BS EN 62047-14:2012

BSI Standards Publication

Semiconductor devices — Micro-electromechanical devices

Part 14: Forming limit measuring method of metallic film materials

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The UK participation in its preparation was entrusted to Technical Committee EPL/47, Semiconductors.

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Published by BSI Standards Limited 2012

ISBN 978 0 580 72297 4

ICS 31.080.99

This British Standard was published under the authority of the Standards Policy and Strategy Committee on 31 May 2012.

Amendments issued since publication

Amd. No.	Date	Text affected

EUROPEAN STANDARD
NORME EUROPÉENNE
EUROPÄISCHE NORM

EN 62047-14

April 2012

ICS 31.080.99

English version

Semiconductor devices - Micro-electromechanical devices - Part 14: Forming limit measuring method of metallic film materials
(IEC 62047-14:2012)

Dispositifs à semiconducteurs - Dispositifs microélectromécaniques - Partie 14: Méthode de mesure des limites de formage des matériaux à couche métallique
(CEI 62047-14:2012)

Halbleiterbauelemente - Bauelemente der Mikrosystemtechnik - Teil 14: Verfahren zur Ermittlung der Grenzformänderung metallischer Dünnschichtwerkstoffe
(IEC 62047-14:2012)

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Foreword

The text of document 47F/108/FDIS, future edition 1 of IEC 62047-14, prepared by SC 47F, "Micro-electromechanical systems", of IEC TC 47, "Semiconductor devices" was submitted to the IEC-CENELEC parallel vote and approved by CENELEC as EN 62047-14:2012.

The following dates are fixed:

• latest date by which the document has to be implemented at national level by publication of an identical national standard or by endorsement	(dop)	2013-01-03
• latest date by which the national standards conflicting with the document have to be withdrawn	(dow)	2015-04-03

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Annex ZA

(normative)

Normative references to international publications with their corresponding European publications

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

NOTE When an international publication has been modified by common modifications, indicated by (mod), the relevant EN/HD applies.

Publication	Year	Title	EN/HD	Year
IEC 62047-1	2005	Semiconductor devices - Micro-electromechanical devices - Part 1: Terms and definitions	EN 62047-1	2006

CONTENTS

SEMICONDUCTOR DEVICES – MICRO-ELECTROMECHANICAL DEVICES –

Part 14: Forming limit measuring method of metallic film materials

1 Scope

This part of IEC 62047 describes definitions and procedures for measuring the forming limit of metallic film materials with a thickness range from 0,5 μm to 300 μm. The metallic film materials described herein are typically used in electric components, MEMS and micro-devices.

When metallic film materials used in MEMS (see 2.1.2 of IEC 62047-1:2005) are fabricated by a forming process such as imprinting, it is necessary to predict the material failure in order to increase the reliability of the components. Through this prediction, the effectiveness of manufacturing MEMS components by a forming process can also be improved, because the period of developing a product can be reduced and manufacturing costs can thus be decreased. This standard presents one of the prediction methods for material failure in imprinting process.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 62047-1:2005, *Semiconductor devices – Micro-electromechanical devices – Part 1: Terms and definitions*

3 Terms, definitions and symbols

3.1 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC 62047-1 and the following apply.

3.1.1
circular grid
grid used for measuring the localized deformation of the specimens within the circle

3.1.2
grid patterns
pattern marked on the surface of the testing material permitting immediate and direct measurement of the formability for the metallic film materials

Note 1 to entry The grid consists of a pattern of small circles or rectangles.

3.1.3
major axis
longest line of the deformed elliptical shape, which passes through both focuses of the ellipse

3.1.4
minor axis
longest line of the deformed elliptical shape, which is perpendicular to the major axis

3.1.5
square grid
grid used for measuring the overall deformation of the testing material

3.2 Symbols

For the purpose of this document, letter symbols given in Table 1 are used.

Table 1 – List of letter symbols

Name and designation	Letter symbol
Grid size	
– initial diameter of the grid before deformation	d_0
– diameter of the grid along the major axis after deformation	d_1
– diameter of the grid along the minor axis after deformation	d_2
Strain	
– major strain	ε_1
– minor strain	ε_2
Equipment, tool and specimen size	
– diameter of the hemispherical punch	D_{punch}
– inner diameter of the die hole	D_{die}
– diameter of the bead ring	D_{bead}
– fillet radius of the upper die edge	r_{de}
– thickness of the testing specimen	t
– height of the testing specimen	h
– width of the testing specimen	w

4 Testing method

4.1 General

The forming limit diagram (FLD) is determined by pressing the micro film material using a hemispherical punch. This pressing process is performed until the film material fractures. The major and minor strains of a deformed specimen can be measured in many ways, for example, by using a digital camera module or an optical device. However, using a digital camera module with sufficient resolution and a high magnifying power lens is recommended.

NOTE See Annex A for principles of forming limit diagram.

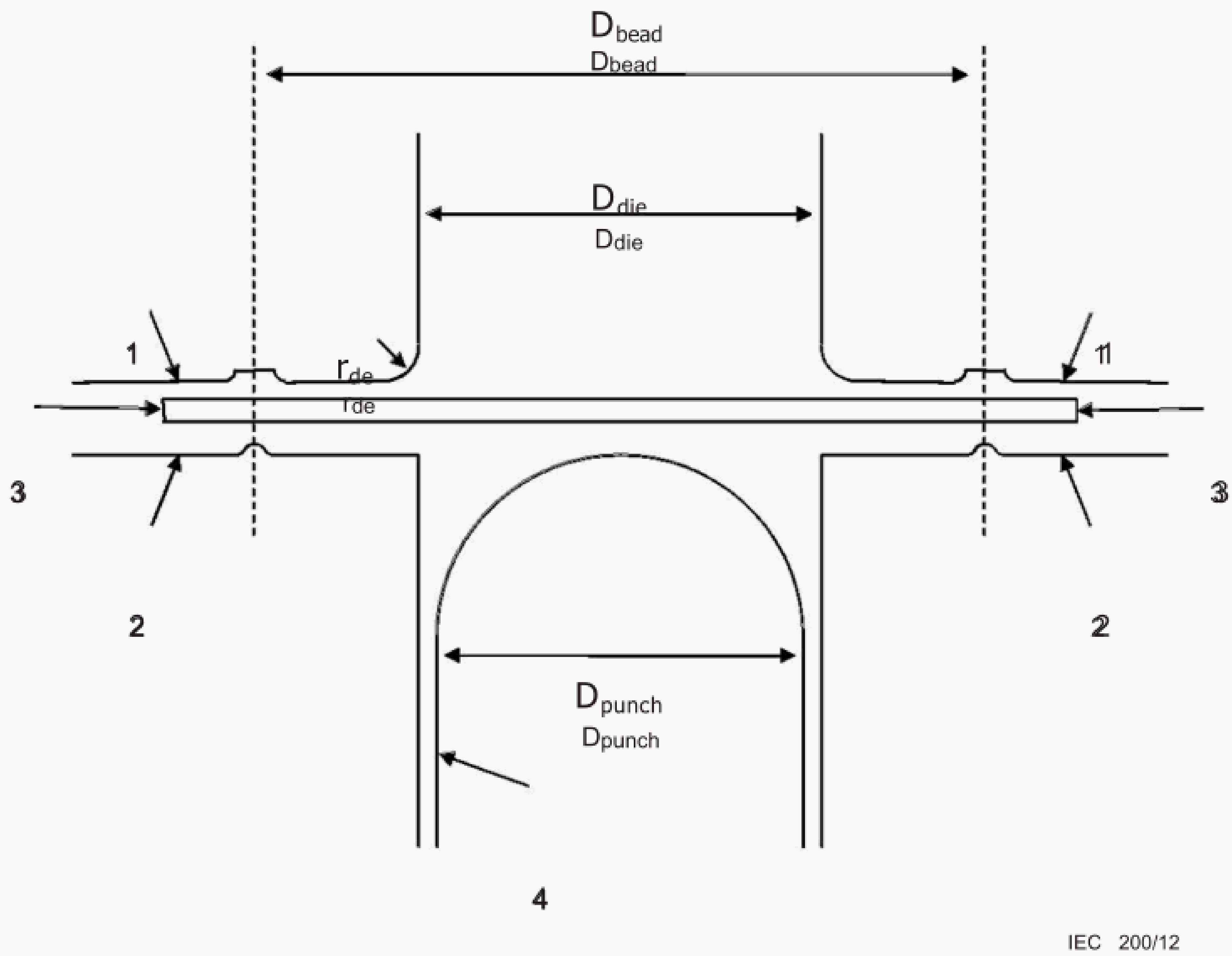
4.2 Equipment

Micro press equipment is utilized as the loading equipment for FLD tests as described in Figure 1. A hemispherical punch is attached to the micro press to stretch the film material to measure the forming limits of the specimen. Conventional hard chrome coating to the punch surface using hexavalent chromium is recommended to guarantee a surface roughness less than 0,8 μm (RMS: Root Mean Square). In addition, lubricants such as graphite can be applied for reducing the friction force between the surfaces of the punch and the specimen. The movement of the punch is controlled by a constant crosshead speed of the measuring devices in the micro press. The punch speed shall be lowered to the quasi-static condition. A punch speed of less than 20 μm/s is recommended in order not to result in the dynamic inertia effect during the test. Although the dimension of the hemispherical punch and the test samples can be varied with forming product and inspected measuring region, it is recommended that the dimension should be determined as the following ratio.

$$D_{die} = D_{punch} + 2{,}5t \quad (1)$$

$$D_{bead} = 2 \times D_{punch} \quad (2)$$

It is also recommended that the hemispherical punch diameter and the die edge radius should be 5 mm and 0,5 mm respectively.



Key

1 upper die

2 lower die

3 specimen

4 hemispherical punch

Figure 1 – Equipment and tools for forming limit tests

4.3 Specimen

Rectangular specimens with different aspect ratios shall be used in the test. At least six kinds of specimens with the aspect ratios of 1,0, 1,5, 1,75, 2,0, 3,5 and 7,0 are recommended as shown in Figure 2 in order to cover the various loading paths on the domain of the forming limit diagram.

$$h = 2{,}5 \times D_{punch} \quad (3)$$

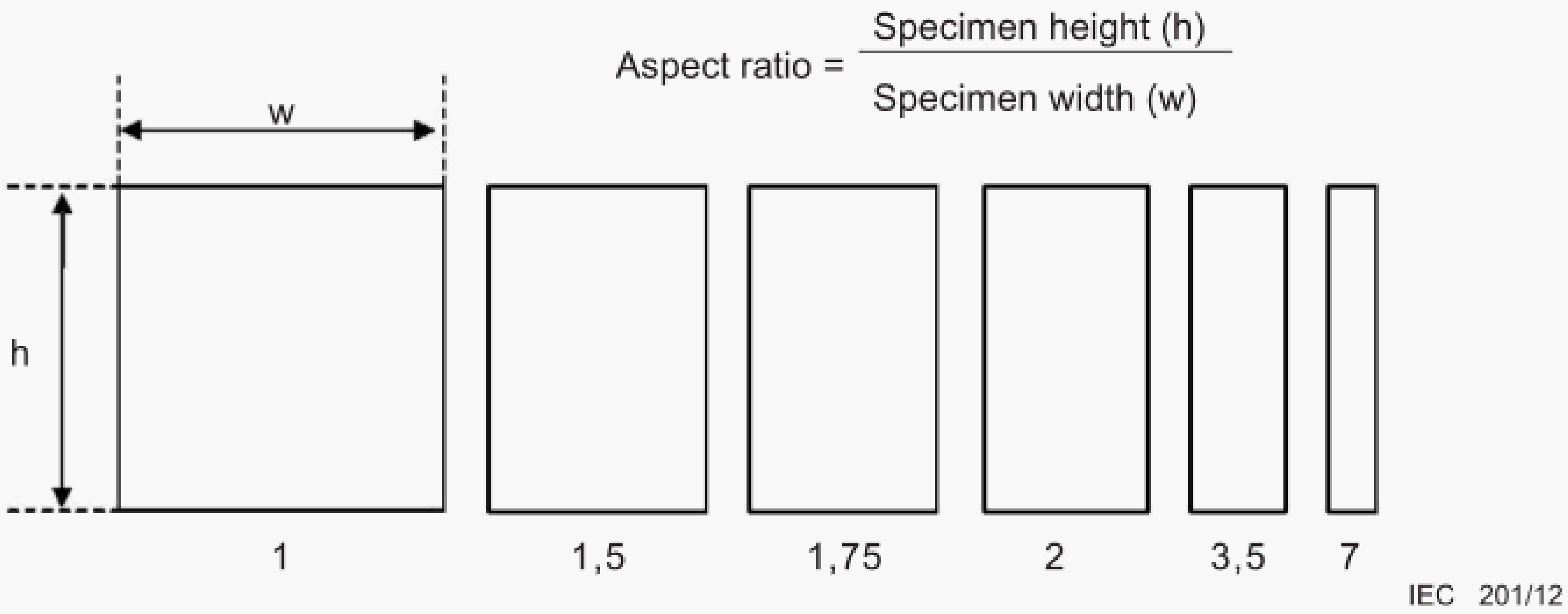


Figure 2 – Rectangular specimens with six kinds of aspect ratio

Grids shall be marked to the surface of the testing sample to measure the localized and overall deformation of the film material. The grid consists of a pattern of small circles or rectangles. It is recommended to arrange the grid patterns with an interval range from 50 µm to 200 µm and that the thickness of the grid is less than 10 % of the specimen thickness.

NOTE See Figure A.3 for detailed grid pattern.

5 Test procedure and analysis

5.1 Test procedure

In a FLD test, the following items from a) to e) are steps to obtain a localized fracture of a specimen which is firstly observed. Then the values of a major strain and a minor strain which are used to quantify the deformation of the specimen will be measured.

a) Preparation of the specimen

Specimens with different aspect ratios are prepared to conduct the test.

NOTE 1 Both the positive and negative region of the FLD curve can be obtained by varying the aspect ratio of the specimen and the lubricant.

b) Grid marking on the specimen

Appropriate marking conditions which have a lesser effect on the microstructure and the properties of materials should be applied in the grid marking since the thickness of the film is relatively smaller.

NOTE 2 See Annex B for detail expression of several grid marking methods.

c) Gripping the specimen

In order to measure the strain only in the testing region, it is important that the sample should be clamped without any sliding. Also, pre-fracture should not occur when it is being clamped.

NOTE 3 See Annex C for several recommended gripping methods.

d) Moving the punch until the specimen fails

The hemispherical punch moves by controlling the constant crosshead speed of equipment until the localized fracture of the specimen is first observed.

e) Measuring the major and minor strains of deformed specimen

Major and minor strains of the deformed specimen are measured representatively using the digital camera module with a high magnifying power lens. The recommended magnification factor of the camera lens is less than 5 µm/pixel in order to measure the strain precisely.

NOTE 4 See Annex D for strain measuring method.

f) Construct the FLD by plotting the measured major and minor strains (refer to Figure 4).

5.2 Data analysis

In order to quantify the deformation of the specimen, two kinds of strains – major and minor strains – are measured between the initial state of the circle and the deformed elliptical shape. After the circular grid deforms, the longest dimensions of the ellipse is major axis and the dimension perpendicular to the major axis is the minor axis, as explained in Figure 3.

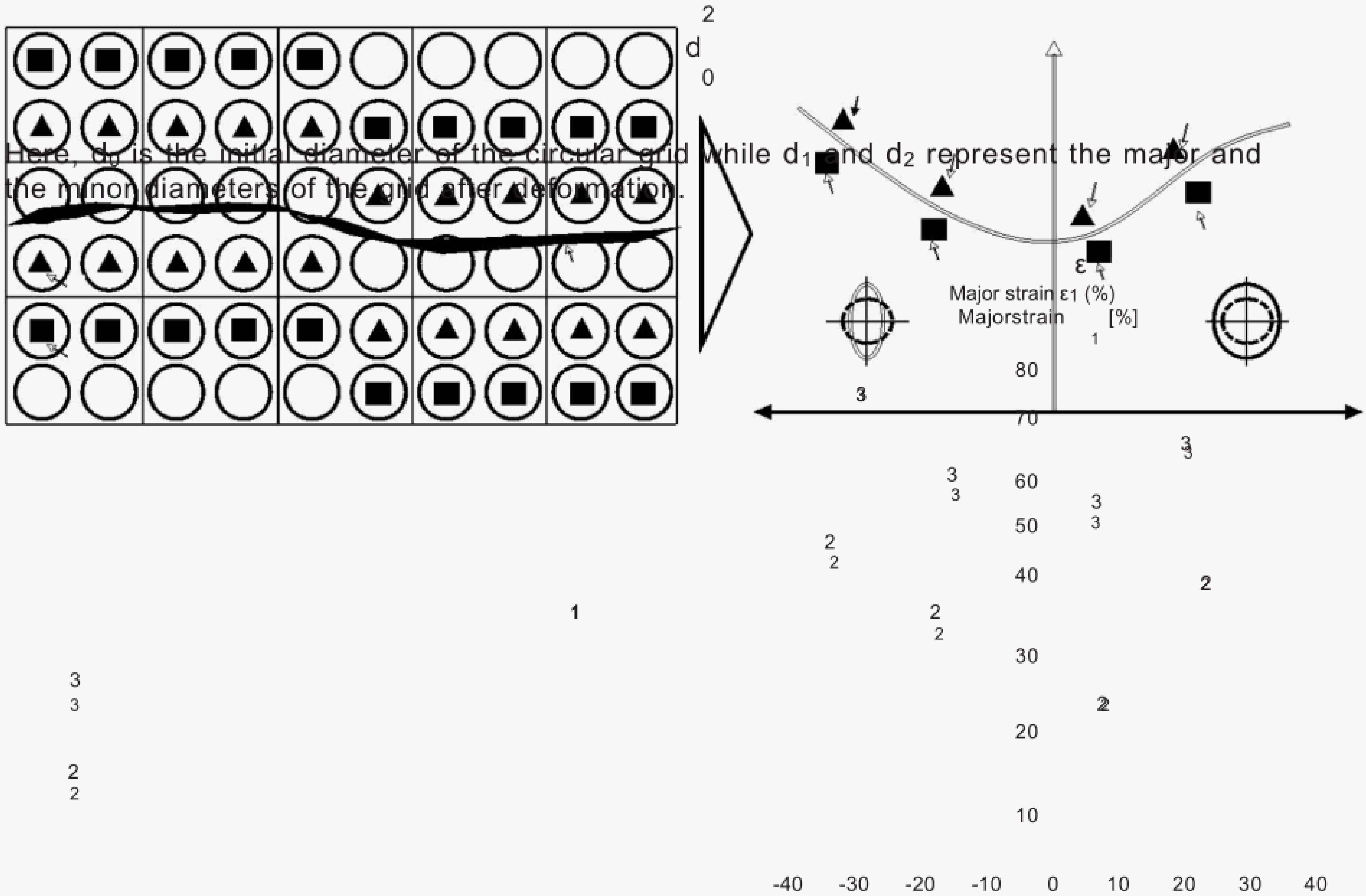
Figure 3 – Strain for forming limit measurement

The major strain, ε_1, and the minor strain, ε_2, are calculated with following equations:

$$\varepsilon_1 = \ln \frac{d_1}{d_0} \quad (4)$$

$$\varepsilon_2 = \ln \frac{d_2}{d_0} \quad (5)$$

Here, d_0 is the initial diameter of the circular grid while d_1 and d_2 represent the major and the minor diameters of the grid after deformation.



ε
Minor strain ε_2 (%)
Minorstrain $_2$ [%]

IEC 203/12

Key

1 fracture

2 good

3 failure

Figure 4 – Construct the forming limit diagram by plotting the major and minor strains

The major and minor strains calculated from the grids in the neighbourhood of the failure zone of the specimen are regarded as critical failure strains. By conducting a series of experiments with various specimens, it is possible to find combinations of major strain and minor strain for which neither necking nor fracture occurs by plotting on the strain domain. The diagram plotting the combinations of major and minor strains is a forming limit diagram as shown in Figure 4.

6 Test report

The test report should contain at least the following information:

a) reference to this international standard;

b) testing material;

c) grid marking method;

d) number of specimens used in the test;

e) dimensions of the specimen(s);

f) description of testing apparatus (punch diameter, gripping method, punch roughness, etc.);

g) lubrication condition;

h) crosshead speed of testing apparatus;

i) strain measurement module: specification of the digital camera, scale factor of each pixel;

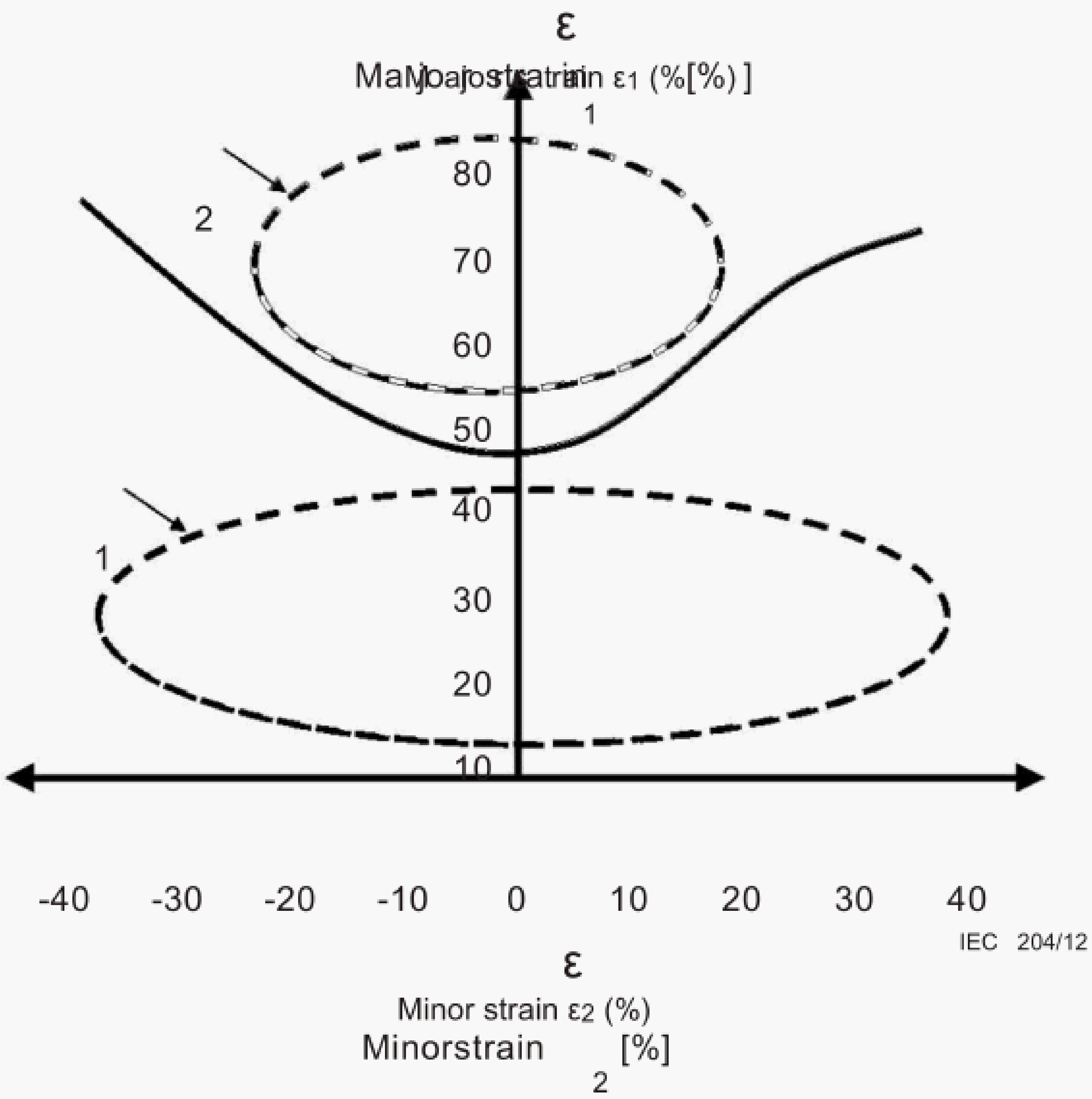
j) measured diameters and calculated strains of each specimen;

k) forming limit diagram.

Annex A
(informative)

Principles of the forming limit diagram

The maximum major and minor strains at fracture are plotted in the strain domains. The surface of metallic film material part deforms differently based on the type of loading. A relationship exists between the deformation of the film material and the type of stressing. By conducting a series of experiments, it is possible to find combinations of maximum strain (corresponding to the major axis of the ellipse) and minimum strain (perpendicular to the major strain and corresponding to the minor axis of the ellipse) for which neither necking nor fracture occurs. The FLD is valid for a definite formability and defines two zones "good" and "failure". The strains plotted are the critical points, where cracks are likely to form. Between the two zones of "good" and "failure", there is a curve of critical deformation shown in Figure A.1



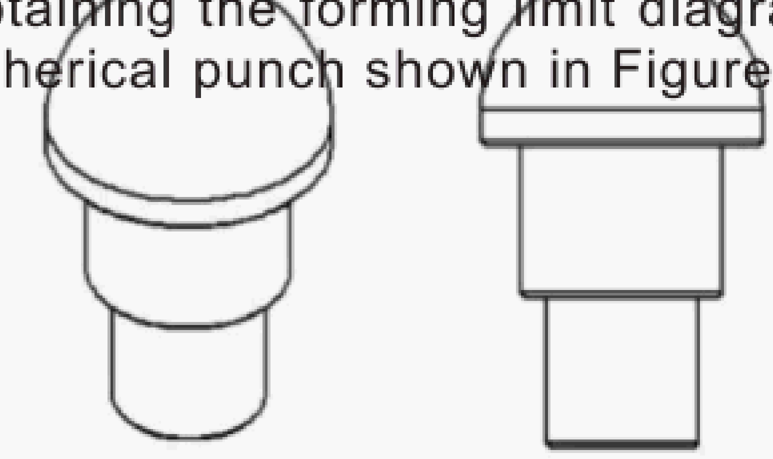
Key

1 good zone

2 failure zone

Figure A.1 – Forming limit diagram

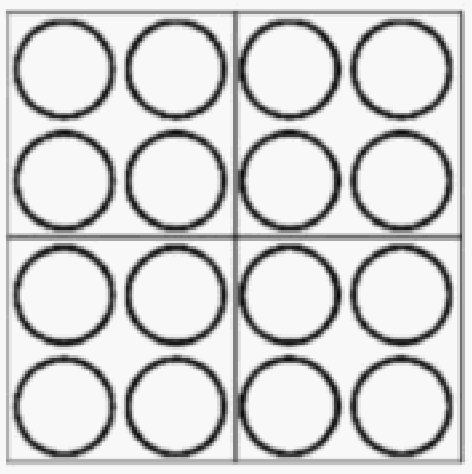
Forming limit diagrams can be obtained by conducting experiments for different zones. The most widely used method of obtaining the forming limit diagram is by means of drawing tests of the specimens with a hemispherical punch shown in Figure A.2.



IEC 205/12

Figure A.2 – Hemispherical punch for forming limit measurement

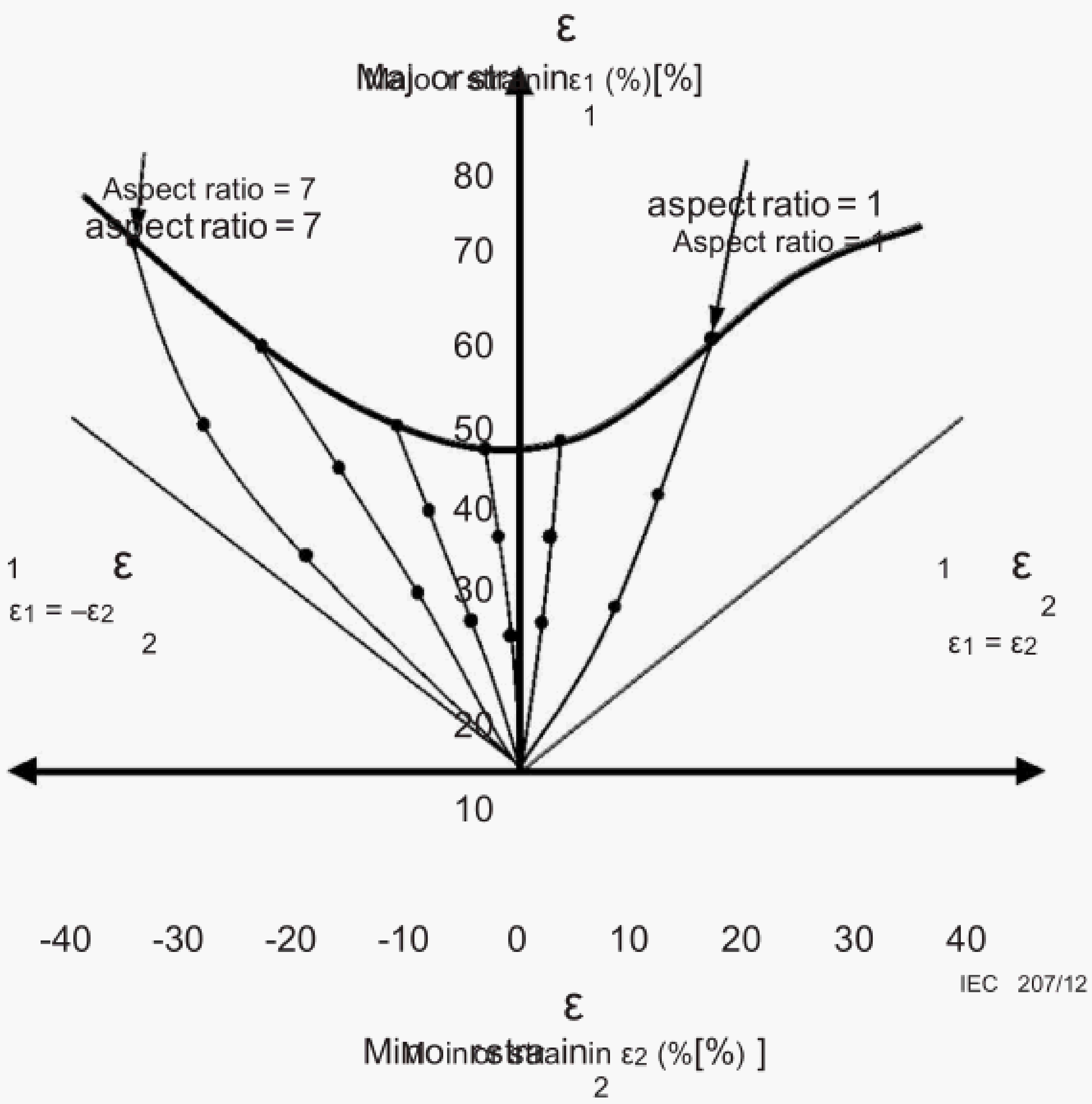
In order to evaluate the deformation behaviour and forming limits of metallic thin film, grid patterns are marked on the specimen. This permits immediate and direct measurement of the formability of the metallic thin film at any location. The grid consists of a pattern of small circles and rectangles as described in Figure A.3



IEC 206/12

Figure A.3 – Grid for forming limit measurement

Circular grid patterns on the surface of a film material part deform differently based on the type of loading. The different stress conditions are simulated by changing the width of the specimen. The specimens with various widths are drawn until cracks occur. With details from these tests, the FLD can be obtained for strain paths ranging from biaxial tension (stretch forming) to equal tension and compression (deep drawing) as explained in Figure A.4. The diagram shall be determined for each particular film material.



IEC 207/12

Figure A.4 – Loading path of the specimen with various aspect ratios

Annex B
(informative)

Grid marking method

B.1 General

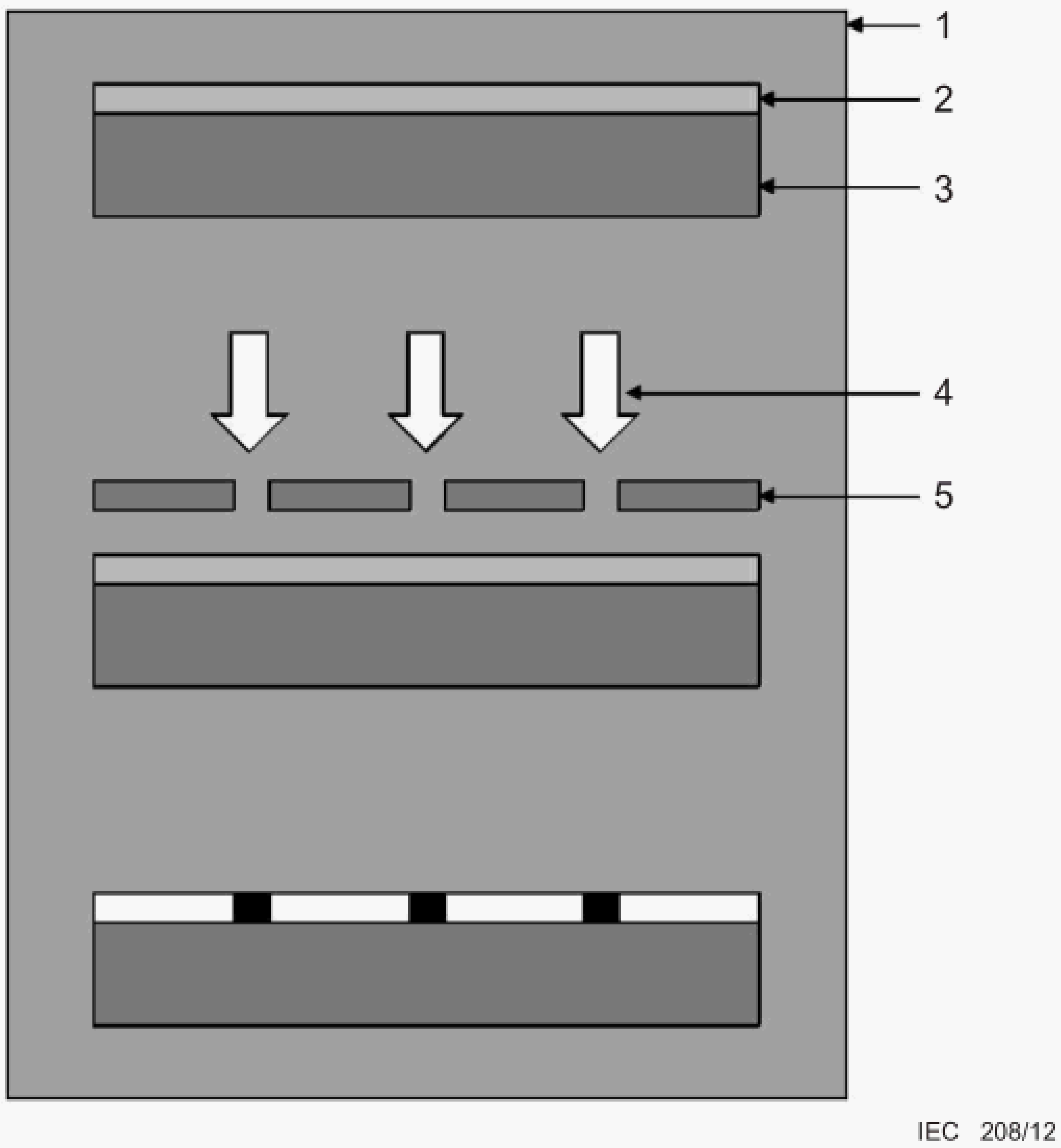
Photographic and inkjet methods are typical grid marking methods. The photographic method can achieve very small-sized grid marking through its precise processing, but there are disadvantages such as complex, slow work. The inkjet method has merits such as simplicity and quickness. However there are limits to precision work. The procedures and concepts for each method are as follows.

B.2 Photographic method

a) Deposit the photographic sensitive materials on the specimen;

b) Expose the photographic sensitive materials using a photo-mask;

c) Clean the specimen (refer to Figure B.1).



Key

1 dark room

2 photographic sensitive materials

3 specimen

4 light

5 photo mask

Figure B.1 – Procedure of a photographic grid marking method

B.3 Inkjet method

a) Place the specimen on the hot plate and inkjet machine;

b) Carry out the inkjet process according to the grid marking tool path data (refer to Figure B.2).

IEC 209/12

Key

1 specimen

2 hot plate

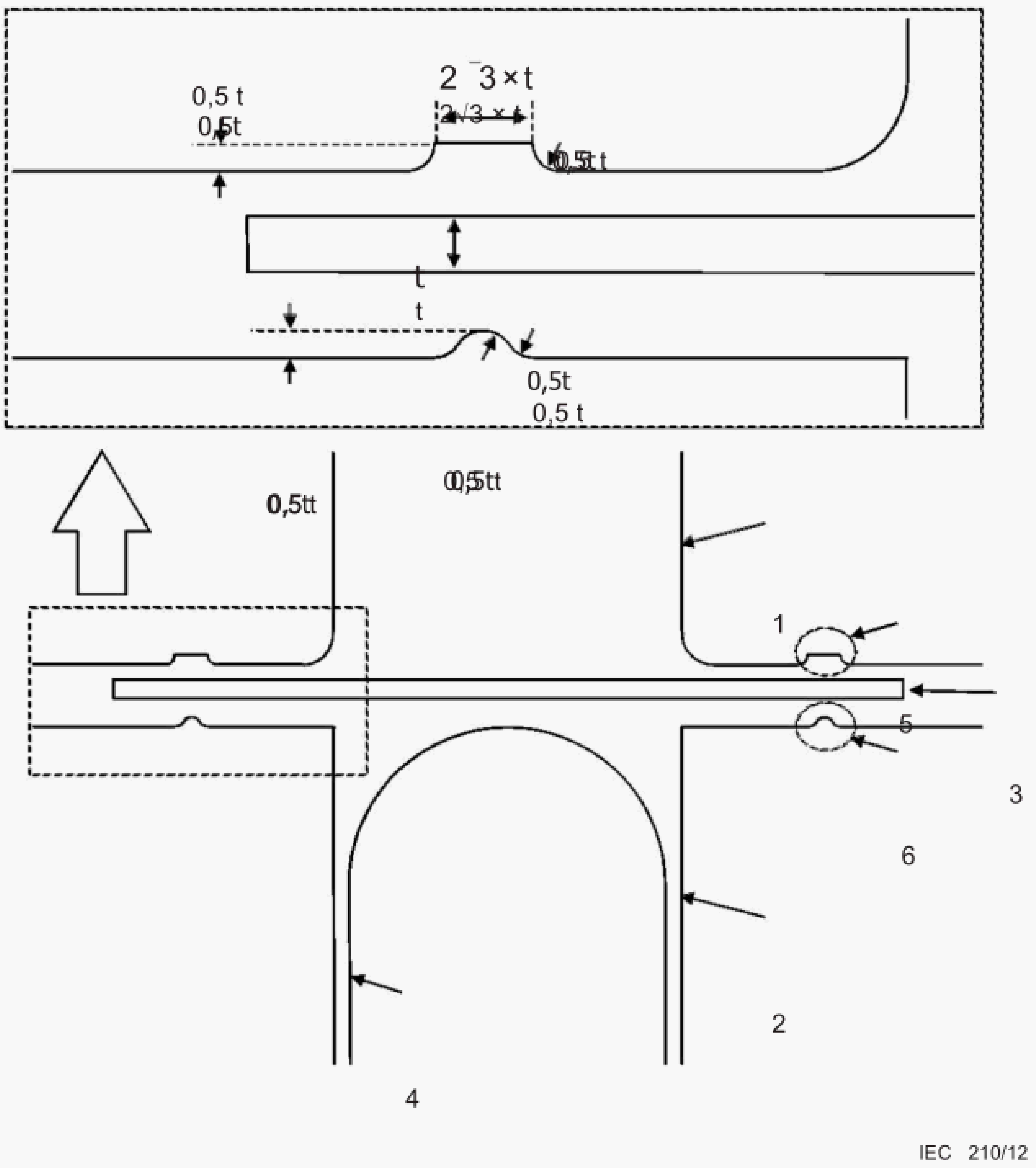
Figure B.2 – Procedure for an inkjet grid marking method

Annex C
(informative)

Gripping method

C.1 Bead method

Figure C.1 shows the gripping method using ring shaped dies composed respectively of the female and male beads in the upper and lower dies. Also, the detailed dimensions of the bead parts are recommended. These dimensions can be modified if they satisfy the no slip conditions of the specimen.



Key

1 upper die

2 lower die

3 specimen

4 hemispherical punch

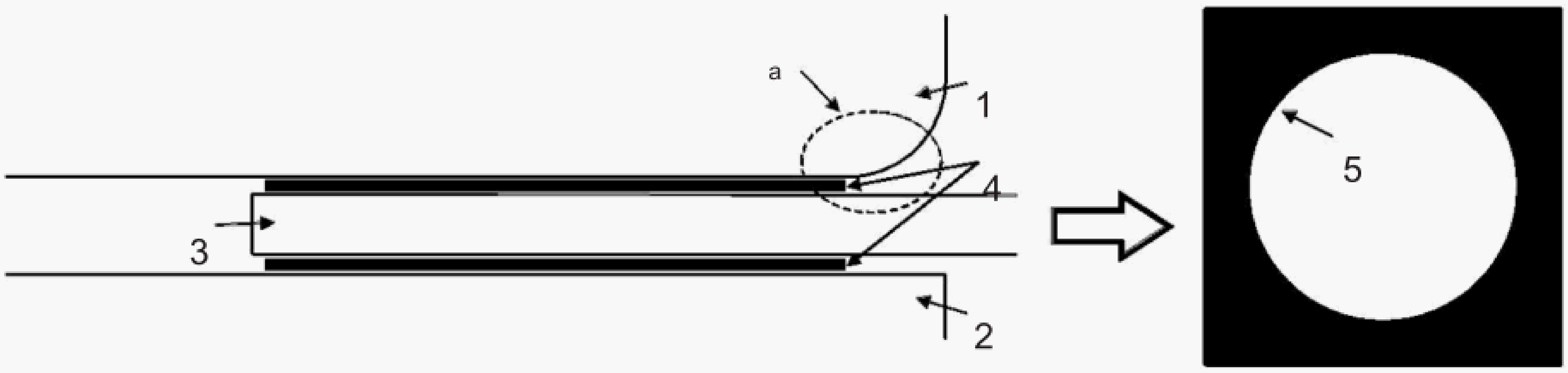
5 female bead

6 male bead

Figure C.1 – Gripping of the specimen using a ring shaped die

C.2 Bonding method

As shown in Figure C.2, a gripping method using adhesive bonding can be adopted in the test. Either upper or lower adhesive can be used if they satisfy the no slip condition. At this point, it should be ensured that the adhesive does not invade the round part of the upper die edge. Additionally, it is recommended that the upper and lower thicknesses of the adhesive layer respectively should not exceed 10 % of the specimen thickness.



IEC 211/12

Key

1 upper die

2 lower die

3 specimen

4 adhesive

5 specimen with adhesive

NOTE Figure C.2 illustrates the bonding method.

[a] It shall be ensured that the round part of the edge is not invaded.

Figure C.2 – Gripping of the specimen using adhesive bonding

Annex D
(informative)

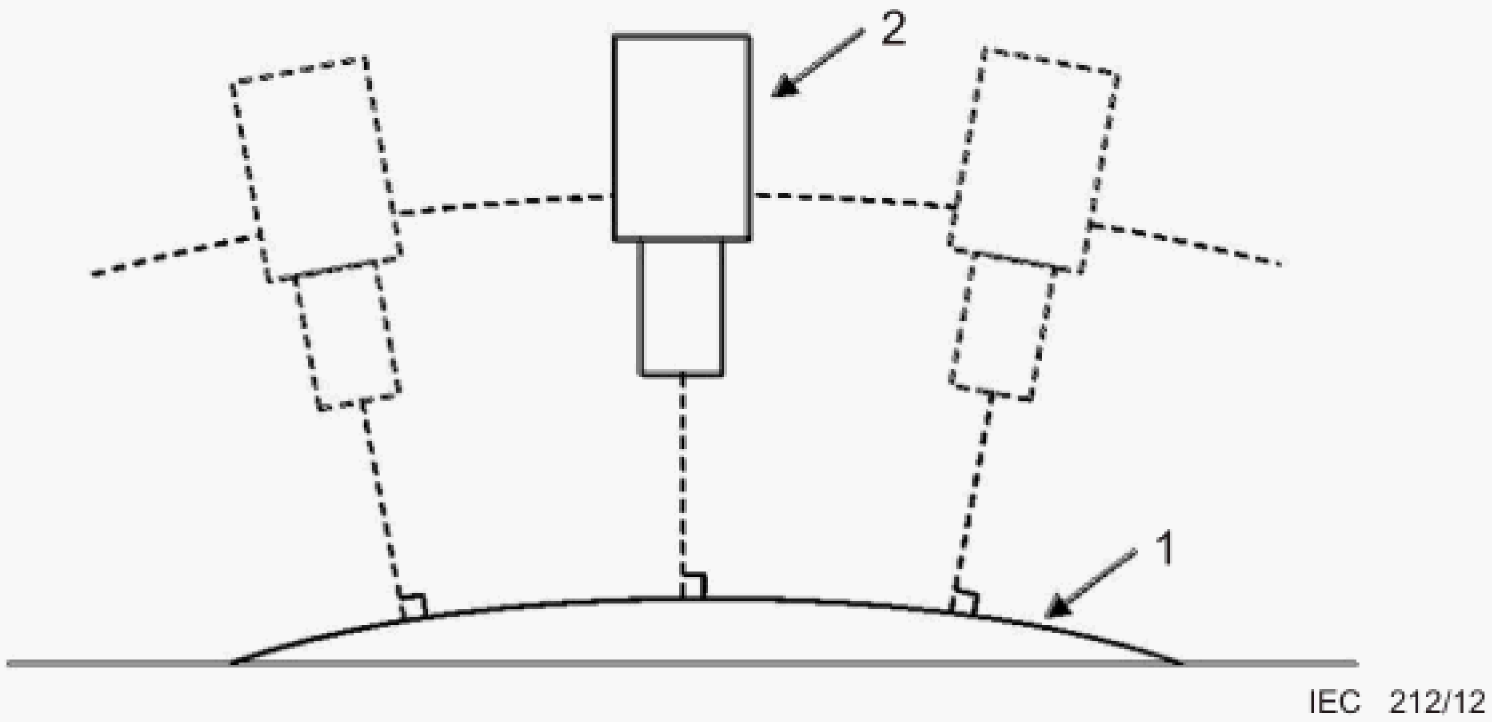
Strain measuring method

Major and minor strains of the deformed specimen can be measured representatively using the digital camera module with a high magnifying power lens. As shown in Figure D.1, the digital camera module shall be located so that the line of sight is perpendicular to the surface of the deformed specimen. Alternatively, the digital camera is fixed and the deformed specimen can be moved. The image captured from the digital camera shall be converted to real scale data by the pixel calculating algorithm described in Figure D.2. Manual calculation of the strains can be adopted, but using a software which can calculate the strains would be convenient. The detailed step-by-step procedure for the strain measurement is as follows.

Step 1. Install the high magnified digital camera over the deformed specimen so that the screen displayed from the camera including the grid pattern of the specimen can be observed clearly.

Step 2. Manipulate the software so that one or more grid patterns on the region of interest of the deformed specimen appear(s) on the monitor.

Step 3. Concerning the corresponding ellipse, calculate the major and minor deformations by counting the pixels.



Key

1 deformed specimen

2 high magnified digital camera

Figure D.1 – Set up for strain measurement using digital camera

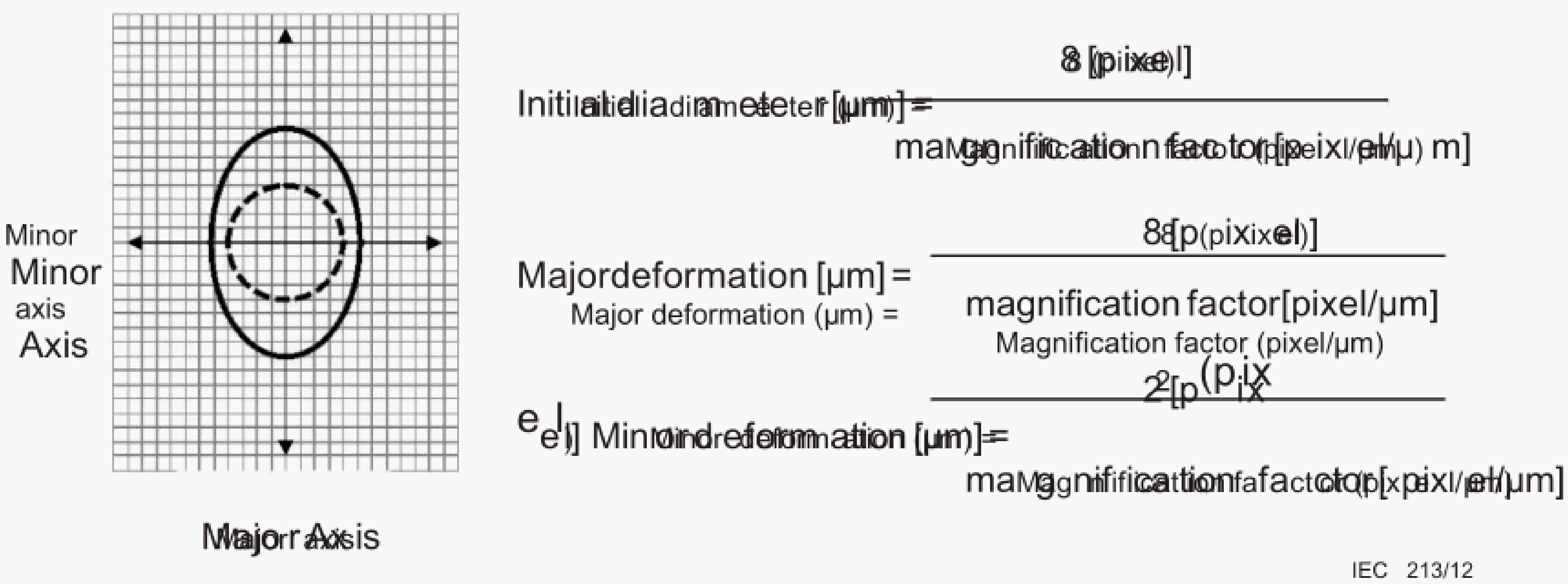


Figure D.2 – Example of pixel converting image of deformed specimen

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