parts in the ISO 945 series can be found on the ISO website.

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.



# Introduction

The shape of the graphite particles is an important characteristic of spheroidal graphite cast irons. It has a critical effect on the mechanical and physical properties of these materials.

# Microstructure of cast irons —

# Part 4:
# Test method for evaluating nodularity in spheroidal graphite cast irons

## 1 Scope

This document specifies a test method for evaluating nodularity in spheroidal graphite cast irons by comparative visual analysis and image analysis techniques.

This document provides figures for different levels of nodularity and graphite particle count of spheroidal graphite cast irons for visual analysis.

## 2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 945-1, *Microstructure of cast irons — Part 1: Graphite classification by visual analysis*

## 3 Terms and definitions

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

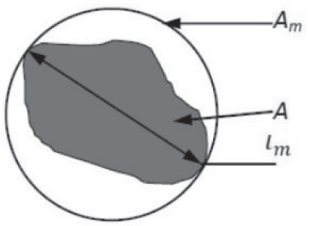
ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at http://www.electropedia.org/

**3.1**
**maximum Féret diameter**
maximum length of an object whatever its orientation

Note 1 to entry: The maximum Féret diameter of a graphite particle is shown in Figure 1.




**Key**

$l_m$ maximum Féret diameter of the graphite particle

$A_m$ area of the circle diameter $l_m$

$A$ area of the graphite particle

**Figure 1 — Illustration of maximum Féret diameter of a graphite particle**

**3.2**
**roundness**
area of a graphite particle divided by the area of the circle where the diameter is the *maximum Féret diameter* (3.1) of the same graphite particle, calculated according to Formula (1):

$$\rho = A / A_{\mathrm{m}} = 4A / \pi \cdot l_{\mathrm{m}}{}^{2} \quad (1)$$

where $\rho$ is the roundness of a graphite particle

**3.3**
**spheroidal graphite**
graphite particles classified as form VI and V in accordance with ISO 945-1 or graphite particles with *roundness* (3.2) ≥ 0,6 to 1,0

**3.4**
**spheroidal graphite cast iron**
cast material, iron, silicon and carbon-based, the carbon being present mainly in the form of *spheroidal graphite* (3.3) particles

**3.5**
**nodularity**
assessment of the proportion of *spheroidal graphite* (3.3) particles in a cast iron sample

Note 1 to entry: Nodularity is generally expressed as a percentage.

**3.6**
**graphite particle count**
number of graphite particles per unit area

## 4 Designations

### 4.1 Graphite classification by visual analysis

To characterize the graphite particles observed, information is generally necessary on the nodularity, the size and the number of the graphite particles. For this purpose, the following symbols shall be used at different positions of the designation.

a) Nodularity is designated by a percentage, in increments of five percentage points; see the reference images of Figure A.1.

NOTE 1 Nodularity of spheroidal graphite cast irons is 50 % as a minimum. Maximum nodularity is usually about 95 %.

b) Graphite particle size is designated by numbers from 3 to 8 in accordance with ISO 945-1. For determining the size range, the largest graphite particle in the field of view is used in accordance with ISO 945-1. If the graphite particles observed in different areas of view cover two sizes, reference to both is possible in accordance with ISO 945-1.

NOTE 2 The reference images given in ISO 945-1 do not represent all the graphite particle sizes that can be present in each of the graphite particle size ranges. The reference image schematics in ISO 945-1 show some graphite particles smaller than the minimum size graphite particles for that size range. The schematics represent what can be seen when viewing a two-dimensional sectioned view of a three-dimensional structure where a normal sized particle is sectioned not through its centreline appears smaller than its actual size.

c) Graphite particle count is designated by numbers; see the reference images of Figure B.1.

EXAMPLE 1 For a spheroidal graphite cast iron, the nodularity, graphite particle size and graphite particle count are 90 %, size 7 and 200 particles/mm$^2$, respectively. The structure is described as follows:



Nodularity 90 %; size 7; 200 particles/mm$^2$.

EXAMPLE 2 For a spheroidal graphite cast iron, the nodularity and graphite particle count are evaluated to be 90 % and 200 particles/mm$^2$ and the graphite sizes cover size 6 and size 7. The structure is described as follows:

Nodularity 90 %; size 6/7; 200 particles/mm$^2$.

The predominant size may be emphasized by underlining the number.

### 4.2 Graphite classification by image analysis

When a cast iron material is examined using the image analysis method in accordance with ISO/TR 945-2, the graphite particles should be classified by the following elements.

a) Nodularity, designated by a percentage number calculated according to Formulae (1) and (2). The results should be reported in whole numbers. For example, 92,6 % is reported as 93 %.

b) Size, designated by numbers from 3 to 8 in accordance with ISO 945-1. For determining the size range, the largest graphite particle in the field of view is used in accordance with ISO 945-1. If the graphite particles observed in different fields of view cover two sizes or more, reference to these size ranges is possible.

c) Graphite particle count, designated by numbers.

EXAMPLE 1 For a spheroidal graphite cast iron, the calculated nodularity, graphite size and graphite particle count are 92,4 %, size 6 and 230 particles/mm$^2$, respectively. The following designation should be used to describe this structure:

Nodularity 92 %; size 6; 230 particles/mm$^2$.

If the graphite particles evaluated in different fields of view cover more than one size, the size and the particle number should be presented in percentage.

EXAMPLE 2 For a spheroidal graphite cast iron, the calculated nodularity and graphite particle count are 92,6 % and 230 particles/mm$^2$. 52 % of the graphite particles are in the range of size 6, 45 % in the range of size 7 and 3 % in the range of size 5. The following designation should be used to describe this structure:

Nodularity 93 %; 52 % size 6 + 45 % size 7 + 3 % size 5; 230 particles/mm$^2$.

## 5 Sampling and sample preparation

Sampling and sample preparation should be carried out in accordance with ISO 945-1 and ISO/TR 945-2.

Attention should be paid to a good metallographical preparation to ensure that the microstructure is not altered and the graphite particle contours show sufficient contrast, especially for image analysis.

## 6 Procedure for graphite classification

### 6.1 General

The polished samples shall be scanned under a microscope in such a manner that a representative area is examined. To examine the graphite form and distribution, a × 100 magnification should preferably be chosen. If necessary, the magnification may be adapted in relation with the wall thickness of the casting so that the form and distribution of graphite can be determined by using the reference images given in Figures A.1 and B.1. Adjust the microscope magnification to match as closely as possible the corresponding images in Figures A.1 and B.1 before classifying the form and distribution of the graphite particles.

## 6.2 Procedure for visual analysis

Visual examination shall be carried out by direct observation using a microscope, by projection on a ground glass of a microscope or by projection on a visual display screen. The area of view should preferably have approximately the same size as that of the reference images. The assessment of the graphite particles can be facilitated by the use of suitably calibrated eye-pieces.

The nodularity and graphite particle count shall be determined by using the reference images given in Figures A.1 and B.1. The graphite size is determined by using the reference images of ISO 945-1. If a visual display screen is used, the combined magnification of both microscope and screen (depending on its size) shall be taken into account.

The evaluation of the results shall be carried out by an operator trained in this metallographic technique.

## 6.3 Procedure for image analysis

Examination shall be carried out by direct observation using a microscope or by projection on a visual display screen. The area of view (the area of each examination) should preferably have approximately the same size as the reference images. Then, an appropriate image should be taken using a microscope, a digital camera or a computer image caption program. The operation should be carried out in accordance with ISO/TR 945-2.

Particles with a maximum Féret diameter less than 10 µm shall be excluded from the evaluation. For thin wall castings with a high number of small graphite particles, this limit value may be reduced to 5 µm with corresponding increase in magnification. The nodularity shall be calculated according to Formula (2).

## 6.4 Calculation of nodularity

Only Form V and VI particles are included as spheroidal graphite particles in the nodularity calculation. The shape of the graphite particle is characterized by its roundness value. The roundness value influences the calculation of nodularity.

Nodularity ($p_{nod}$) is calculated as the area of graphite particles that meet both the size limit and the roundness limits, divided by the total area of all graphite particles above the size limit, according to Formula (2). The graphite particles intersecting the border of the area of view shall be excluded.

$$p_{nod} = \frac{A_{VI} + A_V}{A_{all}} \tag{2}$$

where

$p_{nod}$ is nodularity, in %;

$A_{VI}$ and $A_V$ are the total area of graphite particles with roundness ≥ 0,6 to ≤ 1,0;

$A_{all}$ is the total area of all graphite particles that meet the size criteria, excluding the particles that intersect the border of the area of view.

NOTE The calculation result of Formula (2) is sometimes different from the result of the present count method as stated in ISO 1083. For 90 % nodularity or greater, the variation value is about −4 % to 3 % and for nodularity in the range from 80 % to 89 %, the variation value is about −3 % to 5 % at a confidence level of 90 %. The lower the nodularity, the greater the difference will be.

The graphite particle count is the total number of graphite particles larger than size limit, divided by the test area in mm$^2$.



To obtain correct graphite counts, evaluate whole graphite particles and graphite particles corrected for field edge intersection as defined in ISO 945-1, and calculate graphite particle count in accordance with ISO 945-1. The area measured is the field size (within the frame) multiplied by the number of fields.

### 6.5 Examination fields

When evaluating the nodularity, graphite particle count and size of graphite particles, the whole surface area of the sample should be examined by a sufficient number of examination fields, which shall be chosen randomly. Aberrations such as microporosity or surface anomalies should be excluded. The nodularity, graphite particle count and size of graphite particles should be evaluated on the basis of at least five areas of view and at least 500 graphite particles.

Graphite particles having a maximum Féret diameter < 10 µm shall not be taken into account. This limit can be lower for thin wall castings. Other size limits can be used according to agreements between the manufacturer and the purchaser.

If most of the graphite particles are less than 10 µm or larger than 120 µm, magnification can be larger or smaller than × 100. The number of graphite particles in a field of view should be at least 20.

In special cases, such as heavy section castings, the minimum number of samples and minimum surface area to be evaluated may be defined by agreement between the manufacturer and the purchaser.

### 6.6 Evaluation of the results

The evaluation of the results shall be carried out by an operator trained in this metallographic technique.

The result is the average value of all fields of view. The result shall be reported in whole numbers.

## 7 Reference images

A series of reference images are provided in Annex A for the classification of nodularity (50 % to 95 % nodularity) and in Annex B for the classification of graphite particle count (25 particles/mm$^2$ to 1 000 particles/mm$^2$ with a maximum Féret diameter of 10 µm; 31 particles/mm$^2$ to 2 188 particles/mm$^2$ with a maximum Féret of 5 µm) in spheroidal graphite cast irons.

Annex C gives examples of graphite particle roundness.

## 8 Test report

The test report shall contain the following information:

— identification of the sample or casting;

— the sampling location;

— the designation of the material;

— the number of tested fields;

— the magnification;

— the size limit used, in µm;

— visual analysis or image analysis;

— the nodularity, size of the graphite particles and graphite particle count;

— a reference to this document, i.e. ISO 945-4;

— one or more of: date of the test, date of preparation or signature of the test report;

— the name and address of the testing laboratory;

— the name and address of the organization requesting the test.

For image analysis, the report shall contain the following information:

— the name of image analysis software;

— the number of evaluated graphite particles;

— the graphite content, including the particles that intersect the border of the area of view;

— the pixel calibration factor;

— the total area surveyed;

— the size distribution of nodules with minimum, maximum and standard deviation;

— the mean shape factor value of all particles above the minimum size requirement;

— any deviation from this test method.

If required, the report shall also contain the following information:

— details of the presence of any other graphite form not covered by this document;

— the method to separate joined/contiguous graphite particles (only for image analysis);

— one or more photomicrographs.

The following information shall be recorded:

— the name of the analyst to ensure traceability to the tester.

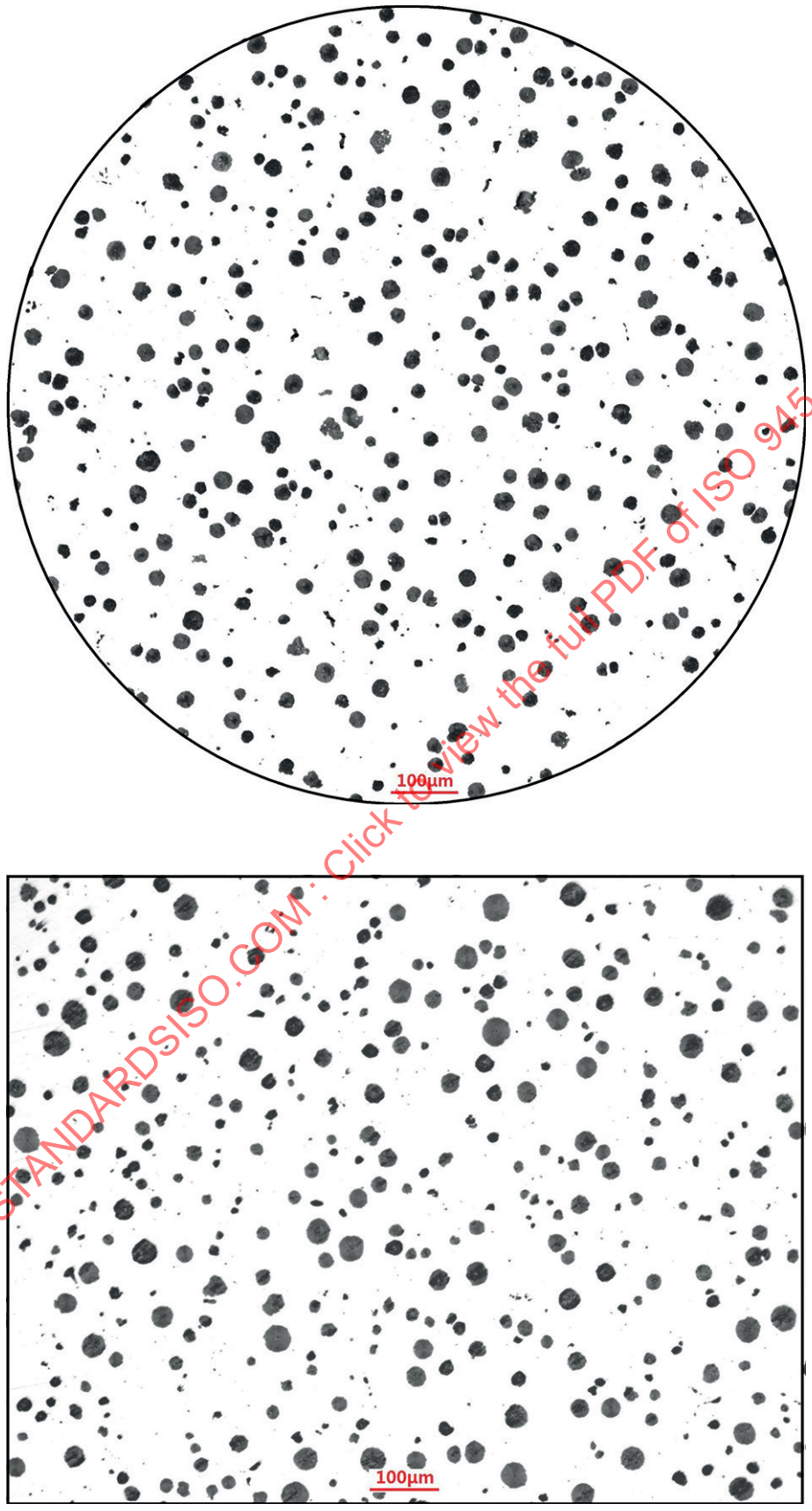


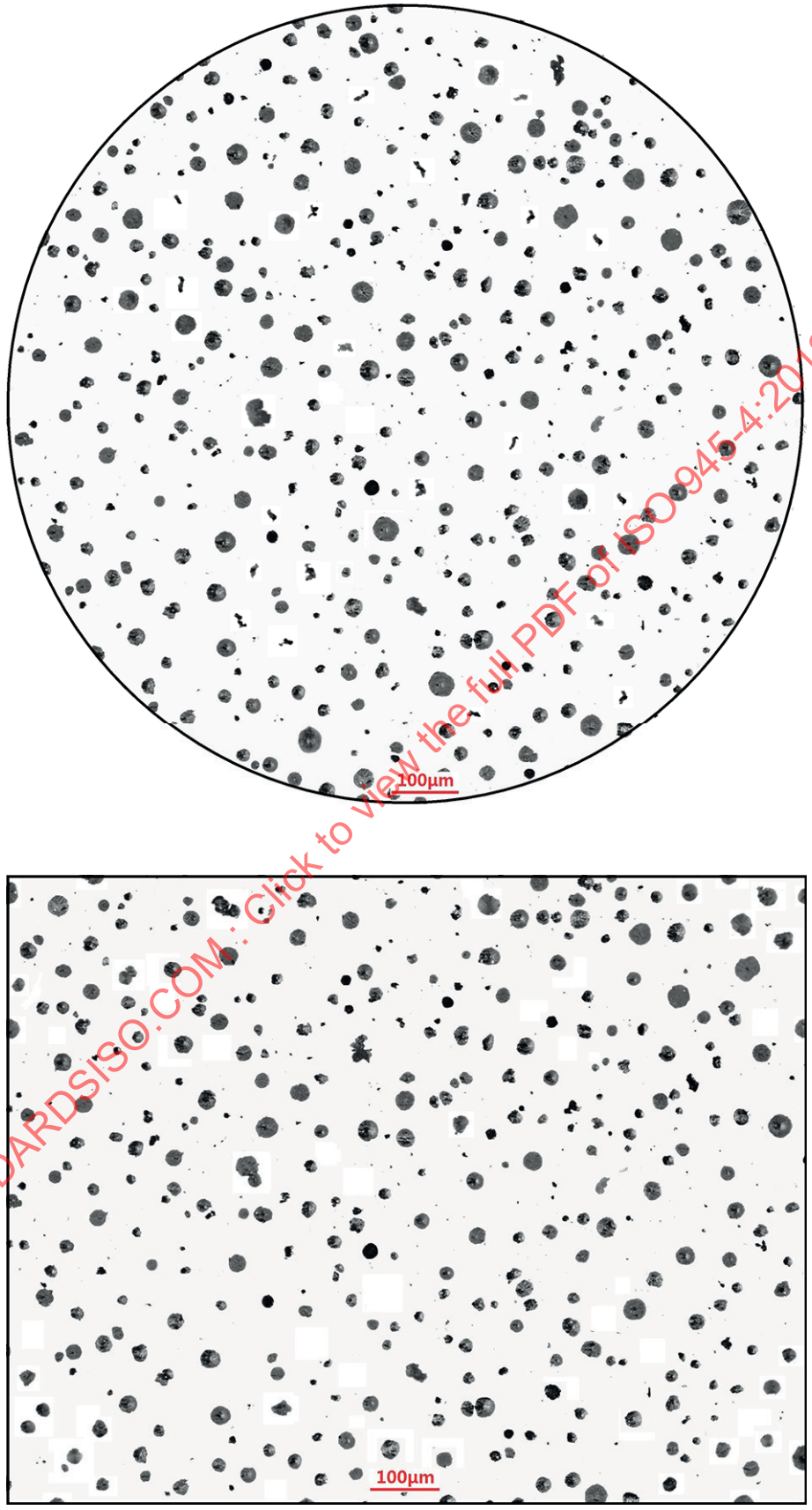
# Annex A
(normative)

# Reference images for nodularity

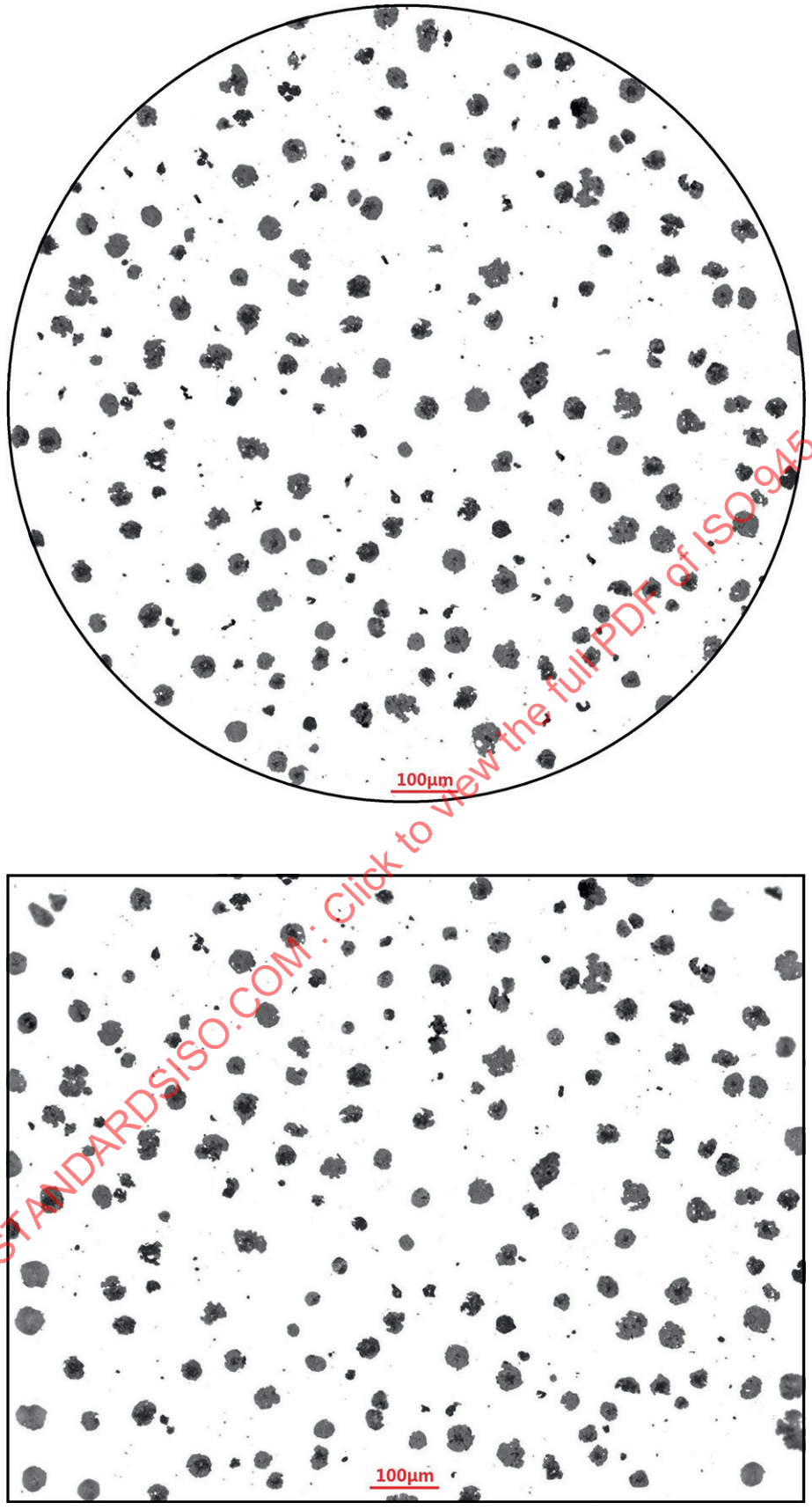
The reference images for nodularity are shown in Figure A.1.




**a) Nodularity 95 %**

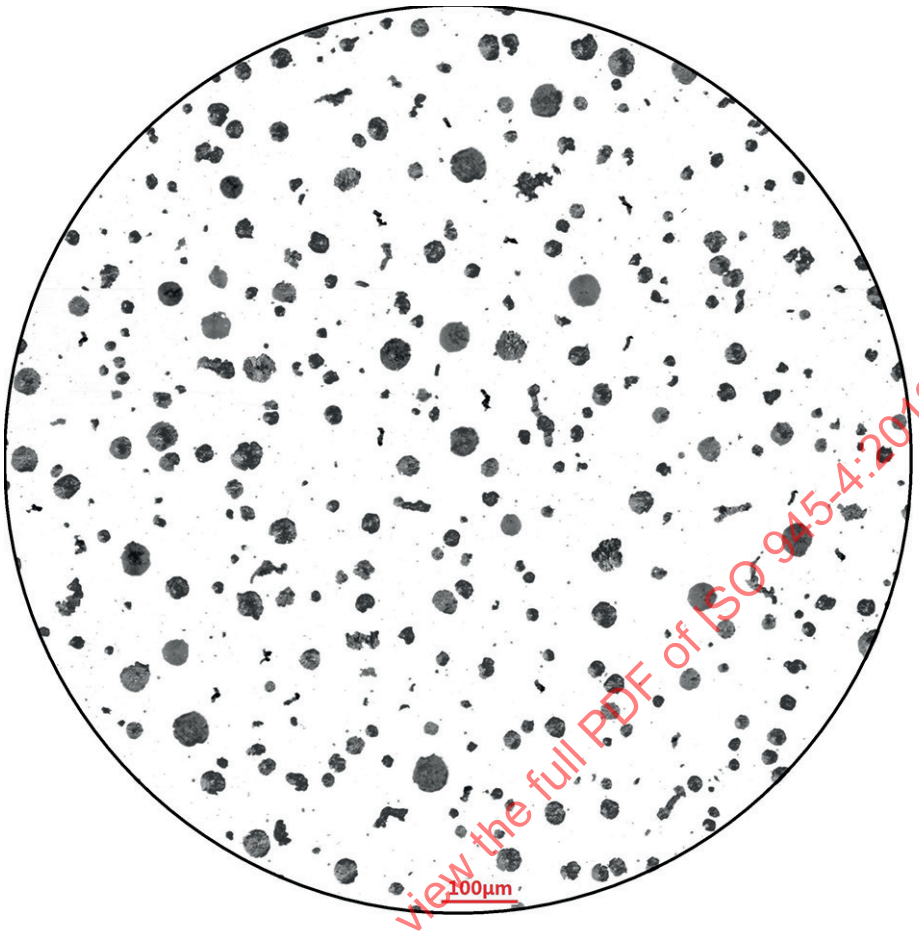


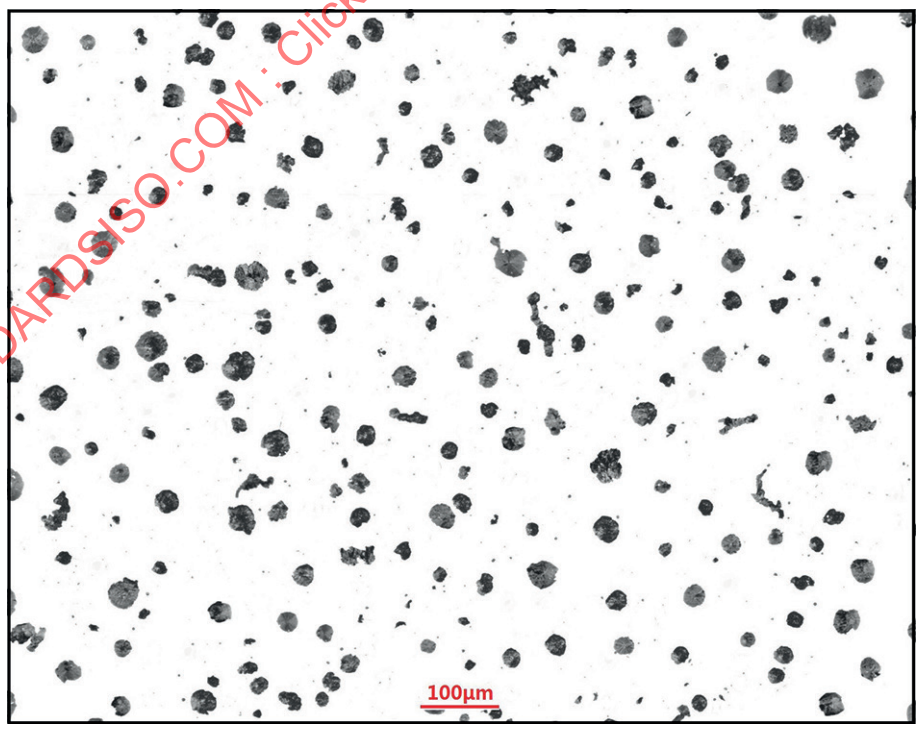

**b) Nodularity 90 %**



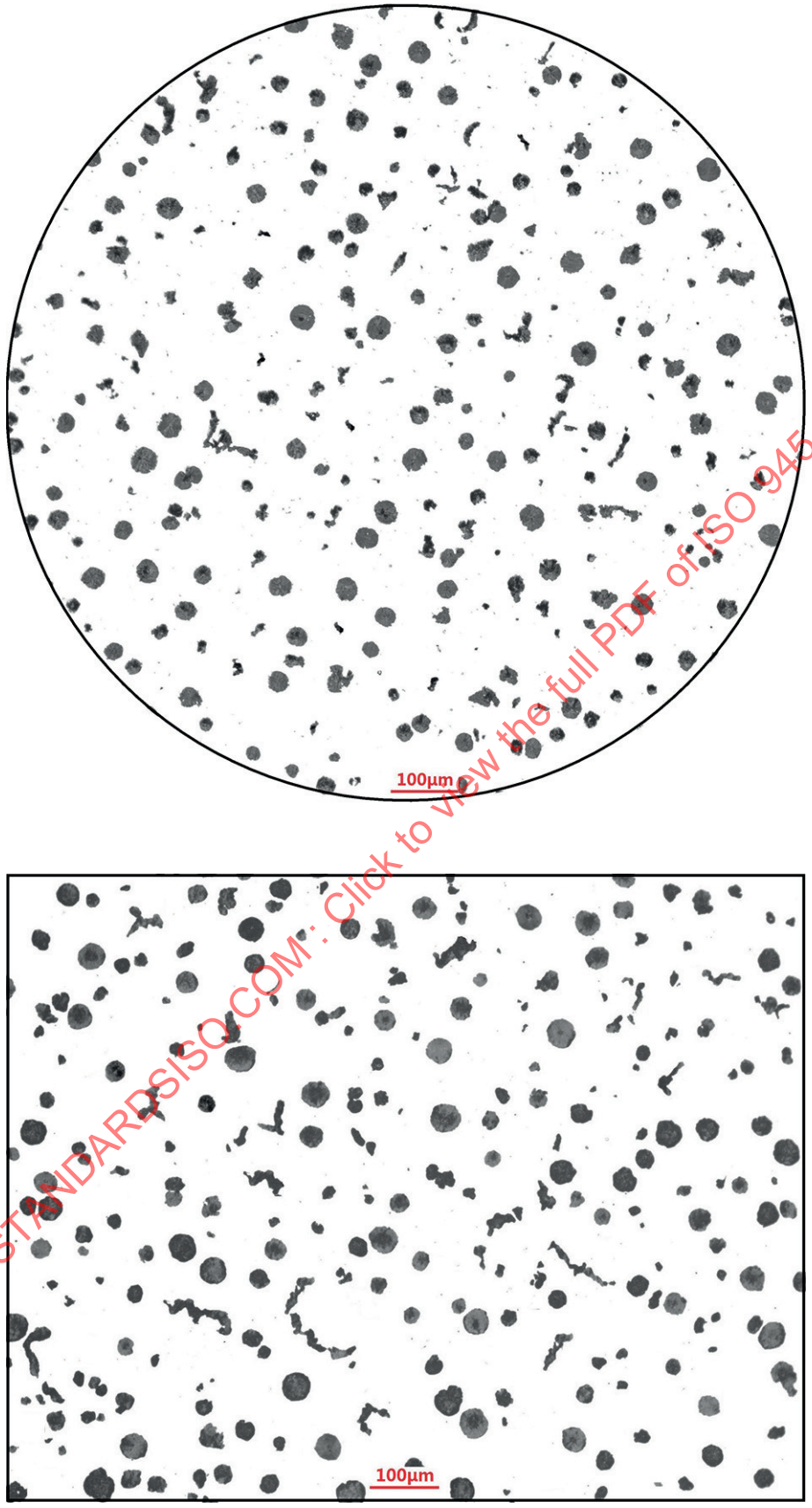



**c) Nodularity 85 %**



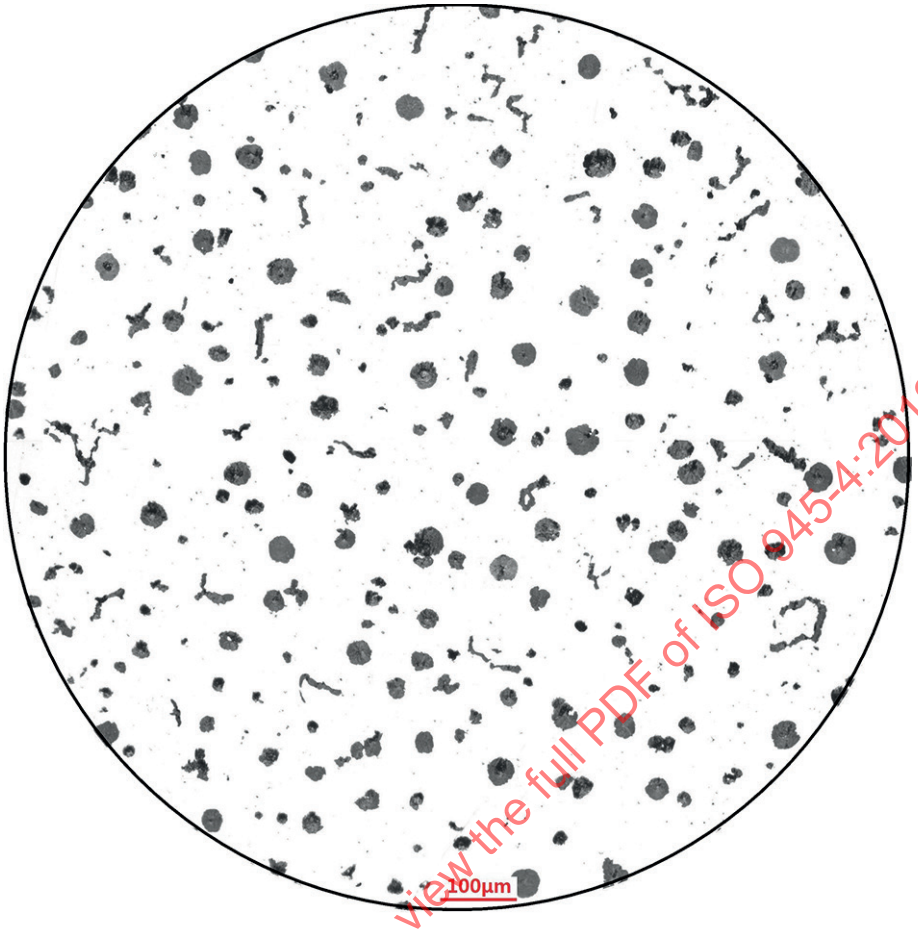



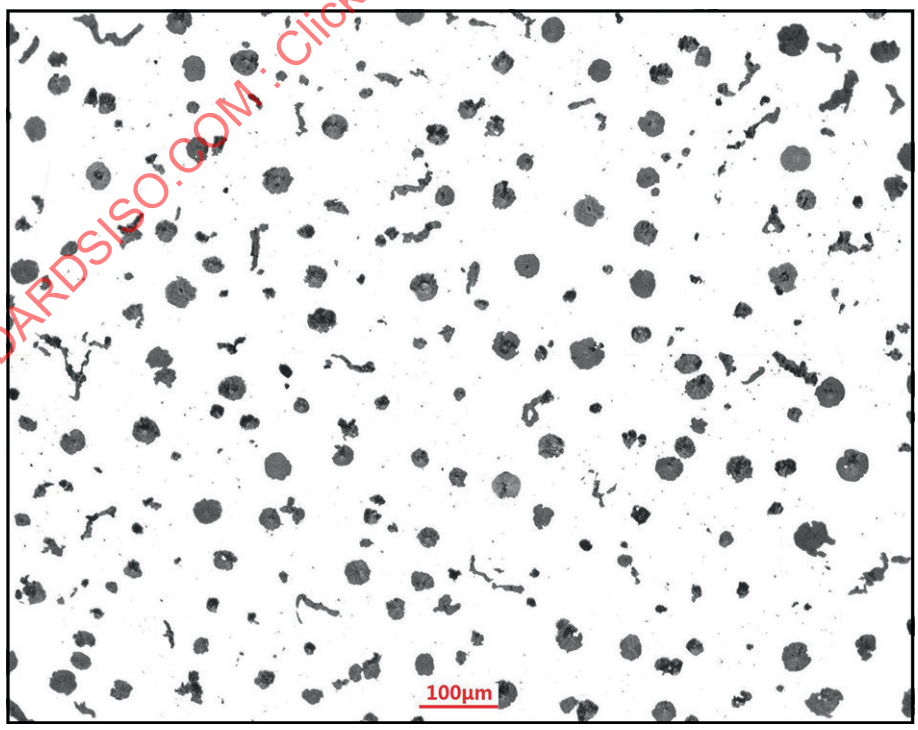

**d) Nodularity 80 %**



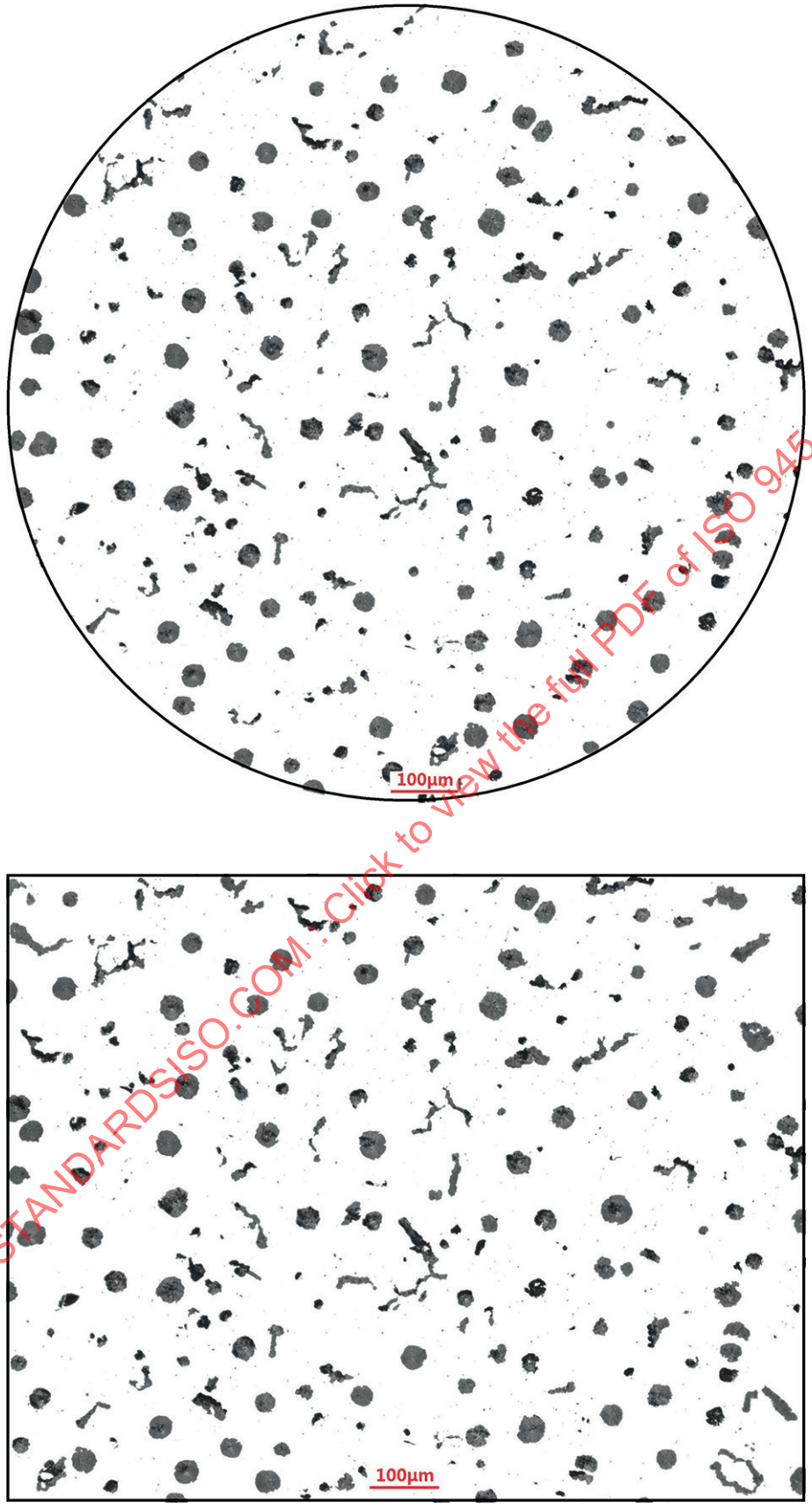



**e) Nodularity 75 %**



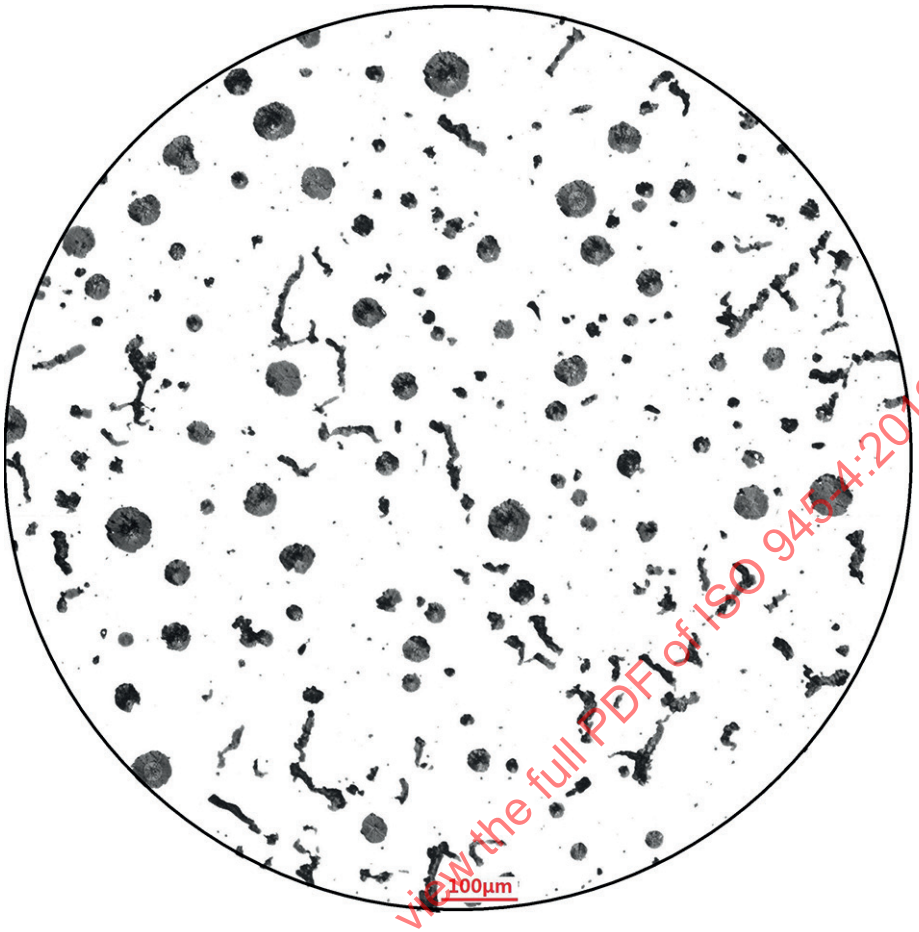



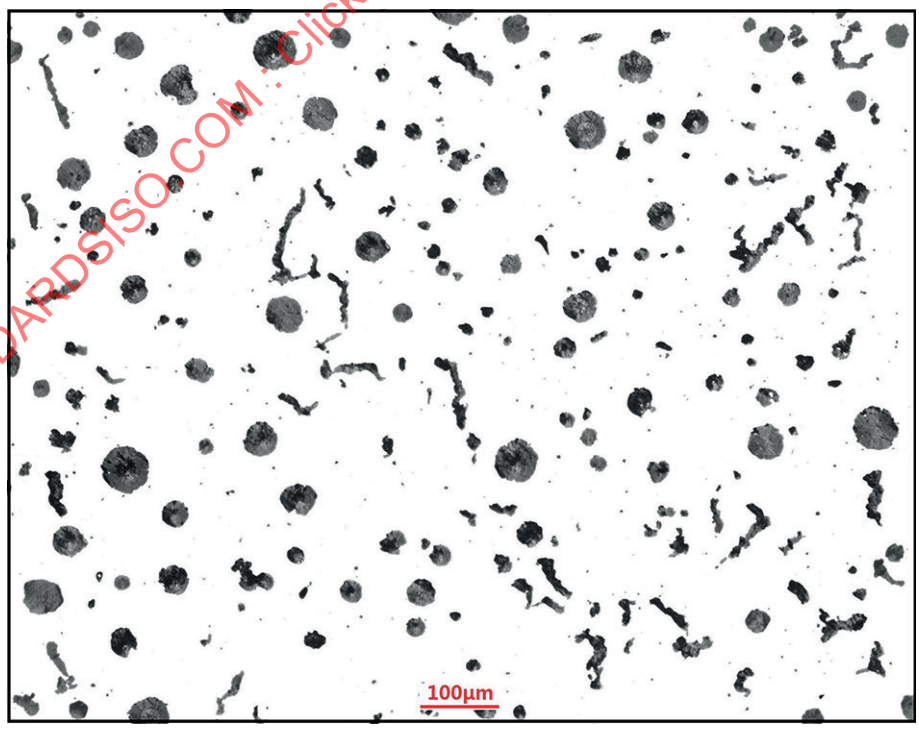

**f) Nodularity 70 %**



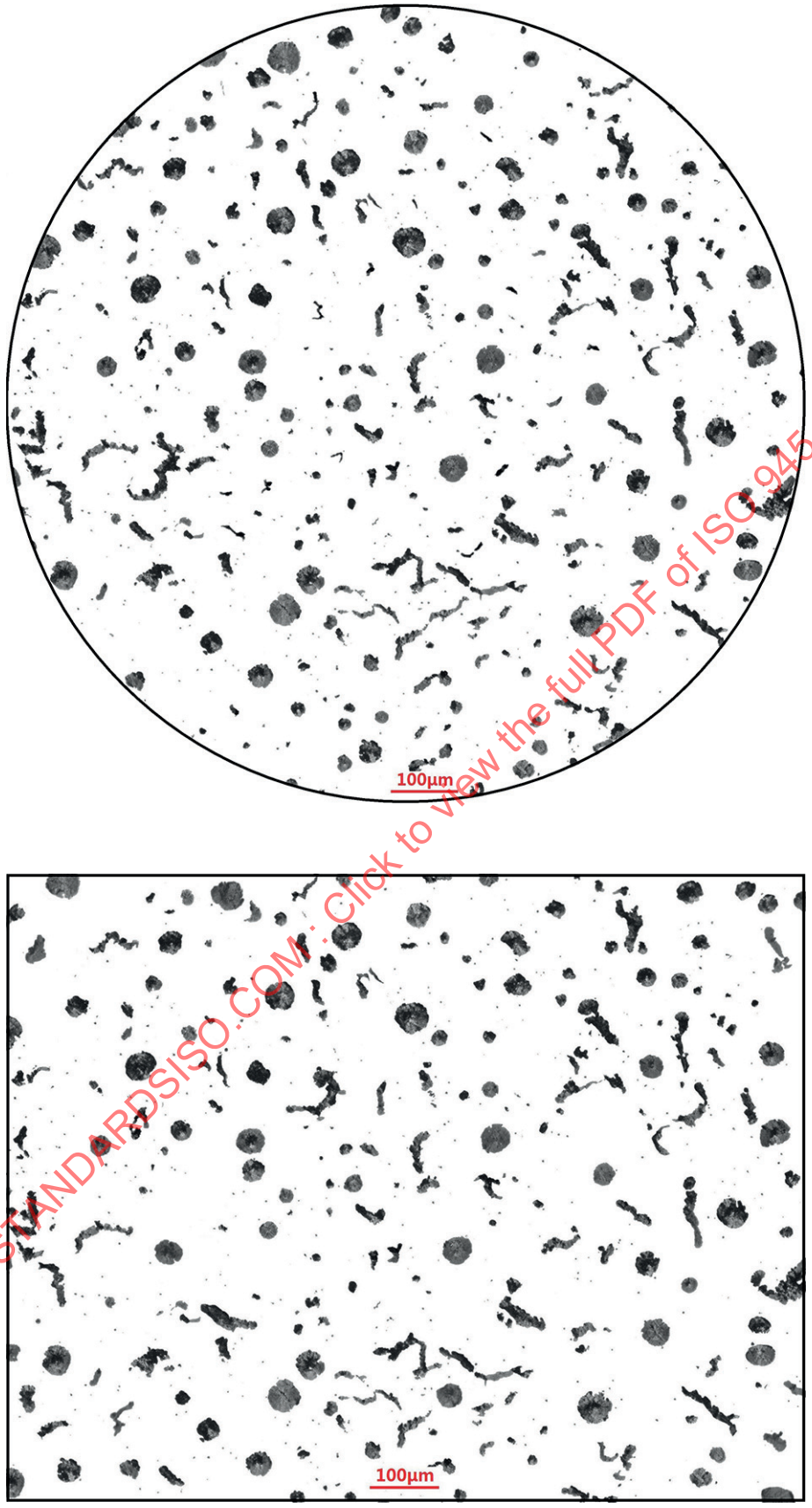



**g) Nodularity 65 %**



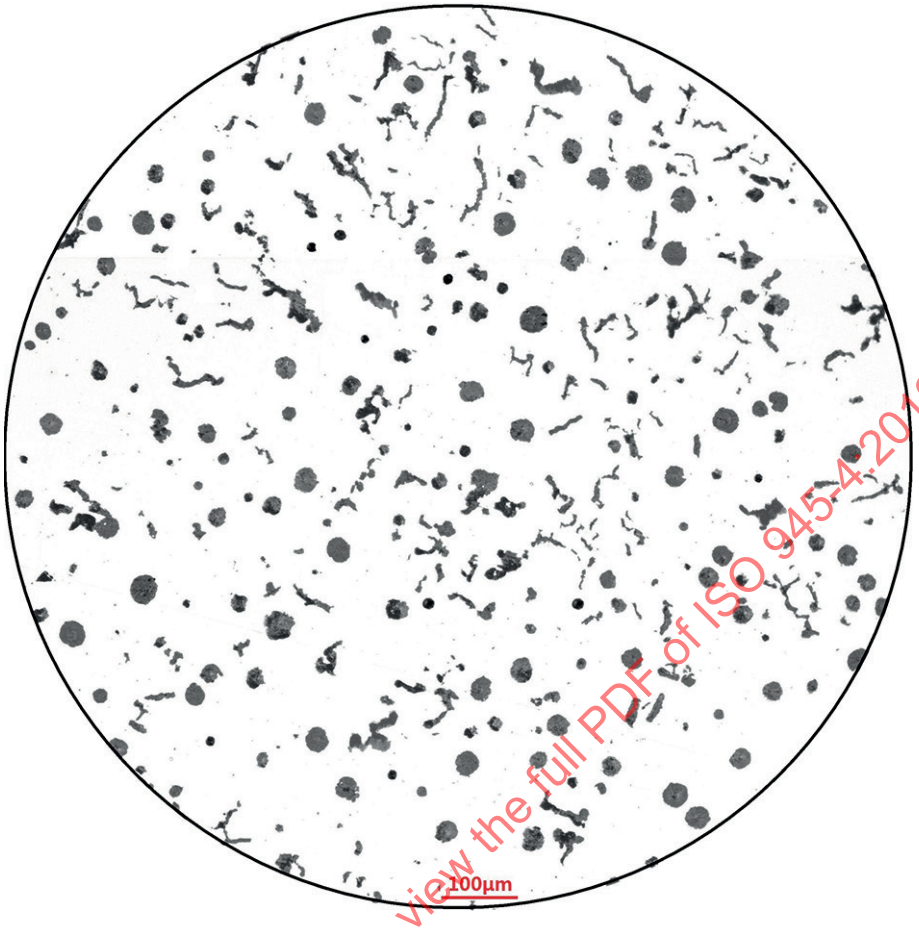



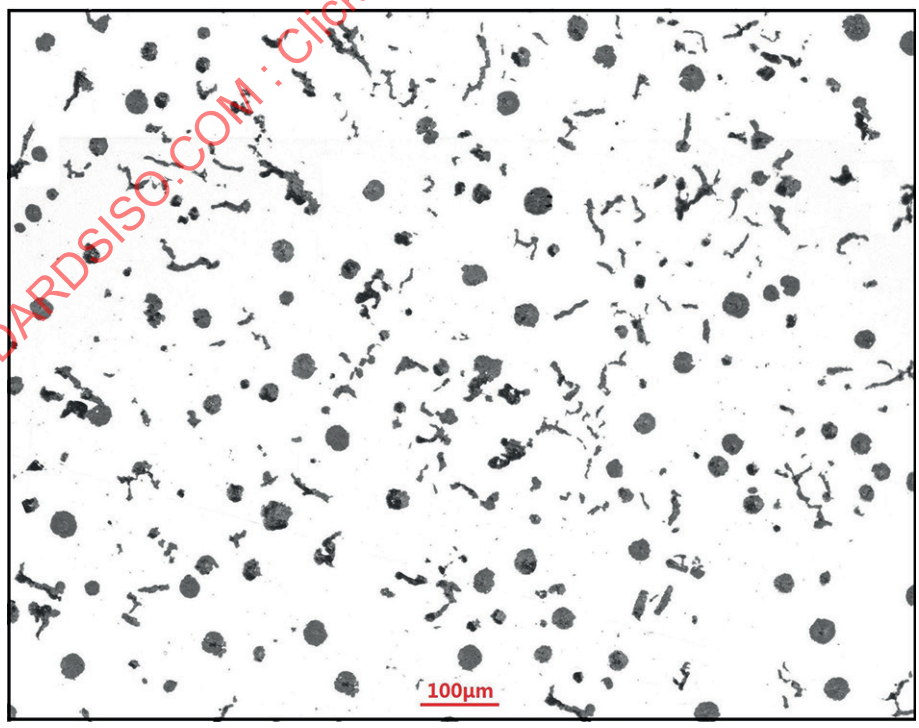

**h) Nodularity 60 %**






**i) Nodularity 55 %**



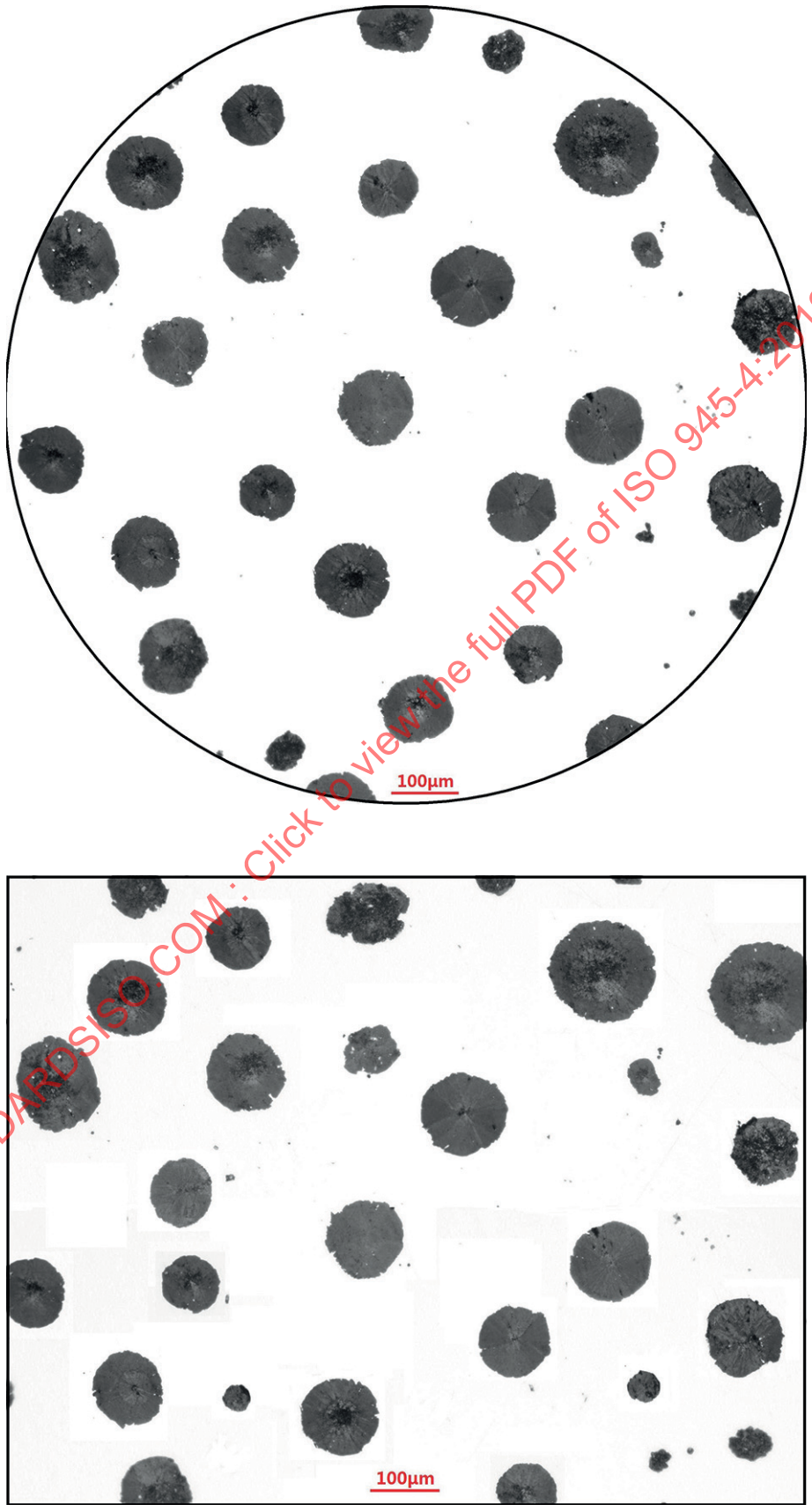

**j) Nodularity 50 %**

**Figure A.1 — Reference images for nodularity**

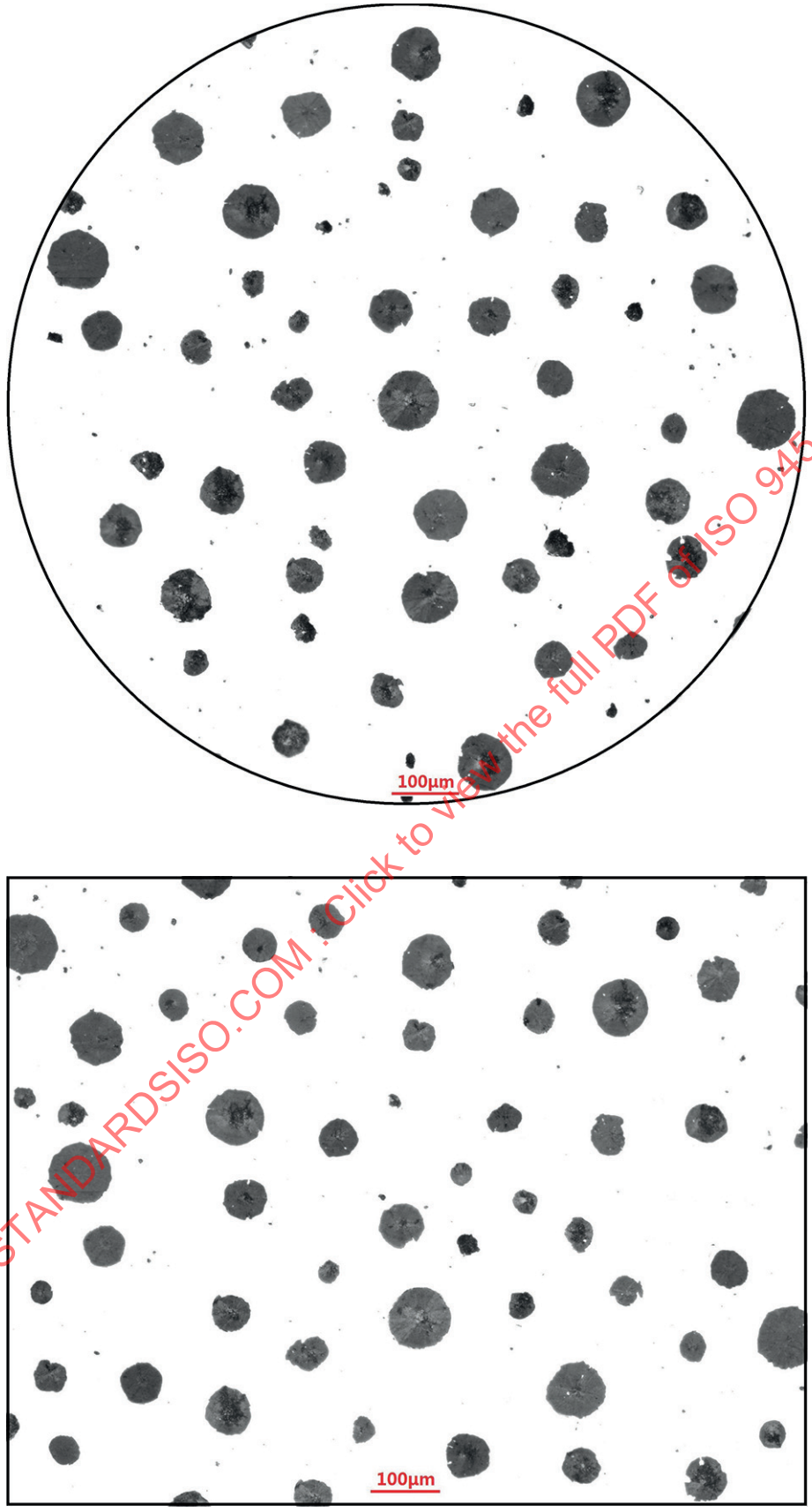
# Annex B
(normative)

# Reference images for graphite particle count

The reference images for graphite particle count are shown in Figure B.1.

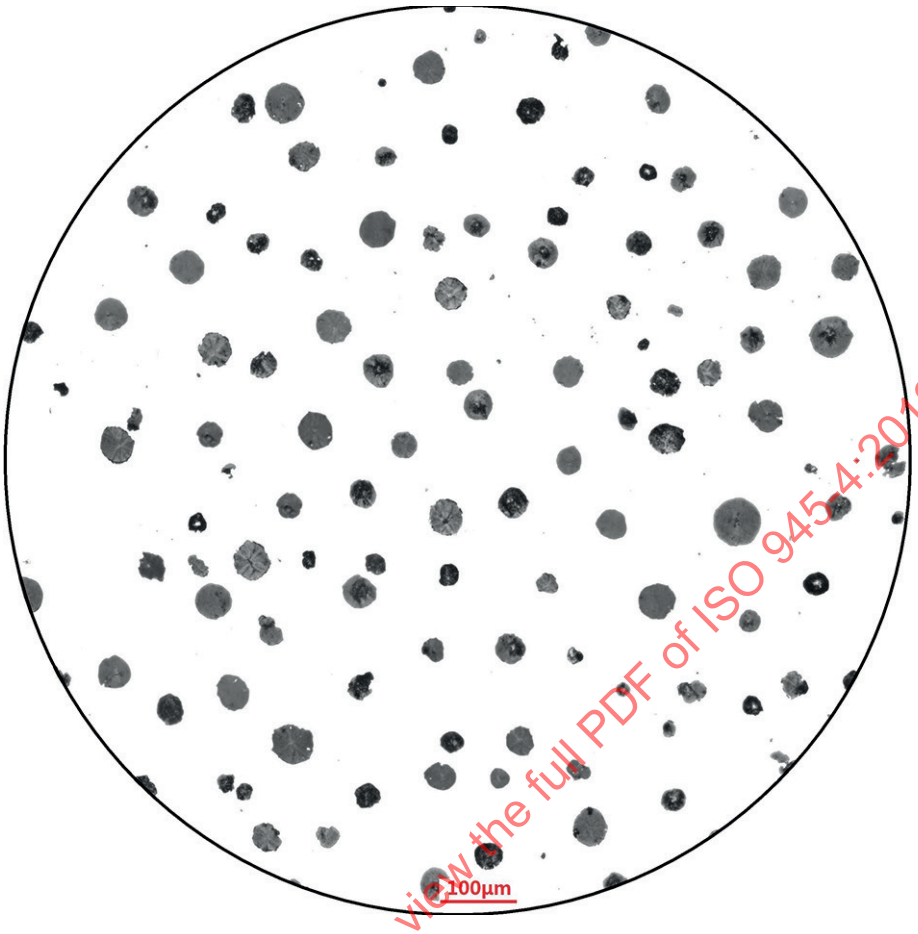


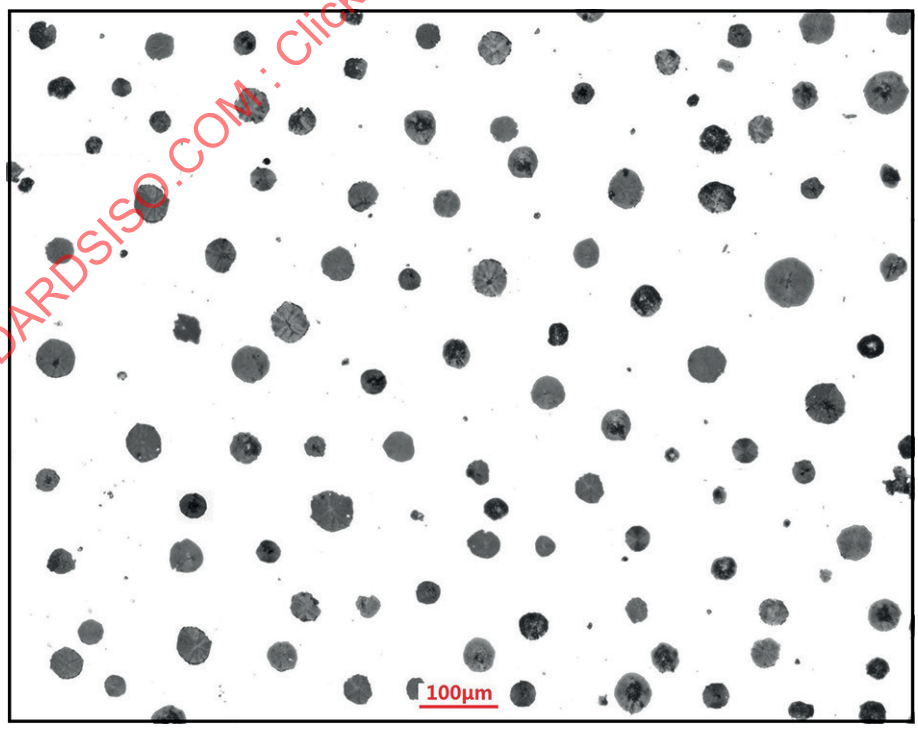

**a) Maximum Féret diameter ≥ 10 µm: 25 particles/mm$^2$;
Maximum Féret diameter ≥ 5 µm: 31 particles/mm$^2$**





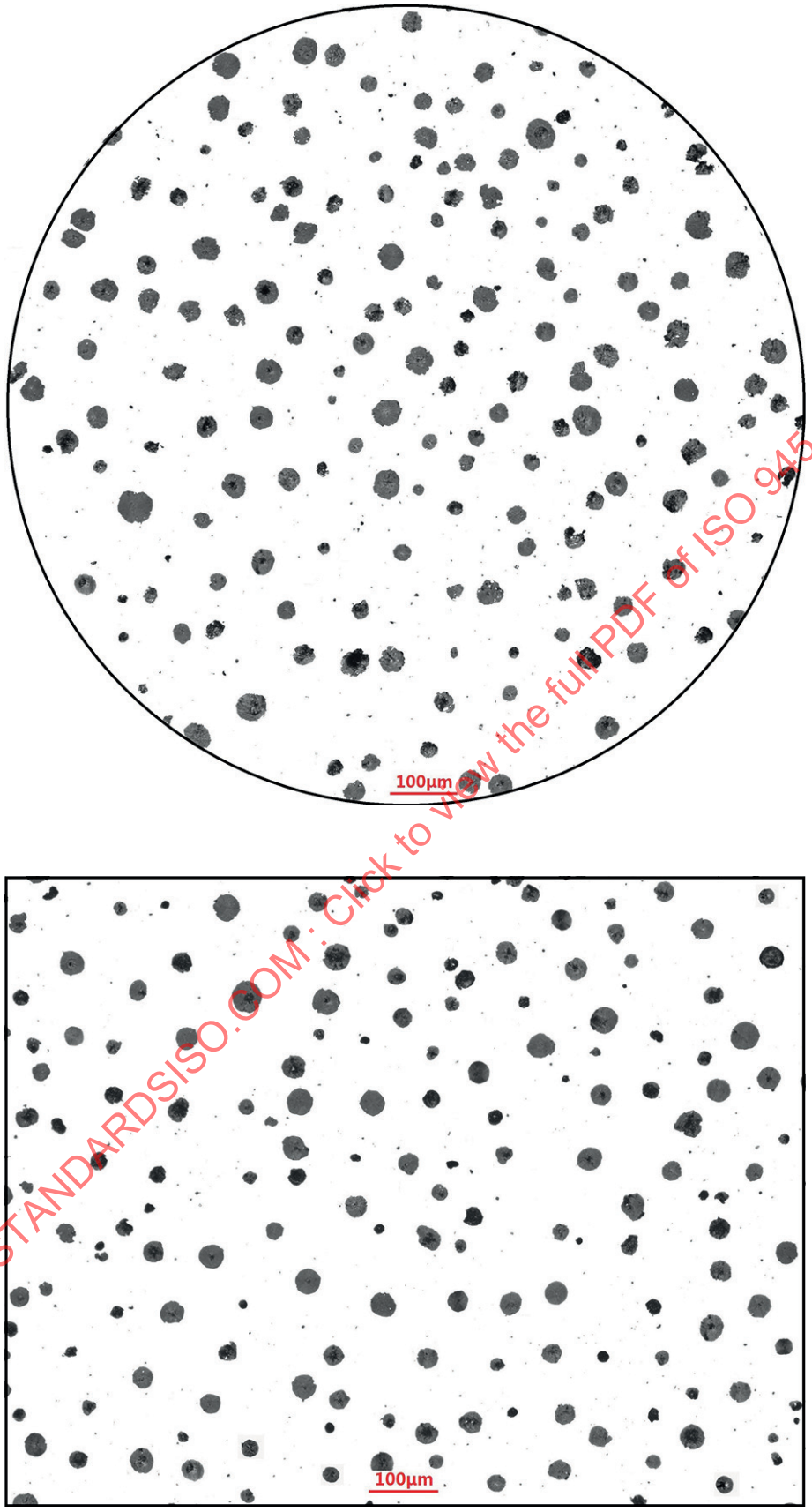

**b) Maximum Féret diameter ≥ 10 µm: 50 particles/mm$^2$;
Maximum Féret diameter ≥ 5 µm: 64 particles/mm$^2$**



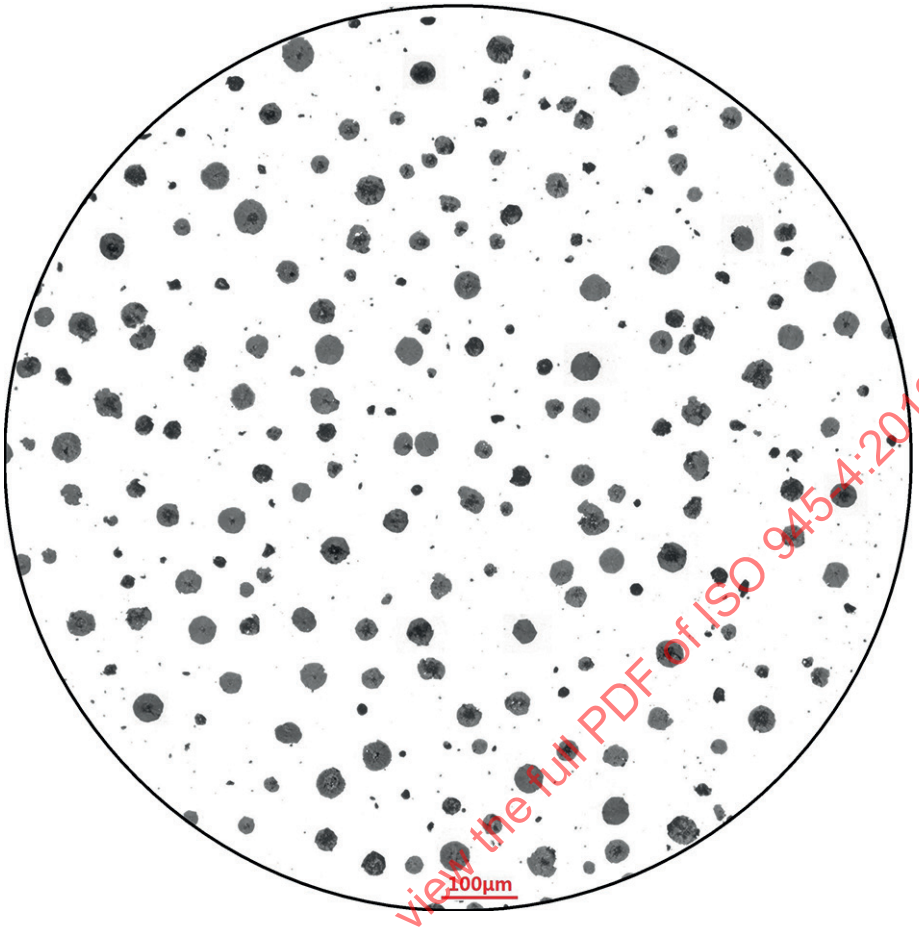


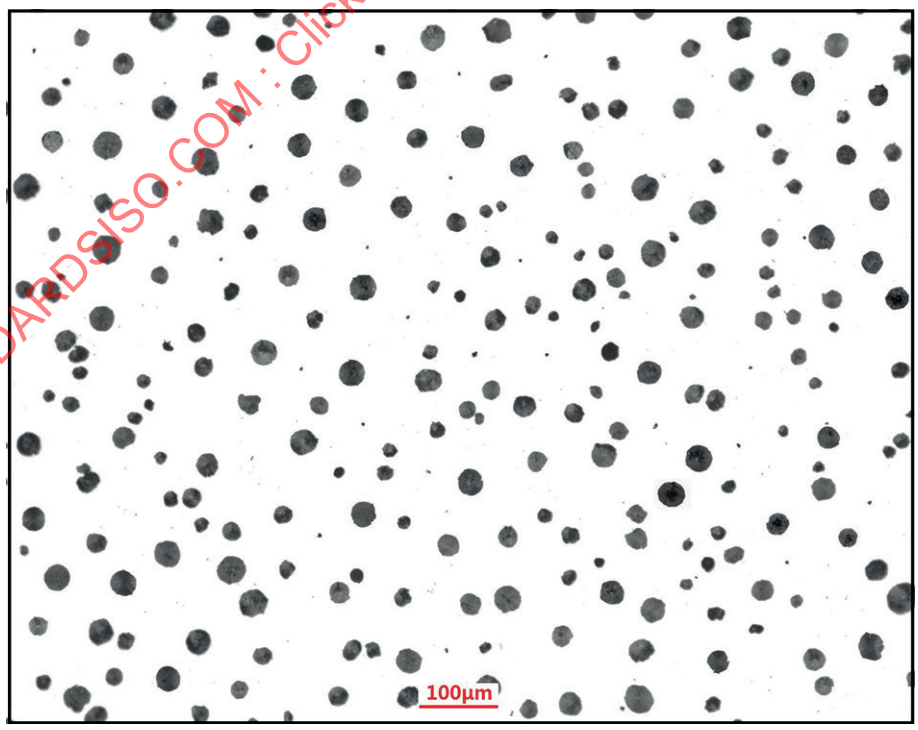

**c) Maximum Féret diameter ≥ 10 µm: 100 particles/mm$^2$;
Maximum Féret diameter ≥ 5 µm: 116 particles/mm$^2$**



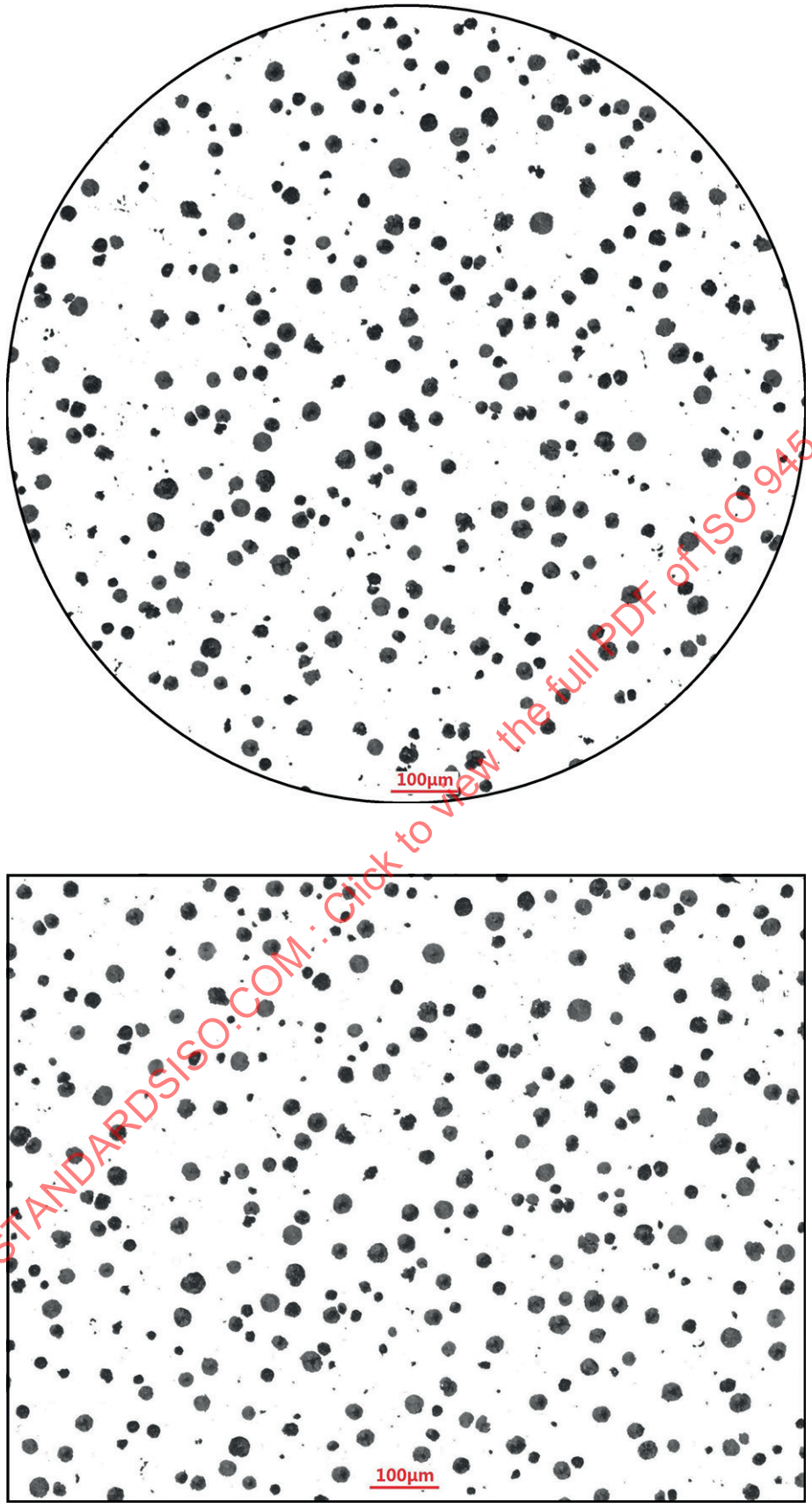



**d) Maximum Féret diameter ≥ 10 µm: 150 particles/mm$^2$;
Maximum Féret diameter ≥ 5 µm: 165 particles/mm$^2$**




**e) Maximum Féret diameter ≥ 10 µm: 200 particles/mm$^2$;
Maximum Féret diameter ≥ 5 µm: 230 particles/mm$^2$**






**f) Maximum Féret diameter ≥ 10 µm: 300 particles/mm$^2$;
Maximum Féret diameter ≥ 5 µm: 350 particles/mm$^2$**