INTERNATIONAL STANDARD

ISO 945-1

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Microstructure of cast irons —

Part 1: Graphite classification by visual analysis

Microstructure des fontes —

Partie 1: Classification du graphite par analyse visuelle

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Foreword

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

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO 945-1 was prepared by Technical Committee ISO/TC 25, *Cast irons and pig irons*.

Together with ISO 945-2, this first edition of ISO 945-1 cancels and replaces ISO 945:1975, which has been technically revised to take into account the expanding range of cast-iron alloys available. In addition, photomicrographs have been included together with schematic images to aid classification.

ISO 945 consists of the following parts, under the general title *Microstructure of cast irons*:

— *Part 1: Graphite classification by visual analysis*

Graphite classification by image analysis will be the subject of a future Part 2.

Introduction

Microstructure designation is a useful feature that provides a means of classifying the graphite form, distribution and size in cast irons.

Graphite classification by visual analysis is a well-established method which is well recognized within the foundry industry as a means of quickly determining the overall graphite microstructure of a cast-iron casting.

Microstructure of cast irons —

Part 1:
Graphite classification by visual analysis

1 Scope

This part of ISO 945 specifies a method of classifying the microstructure of graphite in cast irons by comparative visual analysis.

The purpose of this part of ISO 945 is to provide information about the method of graphite classification. It is not intended to give information on the suitability of cast-iron types and grades for any particular application.

The particular material grade is specified by results from tensile tests or hardness testing and, in the case of austenitic cast irons, by their chemical composition. The interpretation of graphite form and size does not allow a statistically valid statement on the fulfilment of the requirements specified in the relevant material standard. The structure of the metallic matrix (e.g. ferrite, pearlite) has a significant effect on the material properties. Such an interpretation is not the purpose of this part of ISO 945.

2 General

2.1 Designation system for classifying graphite in cast irons

When cast-iron materials are examined under a microscope in accordance with this part of ISO 945, the graphite shall be classified by

a) its form, designated by Roman numerals I to VI (see Figure 1 and Annex A);

b) its distribution, designated by capital letters A to E (see Figure 2 and Annex B); the graphite distribution designation is only specified for grey cast iron (form I);

c) its size, designated by Arabic numerals 1 to 8 (see Figures 3, 4 and 5 and Table 1).

NOTE Figures 1 to 5 show only the outlines and not the structure of the graphite.

FORM

Magnification ×100

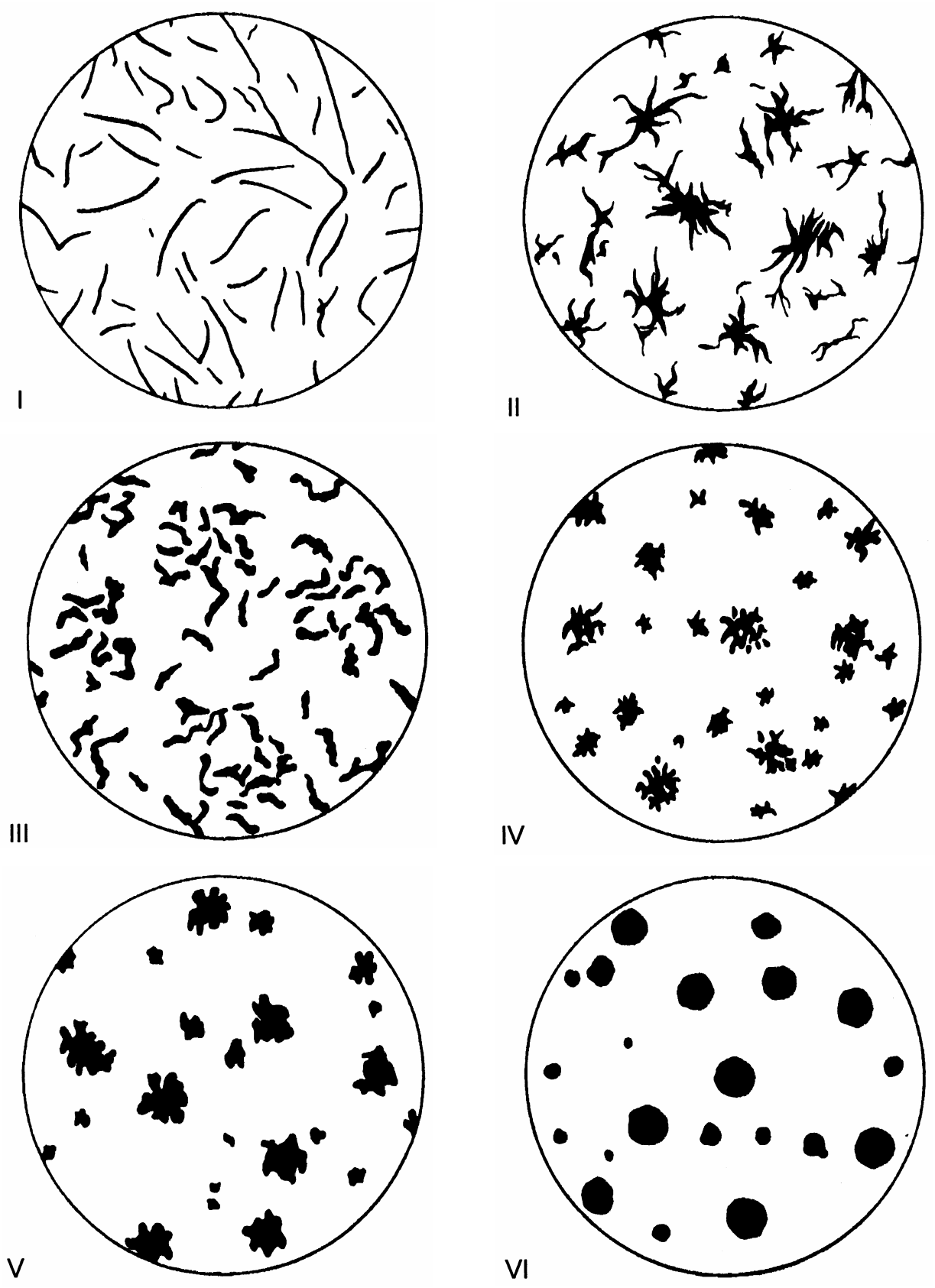


Figure 1 — Principal graphite forms in cast-iron materials — Reference images

DISTRIBUTION

Magnification ×100

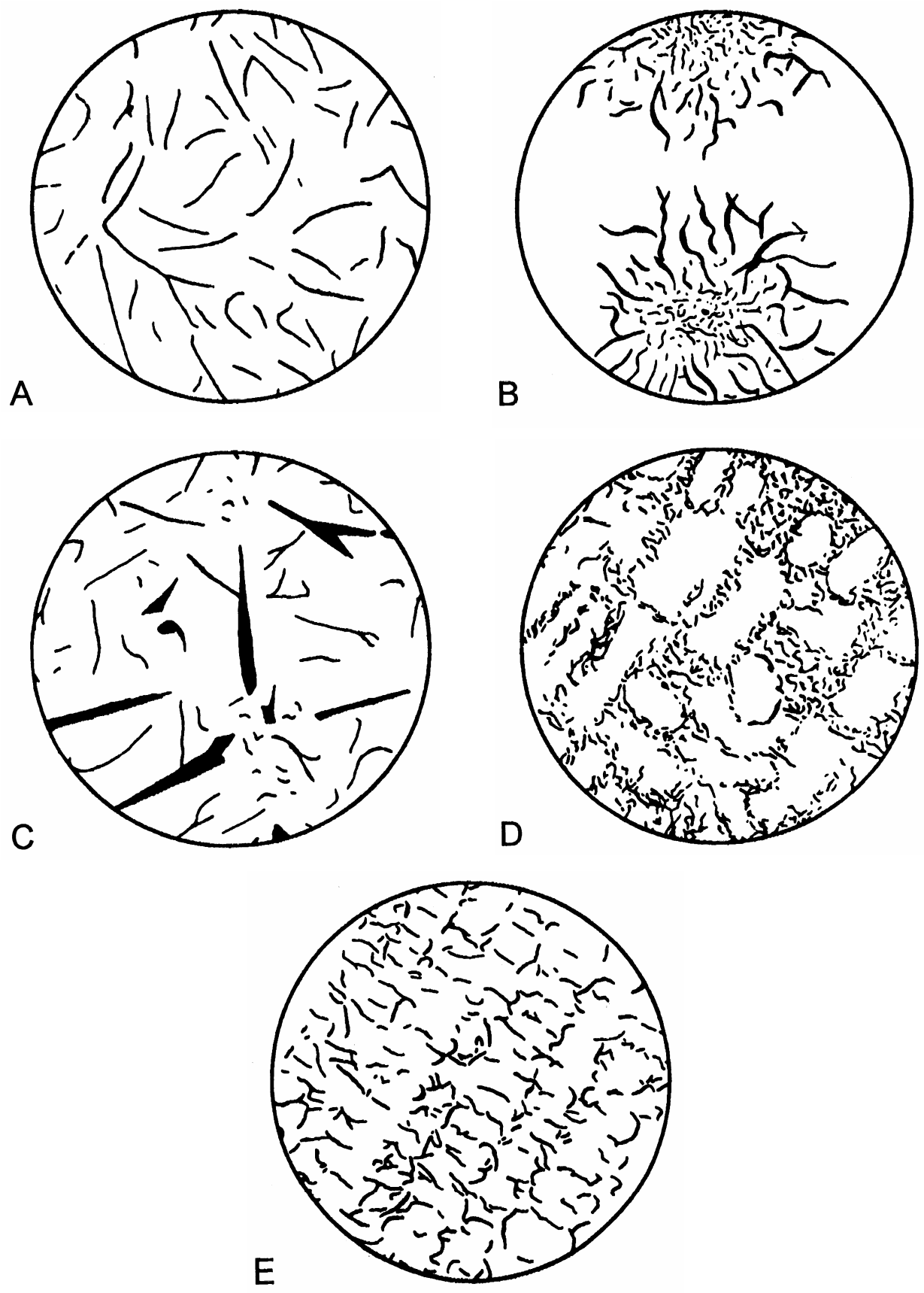
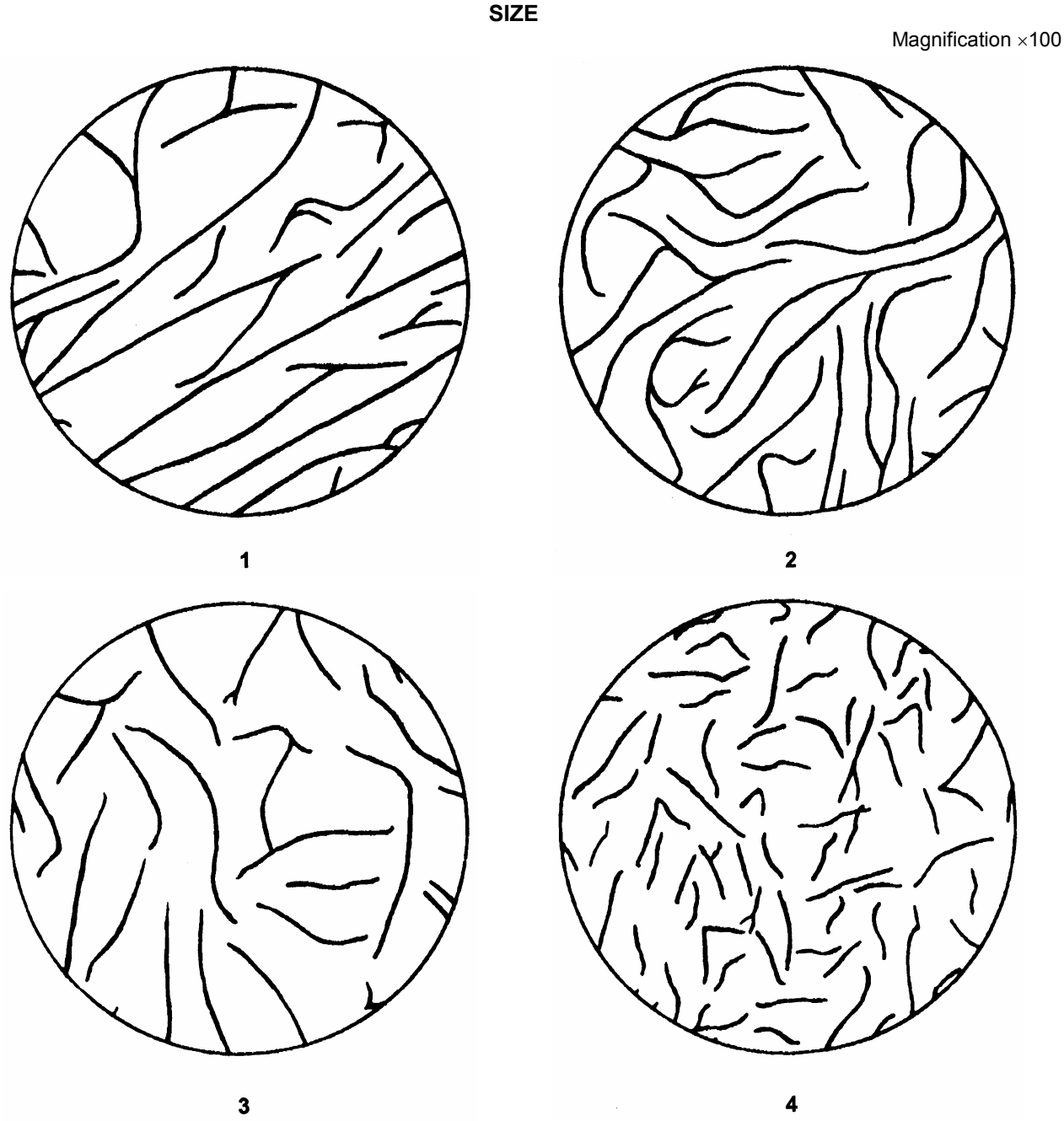


Figure 2 — Reference images for graphite distribution (form I)

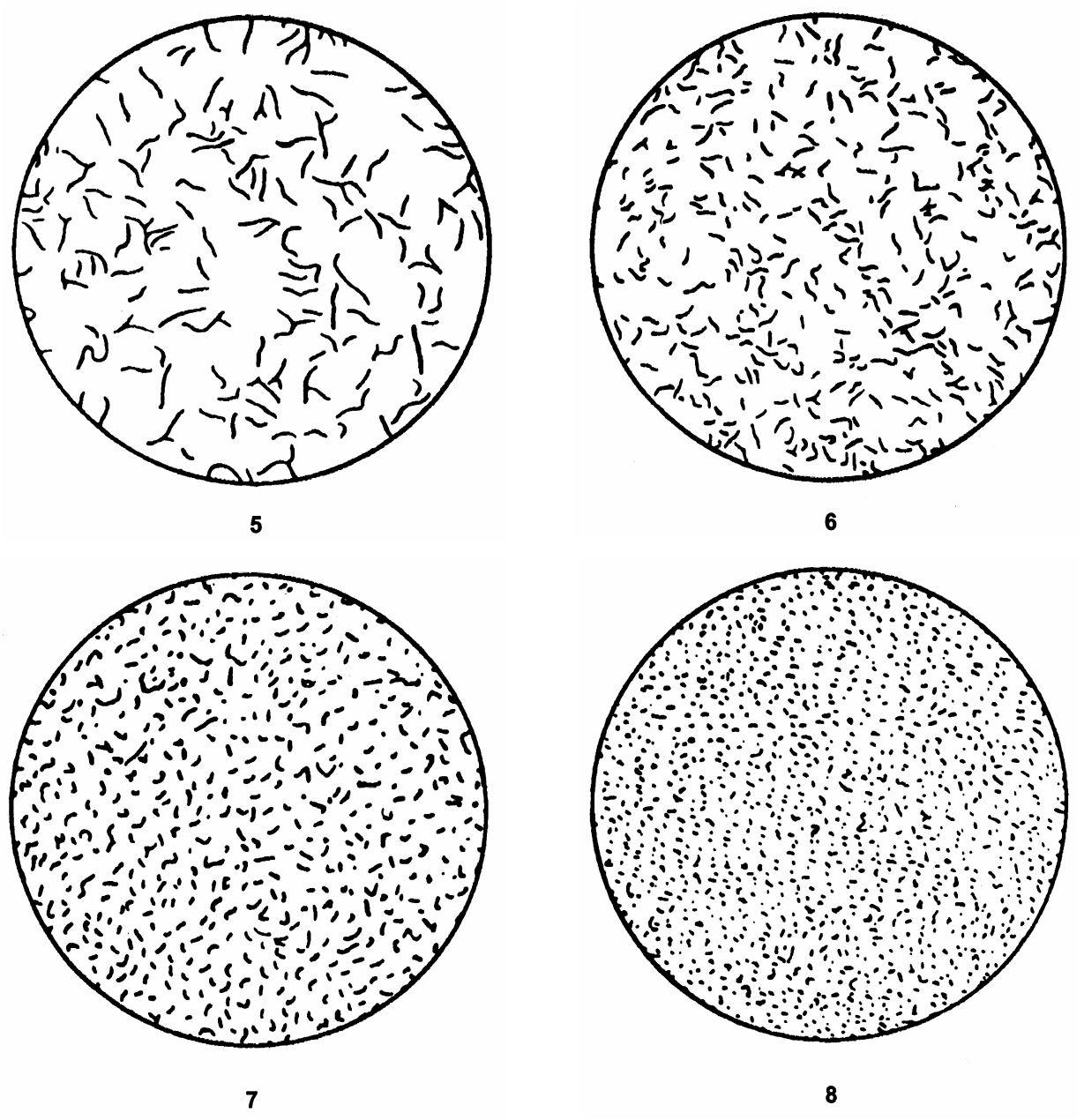


a) Sizes 1 to 4

Figure 3 — Reference images for graphite size (form I)

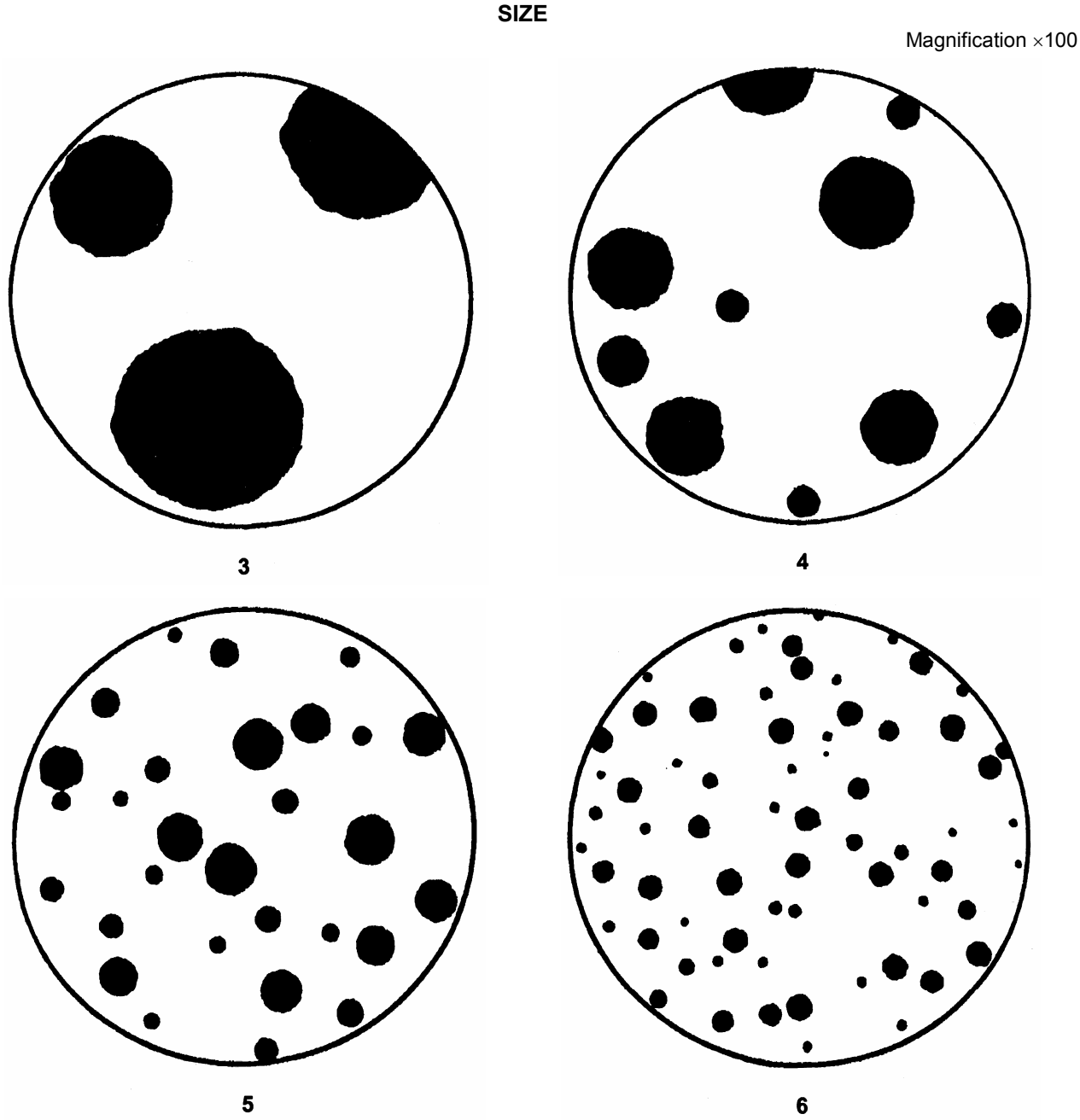
SIZE

Magnification ×100



b) Sizes 5 to 8

Figure 3 — Reference images for graphite size (form I)

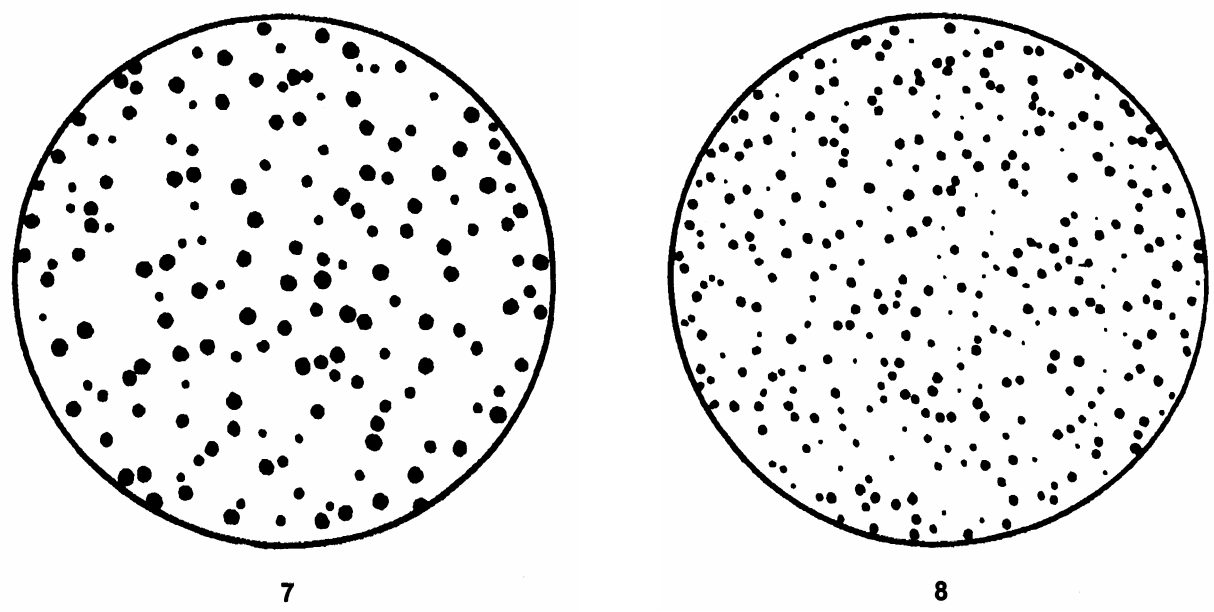


a) Sizes 3 to 6

Figure 4 — Reference images for graphite size (forms IV to VI)

SIZE

Magnification ×100

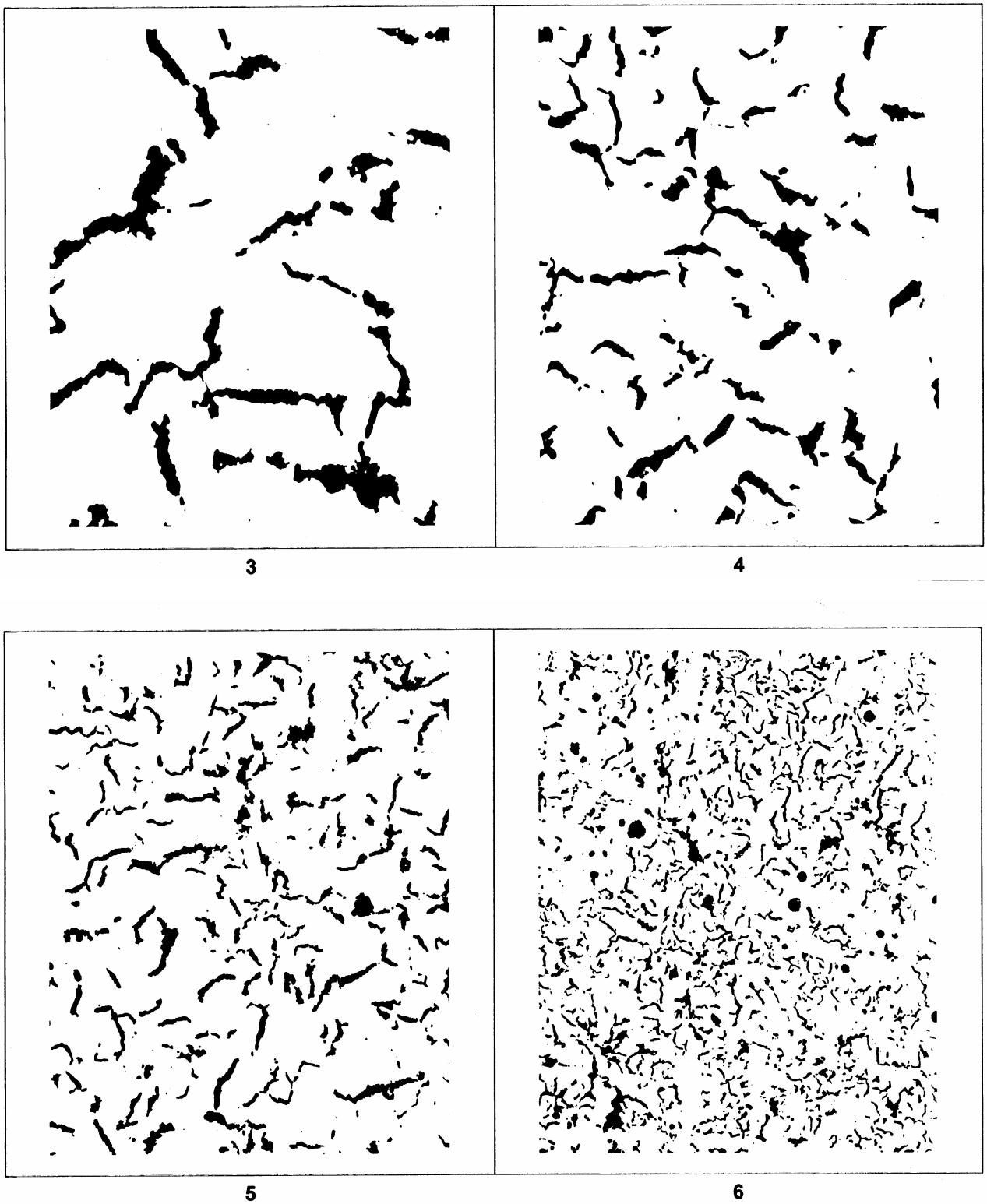


b) Sizes 7 and 8

Figure 4 — Reference images for graphite size (forms IV to VI)

SIZE

Magnification ×100

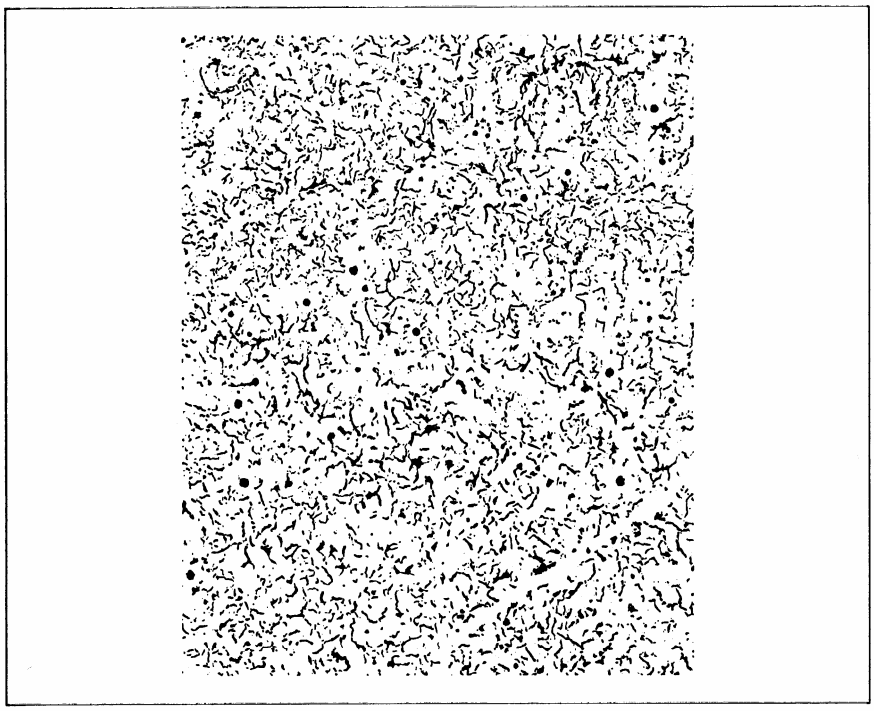


a) Sizes 3 to 6

Figure 5 — Reference images for graphite size (form III)

SIZE

Magnification ×100



7

b) Size 7

Figure 5 — Reference image for graphite size (form III)

2.2 Visual classification of graphite

The reference images given in Figures 1, 2, 3, 4 and 5 provide a basis for classifying graphite forms, distribution and size. The characteristic features of the graphite which occur are designated by letters and numerals. For this purpose, microstructures of graphite are arranged in a series of reference images consisting of schematic microstructures and photomicrographs of cast-iron microstructures. Therefore, among the images representing the size of the graphite, those for graphite form III (vermicular) in Figure 5 correspond to actual structures with the matrix removed. Those for graphite form I in Figure 3 and for graphite forms IV to VI in Figure 4 are fully schematic.

The form, distribution and size of the graphite observed are determined by comparison with the reference images and the allocation of the same classification as that of the images that resemble them most closely. This method permits quick identification of the graphite form.

NOTE The comparison of actual microstructures with schematic images or photomicrographs depends on the subjective impression of the metallographer.

3 Sampling and preparation of samples

3.1 Samples taken from a casting

When taking samples from a casting, it is essential that attention be paid to the location, to the wall thickness, to the distance from the surface and to the presence of chills. The location of the sample in the casting shall be recorded in a report.

If more than one casting is examined, the samples shall be taken from the same location in each casting for the purpose of comparability.

The location of the metallographic specimen shall be agreed between the manufacturer and the purchaser, as stated in the relevant material standard.

3.2 Sample preparation

The area of the polished surface shall be sufficient to give a true representation of the graphite structure. Attention shall be paid to the careful grinding and polishing of the samples, so that the graphite particles appear in their original form, size and distribution. Inappropriate grinding and polishing can cause an unacceptable alteration of the microstructure. If necessary, the method of polishing may be agreed between the manufacturer and the purchaser.

The examination of the graphite under the microscope is usually carried out on the unetched polished section.

4 Procedure for graphite classification

4.1 Procedure for visual classification of graphite

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 $\times$100 magnification should preferably be chosen. If necessary, the magnification may be adapted in relation with the wall thickness so that the form and distribution of graphite can be determined by using the reference images given in Figures 1 and 2 (see also Annexes A, B and C). Adjust the microscope magnification to match as closely as possible the corresponding images in Figures 1 and 2 before classifying the graphite form and its distribution, if appropriate. The graphite size shall only be determined by reference to Figures 3, 4 and 5 and Table 1, preferably at $\times$100 magnification. Other magnifications are permitted (see Table 1, Notes 1 and 2, as well as 5.4).

Examination under the microscope shall be carried out by direct observation in the microscope or by projection on the ground glass of the microscope or on a visual display screen. The field of view should preferably have approximately the same size as the reference images. The measurement of the graphite particles can be facilitated by the use of suitably calibrated eye-pieces.

Form and distribution of graphite shall be determined by using the reference images, given in Figures 1 and 2 (see also Annexes A, B and C). Adjust the microscope magnification to match as closely as possible the corresponding images in Figures 1 and 2 before classifying the graphite form and its distribution, if appropriate.

If the microstructure is visualized on a visual display screen, the combined magnification of both microscope and screen (depending on its size) shall be taken into account.

4.2 Evaluation of the analysis results

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

5 Reference images

5.1 General

A series of reference images (see Figures 1 to 5) showing schematic microstructures and photomicrographs is provided for the classification of the form, distribution and size of the graphite in cast iron.

In addition to reference images, the photomicrographs show actual graphite microstructures (see Annexes A and B).

5.2 Reference images for graphite form

The reference images for the graphite form (see Figure 1) show six characteristic forms which are designated by the Roman numerals I to VI (see also Annex A). These represent the principal types of graphite observed in cast-iron materials. Annex C gives the common terminology and the occurrence of these types of graphite.

The graphite forms are specified in the relevant material standards. Percentages of these graphite forms may also be specified by these standards, e.g. in the case of compacted (vermicular) graphite cast irons.

NOTE ASTM A 247 designates graphite forms in the reverse order compared to this part of ISO 945. It is therefore necessary to specify the test method used to classify the graphite form.

5.3 Reference images for the distribution of graphite (form I)

The reference images for the graphite distribution (see Figure 2) show characteristic graphite distributions designated by the letters A to E.

In addition to reference images, the photomicrographs show actual graphite microstructures (see Annex B).

A variant of distribution C, designated C′, has been included in Annex B. This distribution corresponds to thin-walled castings.

5.4 Reference images for graphite size

Figures 3, 4 and 5 shall be used to determine the graphite size. By agreement between the manufacturer and the purchaser, Table 1 may be used in addition. For $\times$100 magnification, sizes are indicated ranging from a maximum size of the particle of $>$ 100 mm (size 1) down to $<$ 1,5 mm (size 8). The size ranges covered by the size reference numbers 3 to 7 inclusive are based on an average particle size which is half that in the larger size range. When using Table 1, alternative magnifications may be used (see Table 1, Notes 1 and 2).

If necessary, different size ranges may be agreed upon.

NOTE Sizes 1 and 2 have no practical application for graphite forms III to VI. Therefore, they have not been included in Figures 4 and 5.

6 Designation of graphite by form, distribution and size

6.1 Designation system

To characterize the graphite observed, indications are generally necessary on the form, distribution and size of the graphite particles. For this purpose, the following symbols shall be used at different positions of the designation:

— the Roman numerals given in Figure 1 are used for the graphite form at position 1;

— for form I, the capital letters given in Figure 2 are used for the distribution at position 2;

— the Arabic numerals given in Figures 3, 4, and 5 and Table 1 are used for the graphite size at position 3.

EXAMPLE 1 For a grey cast iron with flake (lamellar) shaped graphite particles of form I, distribution A, and size 4, the following designation is used to describe that structure:

I A 4

EXAMPLE 2 For a cast iron with spheroidal graphite particles of form VI and size 4, the following designation is used to describe that structure:

VI 4

Table 1 — Dimensions of graphite particle forms I to VI

Dimensions in millimetres

Size range reference number	Indication of the particle size observed at ×100 magnification	Actual dimension
1	⩾ 100	⩾ 1
2	50 to < 100	0,5 to < 1
3	25 to < 50	0,25 to < 0,5
4	12 to < 25	0,12 to < 0,25
5	6 to < 12	0,06 to < 0,12
6	3 to < 6	0,03 to < 0,06
7	1,5 to < 3	0,015 to < 0,03
8	< 1,5	< 0,015
NOTE 1 When determining size ranges 1 and 2, a lower magnification (×25 or ×50) may be used.		
NOTE 2 When determining size ranges 6 to 8, a higher magnification (×200 or ×500) may be used.		
NOTE 3 For determining size ranges, the largest visible graphite particle size is used.		

6.2 Designation of intermediate graphite sizes

If the graphite observed covers two sizes, reference to both is possible:

EXAMPLE 1 3/4

In addition, the predominant size may be emphasized by underlining:

EXAMPLE 2 3/<u>4</u>

This method can be extended to cover microstructures where more than two sizes are present.

6.3 Designation of mixed graphite forms, distributions and sizes

More complex microstructures containing different types of graphite can be defined by estimating the percentage proportions of the different types of graphite.

EXAMPLE 1 For a cast iron with a graphite area comprising 60 % flake (lamellar) shaped graphite particles of form I, distribution A and size 4 and 40 % flake (lamellar) shaped graphite particles of form I, distribution D and size 7, the following designation is used to describe the structure:

60 % I A 4 + 40 % I D 7

EXAMPLE 2 For a cast iron with a graphite area comprising 85 % spheroidal graphite particles of form VI and size 4 and 15 % vermicular graphite particles of form III and covering sizes 3 and 4, the following designation is used to describe the structure:

85 % VI 4 + 15 % III 3/4

6.4 Nodule count

The graphite nodule count n_F is determined by using the planimetric method (see Reference [2]). Nodules are particles normally classified as form VI or V (or even form IV).

$$n_F = \frac{N}{A} \times F^2 \tag{1}$$

where

n_F is the number of particles per unit surface area of the sample;

N is the number of nodules counted;

A is the magnified area;

F is the linear magnification factor.

EXAMPLE At a magnification of ×100, a circle measuring 79,8 mm in diameter (= 5 000 mm^2) is superimposed over a micrograph. At the preferred magnification of ×100, the circular area should preferably contain at least 50 graphite particles in order to minimize the counting error associated with a circular test pattern. Two counts are made:

n_1 is the number of graphite particles completely within the test circle;

n_2 is the number of graphite particles intersected by the test circle.

The total number of graphite particles in this circle of 5 000 mm^2 is

$$n_{100} = n_1 + \frac{n_2}{2} \tag{2}$$

In this case, to express the nodule count as nodules/mm^2, the result given by Equation (2) has to be multiplied by 2, since

$$\frac{F^2}{A} = \frac{100^2}{5\,000} \tag{3}$$

This operation is repeated on other fields.

The larger the number of fields measured, the more representative is the result.

7 Report

If a report is required, it shall contain the following information:

— identification of the sample or casting;

— the sampling location(s);

— the number of samples taken and the number of areas evaluated;

— the form, distribution and size of the graphite;

— the magnification used;

— a reference to this part of ISO 945;

— the date of the report;

— the name of the organization;

— the name of the person authorized to sign the report.

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

— the nodule count;

— the designation of the material;

— the metallographic preparation procedure used;

— the size of the cast-on sample or separately cast sample and/or the wall thickness of the respective sample;

— the size of the graphite;

— details of the presence of any other graphite form not covered by this part of ISO 945.

One or more photomicrographs may also be included in the report.

Annex A
(informative)

Typical graphite forms in cast-iron materials
(Examples of photomicrographs)

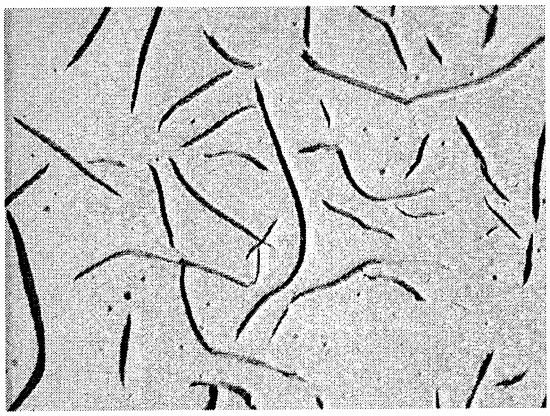
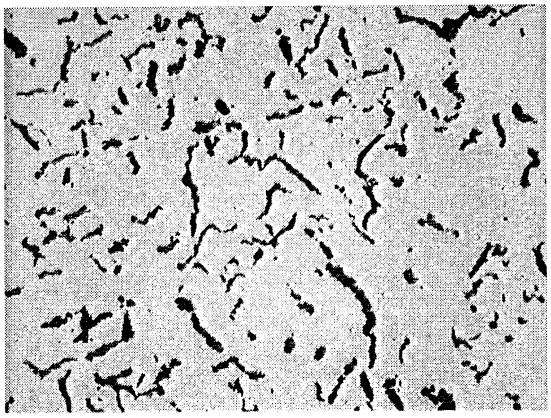
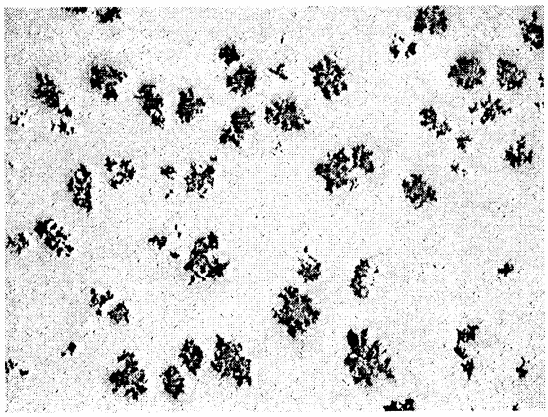
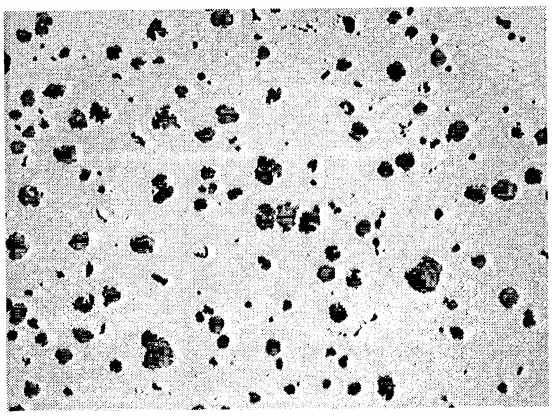
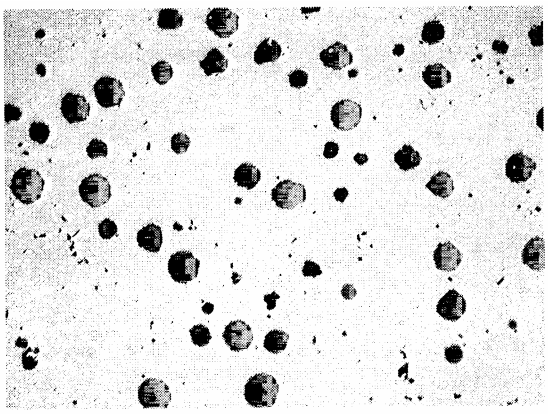
Form I 	**Form II** Form II, represented by the reference image shown in Figure 1, is never encountered alone in cast irons (see Annex C).
Form III 	**Form IV** 
Form V 	**Form VI** 

Figure A.1 — Examples of photomicrographs

Annex B
(informative)

Distribution of flake (lamellar) graphite (form I)
(Examples of photomicrographs)

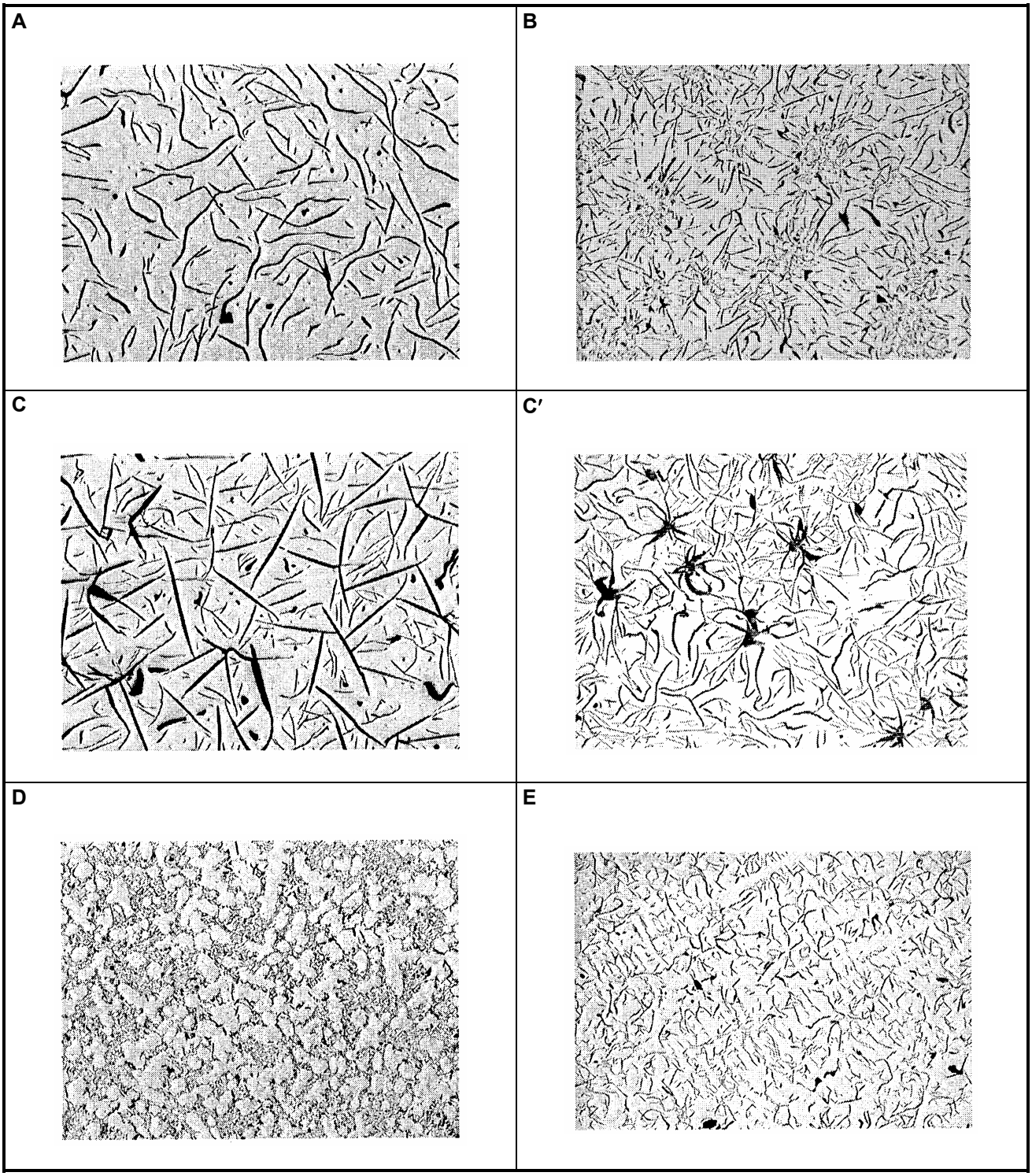


Figure B.1 — Examples of photomicrographs

Annex C
(informative)

Common terminology and main occurrences concerning graphite in cast irons

Table C.1 — Graphite forms (see Figure 1 and Annex A)

Form	Usual terminology	Main spatial characteristics	Occurrence	Relevant material standard
I	Lamellar graphite Flake graphite	Interconnected particles within eutectic cells; lamellar graphite with sharp ends	Principal form in grey cast iron Austenitic cast iron with lamellar/flake graphite Can occur in the rim zone of other cast-iron materials	ISO 185 ISO 2892
II	Crab graphite	Aggregate of graphite flakes	Can occur in rapidly cooled hypereutectic grey cast irons (see Annex B and Table C.2) Can also occur in segregation areas of thick-walled spheroidal-graphite iron castings	ISO 185
III	Vermicular graphite Compacted graphite	Usually interconnected particles within eutectic cells; worm-like appearance with rounded ends	Principal form in compacted-graphite cast iron Can occur in spheroidal-graphite cast iron	ISO 16112
IV	Temper carbon	Isolated particles	Principal form in malleable cast iron	ISO 5922
V	Slightly irregular spheroidal or nodular graphite particles	Isolated particles	Principal form in thick-walled castings made of spheroidal-graphite cast iron, ausferritic spheroidal-graphite cast iron and austenitic cast iron with spheroidal graphite Occurs to a specified extent in compacted-graphite cast iron	ISO 1083 ISO 17804 ISO 2892
VI	*S*pheroidal or nodular graphite particles	Isolated particles	Principal form in spheroidal-graphite cast iron, ausferritic spheroidal-graphite cast iron and austenitic cast iron with spheroidal graphite Occurs to a specified extent in compacted-graphite cast iron	ISO 1083 ISO 17804 ISO 2892

Table C.2 — Graphite distributions in grey cast iron
(see Figure 2 and Annex B)

Distribution	Alternative terminology	Main 2D appearance	Occurrences
A	—	Apparently uniform distribution	Cast iron solidified with a low to intermediate degree of undercooling.
B	Rosette graphite Rosette graphite with undercooling graphite	—	Cast iron solidified with an intermediate degree of undercooling, particularly thin-walled castings.
C	Primary graphite	Aggregate of larger graphite flakes surrounded by smaller, randomly oriented graphite flakes (eutectic graphite)	Hypereutectic cast iron. In thin-walled castings, the larger particles can adopt form II (see Annex B, distribution C′).
D	Fine (interdendritic) graphite Undercooling graphite	Finely branched graphite Fine, randomly oriented graphite flakes in the interdendritic position	Cast iron solidified with a high degree of undercooling. The distribution can be associated with other distributions (for example A and/or B and/or E). Distribution D can appear in the centre of rosette groupings in the case of a relatively high degree of undercooling.
E	Interdendritic graphite	Preferentially orientated graphite flakes in the interdendritic position	Cast iron with low carbon equivalent, solidified with low or moderate undercooling. Local area corresponding to a plane of polish cutting through the main axis of some highly oriented dendrites.

Bibliography

[1] ISO 185, *Grey cast irons — Classification*

[2] ISO 643, *Steels — Micrographic determination of the apparent grain size*

[3] ISO 1083, *Spheroidal graphite cast irons — Classification*

[4] ISO 2892, *Austenitic cast irons — Classification*

[5] ISO 5922, *Malleable cast iron*

[6] ISO 16112, *Compacted (vermicular) graphite cast irons — Classification*

[7] ISO 17804, *Founding — Ausferritic spheroidal graphite cast irons — Classification*

[8] ASTM A 247, *Standard Test Method for Evaluating the Microstructure of Graphite in Iron Castings*

[9] *Foundrymen's Guide to Ductile Iron Microstructures*, 2nd edition, 1987

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