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Aluminium alloy castings — Radiography testing

Pièces moulées en alliages d'aluminium — Contrôle par radiographie

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Contents

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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.

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.

International Standard ISO 9915 was prepared by Technical Committee ISO/TC 79, *Light metals and their alloys*, Sub-Committee SC 7, *Aluminium and cast aluminium alloys*.

Annexes A and B form an integral part of this International Standard. Annexes C and D are for information only.

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Aluminium alloy castings — Radiography testing

1 Scope

This International Standard specifies general rules for appropriate implementation of radiographic inspection and stresses the technical specifications to be defined for agreement on discontinuity acceptance criteria by this technique.

It applies to aluminium castings.

2 Normative references

The following standards contain provisions which, through reference in this text, constitute provisions of this International Standard. At the time of publication, the editions indicated were valid. All standards are subject to revision, and parties to agreements based on this International Standard are encouraged to investigate the possibility of applying the most recent editions of the standards indicated below. Members of IEC and ISO maintain registers of currently valid International Standards.

ISO 1027:1983, *Radiographic image quality indicators for non-destructive testing — Principles and identification.*

ISO 3522:1984, *Cast aluminium alloys — Chemical composition and mechanical properties.*

ISO 5579:1985, *Non-destructive testing — Radiographic examination of metallic materials by X- and gamma rays — Basic rules.*

ASTM E 155-85, *Standard reference radiographs for inspection of aluminium and magnesium castings.*

ASTM E 505-75, *Standard reference radiographs for inspection of aluminium and magnesium die castings.*

3 Radiographic inspection practice

3.1 General

Radiography, of which the basic rules are given in ISO 5579, is a very commonly used technique in aluminium alloy casting industries for testing highly stressed castings or for the final development of sophisticated manufactures. This International Standard has been finalized with a view to obtaining satisfactory radiographs, and to facilitate the interpretation of results with reference to ASTM E 155 and ASTM E 505. Special requirements have to be specified by the customers in accordance with the provisions given in clause 4.

NOTE 1 Casting quality is not assessed using radiography only, but also by other methods of non-destructive testing, and no one method can be automatically retained as a single criterion.

3.2 Principle of the method — Limitation

3.2.1 Radiography consists in recording on a film the image of the inspected casting and of the discontinuities contained therein. For this purpose advantage is taken of the property of materials to be penetrated by electromagnetic radiations with short wavelengths and to absorb part of the radiation. The image will be lighter or darker as a function of X-ray absorption, which in turn depends on the material thickness and nature and on the wavelength used. Radiography will therefore detect differences in specific gravity (due to porosity or holes) and the presence of inclusions according to the nature of discontinuities present in the casting.

3.2.2 However, some discontinuities are not easily detected by radiographic inspection. For complex castings, detection and interpretation of discontinuities are often made difficult by the orientation of the casting and by thickness differences within the

X-ray beam. Discontinuity visibility is mainly dependent on their thickness in the direction of radiation. Very thin discontinuities such as cracks will be hardly visible unless incidence is extremely favourable. In such difficult cases other methods shall be used (ultrasonic testing, penetrant testing, etc.).

3.3 Safety practices

X-ray use shall be associated with special precautions defined according to the regulation in force in each country.

3.4 Qualification of personnel

Radiographic inspection shall be performed by qualified personnel. Such qualification may, if required, be the subject of special certification.

3.5 Execution of radiography

3.5.1 Preparation of castings

Special preparation of the casting surface is not always needed. However, it is desirable to remove pronounced irregularities. Radiographic interpretation shall not be disturbed by the surface finish but shall be carried out taking this factor into account.

3.5.2 Identification

All castings or parts of castings to be radiographed shall be systematically identified. They shall be marked with a serial number permitting unambiguous correlation with the corresponding radiographs. It is thus possible to locate the discontinuities revealed by radiography accurately on the castings.

Markers shall permit identification

— of the casting;

— of areas of special interest on the casting.

Location markers are lead letters or numbers which are placed on the part being examined on the radiation source side, in such a way that defect inspection is not disturbed. This can be achieved, for example, by placing markers on a block (or shim) having approximately the same thickness as the casting being examined. If several radiographs are necessary for covering one casting or an area of a casting, films shall be arranged so as to overlap and markers shall provide evidence that overlap is evident.

3.5.3 Image quality indicators (IQI) (or penetrameters)

3.5.3.1 Image quality indicators are used to assess the radiographic quality of radiographs. They are used to obtain evidence that the conditions for exposure and processing have been adequately chosen and fulfilled.

They are not intended for use in judging the size of discontinuities nor for the establishment of acceptance limits for castings being radiographed.

3.5.3.2 Considering the conventional nature of the indicator use, it is not absolutely necessary that the absorption coefficients of the materials used for the IQI's and the radiographed castings are the same; however, they are usually equivalent.

3.5.3.3 The indicators used are those defined by ISO 1027:

a) IQI's composed of steps including one or several holes whose diameters are equal to the step thickness;

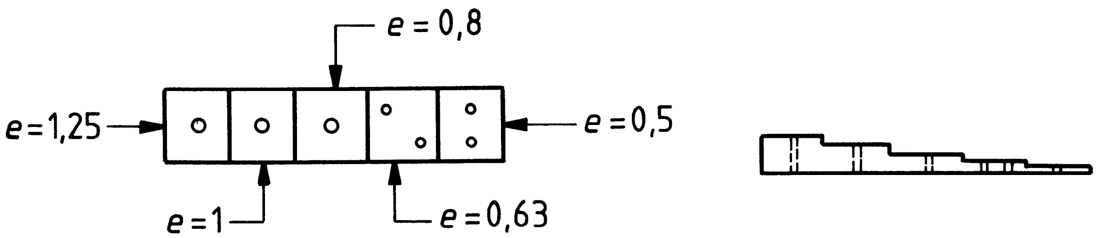
b) IQI's composed of seven wires of different diameters; these are most common for radiographic inspection of aluminium alloys.

The two types of IQI's are described hereafter and given as examples in figures 1 and 2. (See also example of commercial design of wire indicators, annex D).

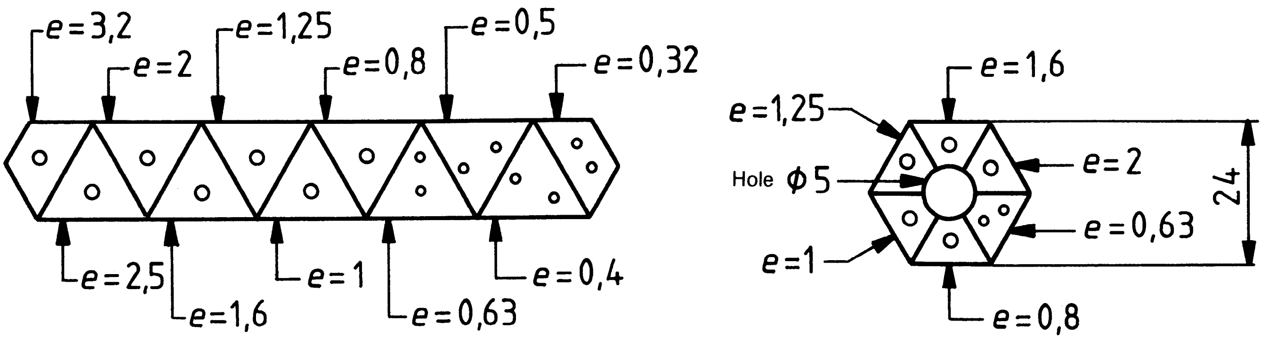
3.5.3.4 The IQI shall be placed on the radiation source side of the casting being examined. Its position shall be such that it does not mask the discontinuities being inspected. If it is located in an area of the casting where thickness is less than the thickness of the area being radiographed, it shall be placed on a block compensating for thickness difference. The block shall be of the same material as the casting, or of material presenting the same absorption.

The hole-type IQI shall be placed as close as possible and normal to the beam axis. The wire-type IQI may have various positions and incidences without losing much of its sensitivity.

Dimensions in millimetres; e = thickness of steps



NOTE — As alternatives to the step arrangement shown above, the steps may be arranged as indicated below.



NOTE — In each step, holes should be drilled in accordance with the requirements of ISO 1027 : 1983, subclause 5.2.

Figure 1 — Examples of step and hole type image quality indicators (ISO 1027)

Dimensions in millimetres; d = wire diameter

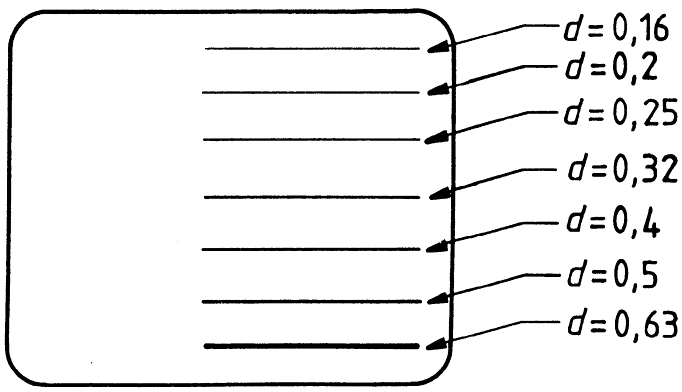


Figure 2 — Example of design of wire-type image quality indicator (ISO 1027)

3.5.4 Defect detection sensitivity and image quality

3.5.4.1 Defect detection sensitivity

Detection sensitivity is defined as the size of the smallest discernable detail measured on a radiograph in the direction of the primary radiation beam.

3.5.4.2 Image quality

The image quality is generally expressed by determining the number of holes or the diameter of the smallest wire visible on the radiograph. This control shall be performed in the same conditions as the reading of the whole radiograph. Steps including two holes must be simultaneously visible for the reading corresponding to a given step to be valid.

NOTE 2 Table 1 gives the diameter of the smallest hole or wire visible under appropriately chosen operating conditions, as a function of the thicknesses to be penetrated. These values are only to be considered for guidance for the correct implementation of radiographic techniques.

Table 1 — Diameters of smallest visible wire or hole

Dimensions in millimetres

Thickness	Diameter of smallest visible wire	Diameter of smallest visible hole
6 to ⩽ 8	0,125	0,25
8 to ⩽ 10	0,16	0,32
10 to ⩽ 16	0,20	0,40
16 to ⩽ 25	0,25	0,50
25 to ⩽ 32	0,32	0,63
32 to ⩽ 40	0,4	0,8
40 to ⩽ 60	0,5	1

3.5.5 Conditions of exposure

The factors which optimize the exposure conditions are as follows.

3.5.5.1 Apparatus

In the case of aluminium alloys, the physical and electrical characteristics of the apparatus play an important part in the quality of radiographs. It is recommended to use generators delivering constant voltage and intended for operation at low voltage with a high current intensity. The tube shall have low level internal filtration and shall be fitted with a beryllium window.

3.5.5.2 Exposure time

The exposure time shall be determined so that film density and image quality are satisfactory.

It is calculated from an exposure chart which is developed for each X-ray tube. For each combination of film density, source-film distance, film type and alloy, the exposure, expressed in milliamperes minutes, is chosen with the voltage to be applied.

3.5.5.3 Intensity

The intensity shall be set to the maximum value achievable with the available X-ray tube, so as to minimize exposure time, according to the voltage chosen (see 3.5.5.4).

3.5.5.4 Voltage

The voltage applied shall be the smallest possible (provided selected film densities) so as to increase pre-film contrast while remaining compatible with a reasonable exposure time. This is especially valid for castings with small thickness variations. In the contrary case, a voltage increase leads to wider thickness latitude.

3.5.5.5 Focus-to-film distance

Any increase in focus-to-film distance results in smaller geometric unsharpness but in extended exposure times. Compromise shall then be achieved. In practice, this distance shall be approximately 0,7 m to 1 m, 0,7 m being considered as a minimum with an optical focus of 1,5 mm × 1,5 mm.

3.5.5.6 Geometric unsharpness

Geometric unsharpness is due to the fact that the X-ray source is not spotlike and that the image of a discontinuity on a film always presents areas of umbra and penumbra. The maximum geometric unsharpness is given by the formula

$$f = \frac{d \cdot a}{F - a}$$

where

d is the useful size, in millimetres, of the focal spot;

a is the distance, in millimetres, from the radiation incidence surface to film;

F is the focus-to-film distance, in millimetres.

It is observed that the greater F is, the smaller the geometric unsharpness is. In practice, it will be ensured that f is less than 0,2 mm.

3.5.6 Scattered radiation

3.5.6.1 Back-scattered radiation

It is indispensable to place a lead layer of adequate thickness behind the film or the film cassette, to absorb back-scattered radiation. A thickness of 3 mm is adequate, but in practice a thicker lead shield is preferred to ensure rigidity.

To check the adequacy of protection against back-scattered radiation, the following measures can be taken. A letter B, for example, is attached to the back of the film or cassette and a radiograph is made in the normal manner. If the image of the letter appears on the radiograph, it is an indication that protection precautions against back-scattered radiation are insufficient.

3.5.6.2 Scattered radiation proper

Radiations with long wavelength (low energy radiation) contribute to scatter, and result in unsharpness. The methods used to minimize scattered radiation are

a) location of filters in the primary radiation beam as close as possible to the X-ray tube (lead leaves or copper plates of a few tenths of millimetre can fulfill this function);

b) use of diaphragms and masks.

Diaphragms are used to limit the X-ray beam cone to the aperture just required to irradiate the specimen. Masks (lead blocks, lead shot, tungsten powder, etc.) can be placed around the specimen to protect the film.

In the case of aluminium alloys, filters are seldom used. Because of the low level of absorption of these materials, the gain in contrast obtained with low energy radiation prevails over the increase in unsharpness due to scattered radiation proper. It is even recommended, to achieve good contrast, to use low internal filtration stations (e.g. stations with beryllium windows).

3.5.7 Image contrast

Image contrast can be defined as the difference in luminous intensity between two neighbouring points of a radiographic image. It is therefore desirable to achieve high contrast so that discontinuities may be detected more easily.

Radiographic contrast is the sum of object contrast and of film contrast.

3.5.7.1 Object contrast

Object contrast can be defined as the difference in radiation intensities transmitted by two neighbouring points on the castings. It is all the higher as

— the difference in casting thicknesses or the relative thickness of the discontinuity with respect to the casting thickness parallel to the beam is more important;

— the radiation is less penetrating (hence low voltages are sought);

— the scattered radiation is reduced.

3.5.7.2 Film contrast

Film contrast is a characteristic of the film on which the radiographic contrast depends. The film contrast can be measured by the slope of the characteristic curve of a given density.

Emulsion characteristics shall be indicated by film suppliers.

3.5.8 Intensifying screens

Lead foil screens are used profitably in the case of radiation whose energy corresponds to voltages in excess of 120 kV.

For aluminium and magnesium alloys, the voltages applied to the tube are hardly ever in excess of this value, and therefore the use of such screens is not necessary, except for thick sections.

Fluorescent screens can be used advantageously with high-speed emulsions (radiographic papers for example). The loss in definition involved with such screens can be compensated by an increase in contrast because of the low potential applied. The radiographic information is then equivalent to that obtained with a slower system.

3.5.9 Density of a radiograph

The conditions of exposure shall be such that radiographic densities in the areas of interest are normally between 2,0 and 3,0. The density of a radiograph is given by the formula

$$D = \lg\left(\frac{\Phi_0}{\Phi}\right)$$

where

Φ_0 is the incident luminous flux;

Φ is the transmitted luminous flux.

Assessment of density is carried out by visual examination using films of different densities which have been previously calibrated, or better, by measurement using a densitometer.

3.5.10 Film — Choice of emulsion

Films can be characterized by such properties as speed, contrast, latitude and graininess. These factors are not independent and the film to be chosen is the one giving the best image quality while reproducing the finest details.

The double or multi-film exposure technique permits the increase of thickness latitude, the reduction of exposure time and the identification of film defects, if any.

Typical applications are summarized in table 2 according to the nature of the emulsion and the various categories of films in frequent use.

Table 2 — Typical applications of films

Type of film	Typical applications
Fast speed film, generally with coarse grain	Thick castings: detection of main discontinuities
Low speed film, generally with fine grain and strong contrast	Thin castings or of uniform thickness: detection of small discontinuities
High latitude film, generally with low contrast	Complex castings: good detection with various thicknesses

3.5.11 Film processing and development

Films shall be developed according to the manufacturer's recommendations, particular care being taken of the development time and temperature.

Radiographs shall be free of imperfections resulting from development or other causes which might interfere with ulterior interpretation.

It is recommended to check the efficiency of film development baths by processing an exposed radiograph under well-defined reproducible conditions through the normal succession of development operations.

The greatest cleanliness is required during the preparation and handling of baths. Introduction of foreign matter, mixture of baths of different origins, etc. shall be avoided. Bath levels tend in the tanks to go down, either by evaporation or by liquid entrainment by films. Replenishments shall be achieved using a maintenance solution to be supplied by the film and developer manufacturer. This solution shall also permit regeneration of worn out developers.

Automatic processing, which is to be chosen when important quantities of films are to be developed, also permits the avoidance of some hazards of manual processing, as a result of more regular operation. Automatic systems shall be carefully and regulary maintained.

3.5.12 Conditions for viewing radiographs

Film viewing shall take place in a dark viewing room, preferably separate from the development laboratory.

The radiograph shall be examined using an illuminator providing uniform illumination which is suitable for the film density. Fluorescent illuminators are satisfactory for radiographs of moderate density. For higher densities, high-intensity illuminators will be required. The illuminators shall normally have an intensity which is sufficient to transmit at least 10 cd/m^2 of light through the film.

The area of interest shall be limited by masks, so as to avoid glare due to extremely bright zones.

The examination of radiographs requires many handling operations. It is recommended that films be handled with the utmost care.

3.5.13 Protection and care of films

Unexposed films shall be stored in such a manner that they are protected from light, heat, humidity and penetrating radiation. They shall be handled with care.

Cassettes, screens, films, etc. shall be kept clean, so as to avoid defects on films that may affect subsequent interpretation.

It is necessary to eliminate those films showing excessive ageing fog periodically, by sampling unexposed films and then processing and developing them under the same conditions as exposed films.

The maximum fog density shall not be greater than 0,2.

3.6 Interpretation of radiographs

3.6.1 Artefacts

3.6.1.1 Artefacts due to castings

It is to be stressed that casting surface shall be free of any roughness which might interfere with readings of radiographs.

Diffraction mottling which appears on radiographs as diffuse lines and dark stains is sometimes observed in the case of badly refined aluminium-silicon alloys where grain size is coarse. It is possible that such details be confused with microshrinkage or microporosities and they can also mask actual discontinuities.

Mottling can be detected by slightly rotating the casting in the course of radiographic operation and by comparing the second radiograph to the original. The mottled pattern is perceptibly altered whereas the images of actual discontinuities keep their shape and position. The lower the X-ray energy, the more intense the mottling effects.

3.6.1.2 Artefacts due to films

Virgin emulsions are particularly affected by mechanical stresses (folds, scratches, pressure, etc.).

These effects appear during development:

— dark stains for folds;

— whitish stains with blurred limits for scratches and pressure points.

3.6.1.3 Artefacts due to procedure

Accidental fog, due to exposure of all or part of the emulsion to daylight or penetrating radiation, can be easily identified.

Handling of films on dirty loading benches causes blemishes with a clear outline to appear. Water gives grey stains; the developer gives a clear black stain. The fixing chemicals leave light stains, and so does the stop bath, although in a less pronounced way.

3.6.1.4 Other artefacts

Other artefacts exist apart from those described in 3.6.1.1 and 3.6.1.3.

Most of them can be avoided if handling is done carefully and they can be easily identified by any skilled operator.

3.6.2 Discontinuities — Interpretation — Type radiographs

Interpretation of radiographs shall be done taking as a basis the standard issued by the American Society for Testing and Materials (ASTM) on "Standard reference radiographs for inspection of aluminium and magnesium castings". The slightly modified text of this standard is given in annex A.

The purpose of reference radiographs is

— to assist in identification and differentiation of discontinuities as a function of their nature and importance;

— to illustrate types of discontinuities and to serve as references for specifications;

— to constitute a set of type radiographs among which customers and suppliers may choose by mutual agreement those special radiographs meeting the minimum requirements for casting acceptance. These minimum requirements may be identified without ambiguity by designation of the nature and magnitude of permissible discontinuities.

4 Technical specifications

4.1 Radiographic test sheet

The radiographic test sheet shall be established by the customer after consulting the founder. According to common usage the test sheet shall be the subject of special specifications, to be compulsorily transmitted to the founder at the time of the enquiry as inspection costs are distinct from casting costs.

It shall mandatorily include the following data:

a) the areas to be radiographed, clearly identified on a sketch or on the drawing itself;

b) the frequency of inspections;

c) the surface condition and finish of the areas to be radiographed, if different from the condition of delivery;

d) when a minimum radiographic sensitivity level is required, the type of image quality indication giving this value shall be specified, together with the reference thickness;

e) the grade of permissible limiting discontinuities as a function of thickness and importance of the areas of interest, with reference to either the definitions of discontinuities to be found in standard ASTM E 155-85 (see annex A) or to specific type radiographs of the casting to be inspected;

f) the choice of the conditions of exposure, type of generator, films to be used, is left to the founder, provided the recommendations in clause 3 are met and unless otherwise required by the customer who may demand that these elements be submitted to him for agreement.

4.2 Test and interpretation of radiographs

4.2.1 The radiographs of the casting area to be examined can only be compared to reference radiographs if they have similar characteristics (density, image quality).

When these characteristics are different, this shall be taken into account for comparative examination on the illuminator, but no rigorous rules can be established for this purpose.

4.2.2 When using reference radiographs, the unit area to be considered shall be a square of side 5 cm. The aim is to try and locate within the area of interest the "unit area" including a maximum number of discontinuities. The image of this area shall then be compared to the reference radiographic images corresponding to the limiting permissible grades.