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Aluminium and aluminium alloys — Classification of Defects and Imperfections in High Pressure, Low Pressure and Gravity Die Cast Products

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National foreword

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Aluminium and aluminium alloys - Classification of Defects and Imperfections in High Pressure, Low Pressure and Gravity Die Cast Products

Aluminium et alliages d'aluminium - Classification des défauts et imperfections des produits moulés par coulée à haute pression, basse pression et gravité

Aluminium und Aluminiumlegierungen - Klassifikation von Fehlern und Unvollkommenheiten für Druckguss, Niederdruckguss und Schwerkraftkokillenguss

This Technical Report was approved by CEN on 9 September 2014. It has been drawn up by the Technical Committee CEN/TC 132.

EUROPEAN COMMITTEE FOR STANDARDIZATION
COMITÉ EUROPÉEN DE NORMALISATION
EUROPÄISCHES KOMITEE FÜR NORMUNG

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Foreword

This document (CEN/TR 16749:2014) has been prepared by Technical Committee CEN/TC 132 “Aluminium and aluminium alloys”, the secretariat of which is held by AFNOR.

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1 Scope

This Technical Report specifies the classification of the defects and imperfections may be present in cast products manufactured by high pressure, low pressure and gravity die casting of aluminium alloys.

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.

EN 12258-1:2012, *Aluminium and aluminium alloys - Terms and definitions - Part 1: General terms*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in EN 12258-1:2012 and the following apply.

3.1
casting process
process in which molten metal is introduced into a mould where it solidifies

[SOURCE: EN 12258-1:2012, 3.1.1]

3.2
die casting process
casting process in which molten metal is injected under substantial pressure, typically above 70 bars, into a metal die and solidifies under this pressure

Note 1 to entry: Die casting process is also referred to as "pressure die casting (process)" or "high pressure die casting (process)".

[SOURCE: EN 12258-1:2012, 3.1.10]

3.3
permanent mould casting process
casting process in which molten metal is introduced by gravity or low pressure into a mould constructed of durable material, typically iron or steel

Note 1 to entry: A permanent mould casting process where the metal solidifies in a metal mould under low pressure (typically less than 1 bar above atmospheric pressure) is also referred to as a "low pressure die casting process".

[SOURCE: EN 12258-1:2012, 3.1.9]

3.4
casting
product at or near finished shape, formed by solidification of the metal in a mould or a die

[SOURCE: EN 12258-1:2012, 2.5.1]

3.5
dendrite
crystal that has a tree-like, branching pattern, being most evident in cast metals slowly cooled through the solidification range

[SOURCE: EN 12258-1:2012, 4.5.17]

3.6
microstructure
structure of a metal as revealed by microscopic examination of a surface, typically after mechanical and/or chemical preparation, e.g. polishing and micro-etching

[SOURCE: EN 12258-1:2012, 4.5.10]

3.7
dendrite arm spacing
mean distance of adjacent secondary arms of a dendrite

[SOURCE: EN 12258-1:2012, 4.5.18]

3.8
defect
quality characteristic which is lower with respect to the level or state foreseen (usually specified) and which does not allow the product to carry out a function requested

[SOURCE: EN 12258-1:2012, 7.1.2]

3.9
imperfection
quality characteristic which is for a some extent lower with respect to the level or state foreseen or a deviation from a continuous appearance of the base material not yet evaluated against a threshold level (a technical OK / not OK evaluation is not allowed)

Note 1 to entry: The term “inhomogeneity” can also be used.

Note 2 to entry: This does not mean necessarily that the product is not suitable for use. An imperfection needs to be evaluated by means of a proper scale, based on the related specifications, to decide if the product has a quality level making it suitable for the use.

3.10
shrinkage cavity
void left in cast metals as a result of solidification shrinkage

[SOURCE: EN 12258-1:2012, 5.2.10]

3.11
gas porosity
porosity caused by entrapped gas, evolution by evaporated organic release compounds, or by evolution of dissolved hydrogen during solidification

3.12
inclusion
extraneous material accidentally entrapped into the liquid metal and whose possible root causes are melt treatment procedures initiating oxidation, transported to the melt by contaminated ingot surfaces, transported into castings due to abrasion of process equipment, entrapped into the metal surface during hot or cold working

3.13
blister
raised spot whose inside is hollow, that forms on the surface of products and is caused by the expansion of entrapped gas at the opening of the die or during conditions of elevated temperature in subsurface regions, typically during thermal treatment

3.14
hot crack
crack formed in a cast metal or in a welding because of internal stress developed upon cooling at the solidus temperature or slightly above

[SOURCE: EN 12258-1:2012, 5.2.8]

3.15
cold crack
crack in cast metal initiated by mechanical stresses at temperatures significantly below the solidus temperature

[SOURCE: EN 12258-1:2012, 5.2.9]

3.16
corrosion
deterioration of a metal by chemical or electrochemical reaction with its environment

[SOURCE: EN 12258-1:2012, 5.6.14]

3.17
flash
thin protrusion into the parting surface of a die which forms when metal, in excess of that required to fill the impressions, is forced between the die interfaces

4 Classification of defects and imperfections in high pressure, low pressure and gravity die cast products

4.1 General

Defects and imperfections implemented in the present classification are metallurgy-related, i.e. directly bound to high pressure, low pressure and gravity die casting processes.

The defects and imperfections are classified using a scheme based on three levels:

a) The level I is based on morphology/location of defects and imperfections, with reference to the investigation techniques suitable for their detection (visual inspections and controls involving the bulk material): there are internal (Table 1) and external or surface (Table 2) defects and imperfections. Sub-surface defects and imperfections (i.e. so close to the surface that they can affect external aspect detectable by conventional surface investigation techniques) are considered surface defects and imperfections. Finally, the geometrical defects and imperfections (Table 3) refer to the casting shape in terms of dimensions and tolerances.

b) The level II is mainly focused on the metallurgical, physical, chemical and process-based origin of defects and imperfections. They are grouped into several classes according to their general metallurgical origin:

   1) defects and imperfections related to the presence of gas (gas-related defects and imperfections);

   2) defects and imperfections related to material volume contraction during metal solidification (shrinkage defects and imperfections);

   3) defects and imperfections related to thermal contraction prevented by previously solidified metal or by the die (thermal contraction defects and imperfections);

   4) defects and imperfections related to incorrect filling of the die-cavity (filling defects and imperfections);

5) defects and imperfections related to metal/die interaction;

6) defects and imperfections related to the presence of unsuitable phases (undesired phases), originating from the interaction of the metal with external environment during melting, pouring, casting, filling or extraction/ejection from the die.

As previously observed, the knowledge of metallurgical origin could supply starting points for corrective actions (e.g. on process parameters).

c) The level III is used to identify the specific types of defects and imperfections. Usually, the term adopted to describe a particular type of defect and imperfection allows a better definition of its metallurgical origin, which was preliminarily identified in the previous level.

NOTE Other defects and imperfections, related to subsequent operations (handling finishing, machining), have not been considered.

4.2 Classification

Table 1 — Classification of internal defects and imperfections

Level I	Level II		Level III	
A Internal defects and imperfections	A1	Shrinkage defects and imperfections	A1.1	Macro-shrinkage
			A1.2	Interdendritic shrinkage
			A1.3	Layer porosity
	A2	Gas-related defects and imperfections	A2.1	Air entrapment porosity
			A2.2	Hydrogen porosity
			A2.3	Vapour entrapment porosity
			A2.4	Lubricant and/or die release agent entrapment porosity
	A3	Filling-related defects and imperfections	A3.1	Cold joint
			A3.2	Lamination
			A3.3	Cold shot
	A4	Undesired phases	A4.1	Inclusion
			A4.2	Undesired structure
	A5	Thermal contraction defects and imperfections	A5.1	Cold crack
			A5.2	Hot tear, hot crack

Table 2 — Classification of surface defects and imperfections

Level I	Level II		Level III	
B Surface defects and imperfections	B1	Shrinkage defects and imperfections	B1.1	Sink
	B2	Gas-related defects and imperfections	B2.1	Blister
			B2.2	Pinhole
	B3	Filling-related defects and imperfections	B3.1	Cold joint, Vortex
			B3.2	Lamination
			B3.3	Cold shot
	B4	Undesired phases	B4.1	Surface deposit
			B4.2	Contamination, inclusion
	B5	Thermal contraction defects and imperfections	B5.1	Cold crack
			B5.2	Hot tear, hot crack
	B6	Metal-die interaction defects and imperfections	B6.1	Erosion
			B6.2	Soldering
			B6.3	Thermal fatigue marks
			B6.4	Ejection mark
			B6.5	Corrosion of the die

Table 3 — Classification of geometrical defects and imperfections

Level I	Level II		Level III	
C Geometrical defects and imperfections	C1	Lack of material	C1.1	Incompleteness
	C2	Excess material	C2.1	Flash
	C3	Out of tolerance	C3.1	Deformation

5 Definition of defects and imperfections

5.1 General

A short definition of each defect and imperfection is given here. Internal and surface defects and imperfections are grouped on the basis of the phenomena generating them (shrinkage, gas entrapment or development, filling, formation of undesired phases, thermal contraction, metal-die interaction).

Extended definitions, as well as morphology and metallurgical origin descriptions and representative figures/schemes for each defect and imperfection are given in Annex A, as well as possible detection and investigation methods.

Annex B collects the translations of defects and imperfections terminology from English to Italian, French, German and Spanish languages.

Annex C reports, for each defect and imperfection, the typical size and the main detection techniques.

5.2 Shrinkage defects and imperfections

— **Macro-shrinkage (A1.1)**

A relatively large shrinkage cavity with irregular shape formed inside a hot spot due to the volume contraction when liquid metal transforms into solid and not enough liquid metal flows to contrast it.

— **Interdendritic shrinkage (A1.2)**

Several cavities located in interdendritic regions formed when the liquid flow in the mushy zone is inadequate to counterbalance the metal shrinkage.

— **Layer porosity (A1.3)**

Particular case of shrinkage cavities aligned along a specific surface; typically such surface corresponds to the neutral thermal axis/surface of the casting.

— **Sink (B1.1)**

A surface depression related to the presence of a sub-surface shrinkage porosity. The thin metal layer above is not able to sustain stress arising from the contraction of the internal region and from the surrounding pressure, and it plastically deforms.

5.3 Gas-related defects and imperfections

— **Air entrapment porosity (A2.1)**

Small cavities formed as consequence of the presence of air bubbles trapped inside liquid metal. They appear as spherical or ellipsoidal cavities characterized by relatively smooth surface.

— **Hydrogen porosity (A2.2)**

Due to the abrupt reduction of atomic hydrogen solubility in the solid phase, the dissolved hydrogen recombinate to form small cavities with smooth and not oxidized surface.

— **Vapor entrapment porosity (A2.3)**

Cavities similar to air entrapment porosity caused by residual humidity on the die surface.

— **Lubricant/release agent entrapment porosity (A2.4)**

Cavities similar to air entrapment porosity caused by decomposition gases of lubricant and/or die release agent that remain trapped into liquid metal in form of bubbles.

— **Blister (B2.1)**

Small surface areas which blow up if internal pressure of sub-surface gas related porosity is high enough (it increases with temperature) to plastically deform the metal skin that covers it. It is caused by the expansion of entrapped gas at the opening of the die or during conditions of elevated temperature in subsurface regions, typically during thermal treatment.

— **Pinhole (B2.2)**

Rounded cavity usually smooth-walled of varied size, isolated or grouped irregularly, located on the surface or in sub-surface regions, and due to gas rising from core materials.

5.4 Filling-related defects and imperfections

— **Cold joint and Vortex (A3.1 – B3.1)**

A cold joint forms when a relatively cold liquid metal flow meets another warmer flow around it and causes different microstructures separated by a thin oxide film. A particular cold joint defect and imperfection is vortex: a vortex forms on the surface when only one flow rolls itself up and generates a particular spiral distribution of oxide films and microstructures. Alternative terms are cold shut and cold lap.

— **Lamination (A3.2 – B3.2)**

A thin surface metallic layer having at least partial separation surface from the bulk metal with imperfect adhesion to the inner metal

It could be an internal defect and imperfection also: the lamination is partially separated by oxide films from the metal.

— **Cold shot (A3.3 – B3.3)**

A small amount of metal with much finer microstructure than the surroundings zone originated from the contact of a small portion of liquid metal with the surface of the die and rapidly solidifies.

5.5 Undesired phases

— **Inclusion (A4.1 – B4.2)**

Small particles or thin films of non-metallic phase, usually oxides or dross or fragments of refractory coatings, entrapment in the casting.

— **Undesired structure (A4.2)**

Local zone of the casting with unsuitable structures characterized by high hardness or brittleness or higher value of SDAS (Secondary Dendrite Arm Spacing) compared with general microstructure scale. Undesired phases may derive from the shot sleeve as early solidified products (ESP) with an explicit coarser microstructure, from macro-segregation of alloying elements, from treatments of molten alloy (e.g. during refinement or modification).

— **Surface deposit (B4.1)**

A layer with various chemical composition, thickness and distribution that is deposited on the surface of the casting.

5.6 Thermal contraction defects and imperfections

— **Cold crack (A5.1 - B5.1)**

A sharp edged, narrow opening forms at temperatures significantly below solidus temperature, where the greater thermal contraction of the casting with respect to the die is prevented by particular part/die geometry resulting in the stress generating usually trans-crystalline cracking. Tips of dendrites usually are not characteristic for the cold cracks surfaces.

— **Hot tear, hot crack (A5.2 - B5.2)**

A discontinuity forms at high temperature (solidification range) in the solid portion of the mushy zone originated by the thermal tension. Hot tear surface is oxidized and related to the dendritic morphology.

5.7 Metal-die interaction defects and imperfections

— **Erosion (B6.1)**

An excess of material on the surface of the casting that reproduces, in negative, a defect and imperfection of the die caused by erosive phenomena.

— **Soldering (B6.2)**

Surface roughness or localized lack of surface material due to the formation of Al- and Fe-containing intermetallic phases on the surface of the die.

— **Thermal fatigue mark (B6.3)**

Narrow reliefs with a particular pattern on the surface of the casting related to thermal fatigue damage of the die cavity.

— **Ejection mark (B6.4)**

Local superficial plastic deformation that occurs during the ejection of the cast part due to the presence of an undercut on the die.

— **Corrosion of the die (B6.5)**

Surface roughness of the cast product resulting from the corresponding die surface area attacked by environment (corrosion phenomena).

5.8 Geometrical defects and imperfections

— **Incompleteness (C1)**

Lack of material with respect to designed cast geometry due to uncompleted filling of the die cavity.

— **Flash (C2)**

An excess of material that forms by liquid metal intruding into the gap formed between the separation surfaces of different parts of the die, and that is not properly removed.

— **Deformation (C3)**

A geometrical non-conformity of the casting to its design geometry related for instance to the thermal contraction during cooling.

Annex A
(informative)

Description of defects and imperfections in High Pressure, Low Pressure and Gravity Die Cast Products

A.1 Internal defects and imperfections

A.1.1 Shrinkage defects and imperfections

A.1.1.1 Macro-shrinkage (Type A1.1)

Definition: A macro-shrinkage is a relatively large (with respect to casting thickness) shrinkage cavity, formed inside a hot spot and due to the volume contraction during solidification [see Bibliography [8-17]].

Morphology: A macro-shrinkage is characterized by rough and spongy surfaces for the presence of emerging dendrites as a consequence of their interrupted growth. A macro-shrinkage can reach several millimetres in diameter (>0,5 mm). It can be detected by means of radiographic (according to EN 12681), ultrasonic inspections and metallographic tests.

Metallurgical origin: The formation of a macro-shrinkage depends on die-filling conditions, alloy physical properties (e.g. solidification range), geometry of the casting and process parameters.

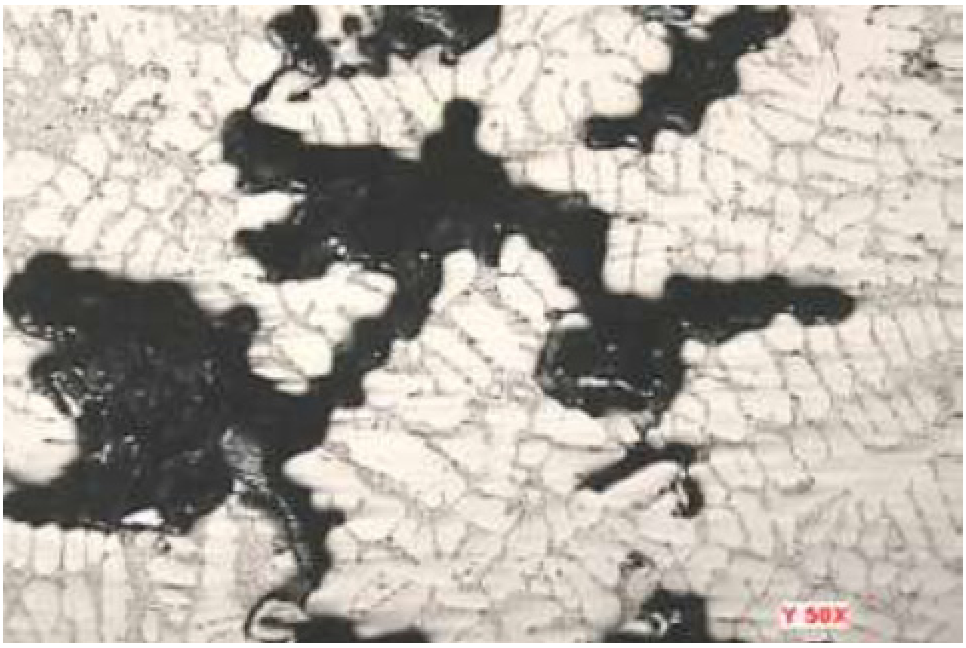


Figure A.1 — Macrograph of macro-shrinkage

A.1.1.2 Interdendritic shrinkage (Type A1.2)

Definition: An interdendritic porosity consists of several cavities located in the interdendritic regions, and forms when the liquid flow in these regions is inadequate to counterbalance the shrinkage of the metal during solidification [see Bibliography [8-17]].

Morphology: The interdendritic porosity is characterized by a net of long and narrow three-dimensional branches. The size of an interdendritic shrinkage varies between 10 and 150 µm. This defect/imperfection can be detected by means of ultrasonic inspections and metallographic tests. Radiographic inspection (according to EN 12681), better if equipped with high resolution facility, can also be used.

Metallurgical origin: The formation of the interdendritic porosity is favoured by a wide mushy zone, as could be the case of wide solidification range and low temperature gradients (e.g. in the last solidified regions of a thick casting). The interdendritic porosity could be a preferred path for gas, thus be deleterious for pressure tightness. This defect/imperfection could also be a preferred path for crack propagation.

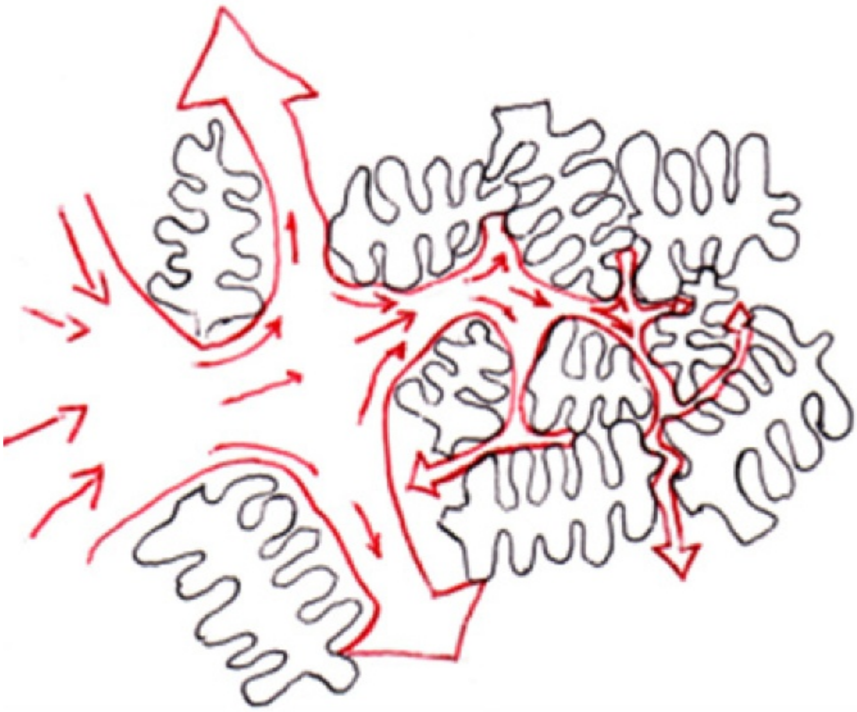


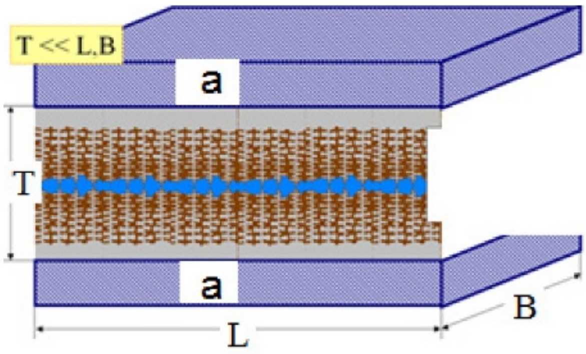
Figure A.2 — Metal flow around dendrites

A.1.1.3 Layer porosity (Type A1.3)

Definition: A layer porosity consists of a set of shrinkage defects/imperfections aligned typically along the neutral thermal axis/surface of the casting in its thin regions (where the component thickness is far smaller than the two other dimensions and the thermal gradient is lower than all adjacent points) [see Bibliography [8-12], [15]].

Morphology: A layer porosity is made up of a set of small shrinkage cavities laying on a surface, typically the neutral thermal one. The size of layer porosity varies between 10 μm and 100 μm. This defect/imperfection can be detected by means of ultrasonic inspections and metallographic tests. Radiographic inspection (according to EN 12681), better if equipped with high resolution facility, can also be used.

Metallurgical origin: The layer porosity forms when the solidification fronts converge towards two surfaces and the last solidifying liquid metal cannot flow within the dendrites of the mushy zone.



Key

a die

α phase

Al-Si eutetic

Porosity

Figure A.3 — Formation of layer porosity

A.1.2 Gas-related defects and imperfections

A.1.2.1 Air entrapment porosity (Type A2.1)

Definition: The air entrapment porosity consists of small cavities due to air bubbles trapped inside the liquid metal [see Bibliography [8-17]].

Morphology: Air entrapment porosities appear as spherical or ellipsoidal cavities characterized by relatively smooth surfaces on which a thin oxide layer (due to the high-temperature interaction between air and the liquid metal) could be found.

The final distribution of cavities within the casting depends on the path of the metal. The size of air entrapment porosity is 10 µm - 2000 µm. This defect/imperfection can be detected by means of radiographic (according to EN 12681), ultrasonic inspections and metallographic tests.

Metallurgical origin: Air bubbles can form in turbulent liquid metal vein either when it is in the shot sleeve, in filling channels or inside die cavity.

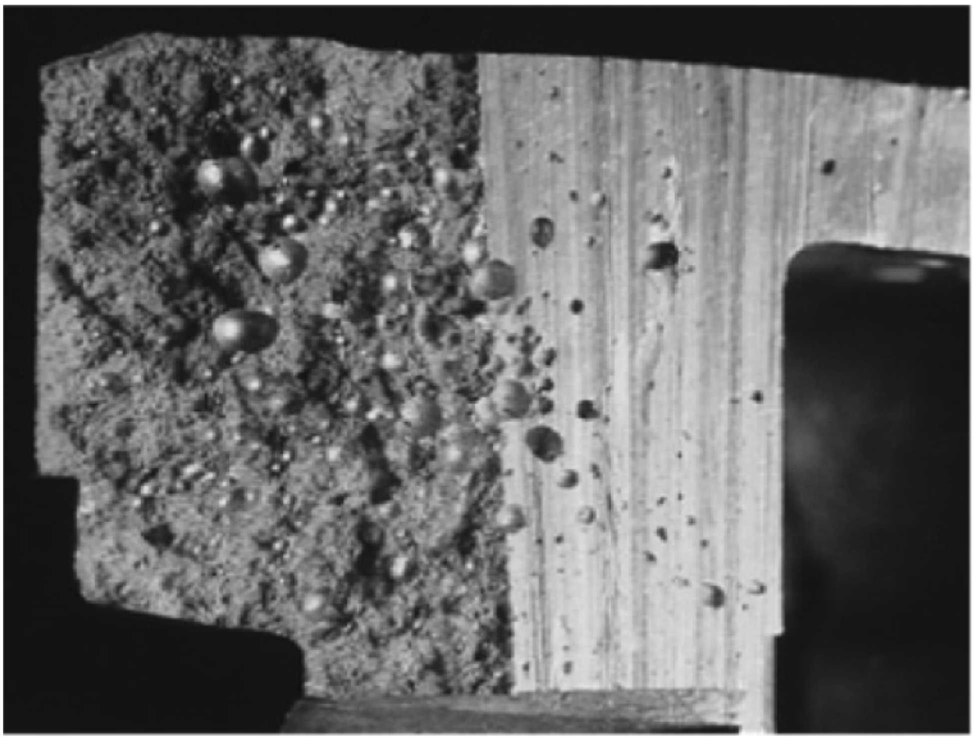


Figure A.4 — Entrapped air porosity in the casting

A.1.2.2 Hydrogen porosity (Type A2.2)

Definition: The hydrogen porosity consists of cavities due to the presence of hydrogen in the melt [see Bibliography [8-17]].

Morphology: Hydrogen porosity consists of approximately spherical cavities characterized by smooth and no-oxidized surface. Such cavities have a rather small size (0,05 mm -0,5 mm of diameter) and are distributed almost homogeneously within the casting. This defect/imperfection can be detected by means of radiographic (according to EN 12681), ultrasonic inspections and metallographic tests.

Metallurgical origin: Humidity can cause the presence of monoatomic hydrogen within the liquid metal at high temperature. Due to the abrupt reduction of hydrogen solubility in the solid phase, the solidifying region rejects hydrogen and this element concentrates in the liquid near the liquid/solid interface, where it combines into molecular form.

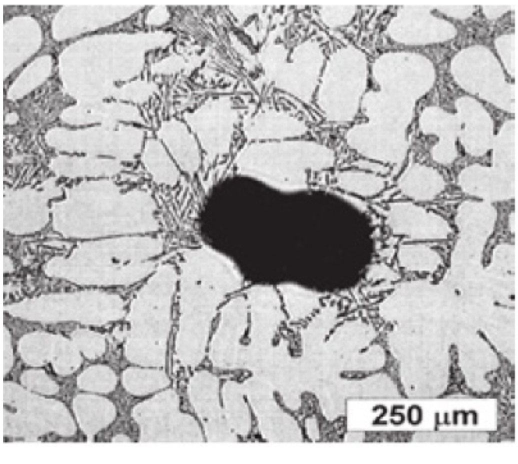


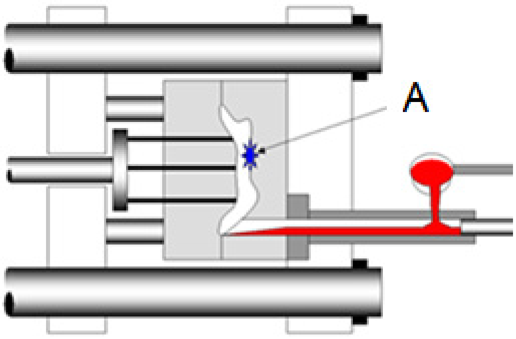
Figure A.5 — Entrapped air porosity in the casting

A.1.2.3 Vapor entrapment porosity (Type A2.3)

Definition: The vapor entrapment porosity consists of cavities caused by the residual humidity of the die. Humidity becomes vapor when it comes into contact with the molten metal [see Bibliography [8-10], [15]].

Morphology: The vapor entrapment porosity is generally in the form of approximately spherical cavities with smooth surfaces. Due to the generally localized presence of humidity on the die, cavities are typically concentrated, even if in regions of the casting that could be far from the area where they originated. The size of vapor entrapment porosity is 0,5 mm - 3,0 mm. This defect/imperfection can be detected by means of radiographic (according to EN 12681), ultrasonic inspections and metallographic tests.

Metallurgical origin: The presence of humidity on the die surface could result from an excess of the water-based lubricant.



Key

A residual humidity

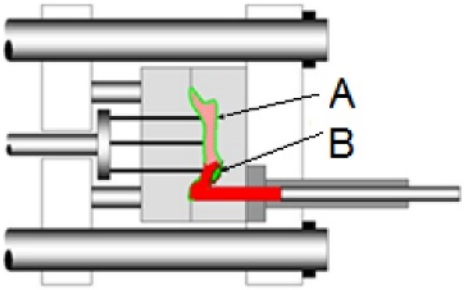
Figure A.6 — Schematics of vapor entrapment porosity

A.1.2.4 Lubricant/release agent entrapment porosity (Type A2.4)

Definition: The lubricant/release agent entrapment porosity forms when the gases - resulting from the decomposition of the lubricant/release agent - remain trapped into liquid metal in form of bubbles [see Bibliography [8-10], [15]].

Morphology: The lubricant/release agent entrapment porosity is characterized by small, approximately spherical cavities with smooth surfaces. The surface of the cavities appears darker respect to the surface of gas-related defects/imperfections due to the presence of combustion products on it. The size of a lubricant /release agent entrapment porosity varies between 0,5 mm and 3,0 mm. This defect/imperfection can be detected by means of radiographic (according to EN 12681), ultrasonic inspections and metallographic tests.

Metallurgical origin: The lubricant/release agent entrapment porosity is caused by an excessive quantity of lubricant/release agent on the die surface and/or piston/sleeve coming into contact with molten metal.



Key

A lubricant film

B gas development from lubricant

Figure A.7 — Schematics of lubricant entrapment porosity

A.1.3 Filling-related defects and imperfections

A.1.3.1 Cold joint (Type A3.1)

Definition: A cold joint is a discontinuity of metallurgical type (either microstructural and/or metallic) rather than of geometrical-type (such as, for example, a cavity or a crack) [see Bibliography [8-10], [12-16]].

Morphology: The appearance of this defect/imperfection depends on the conditions of the metal flows at the moment of their confluence and on their location within the die-cavity. This defect/imperfection can be detected mainly by means of metallographic tests.

Metallurgical origin: The cold joint forms when a relatively cold liquid metal flow - at least partially solidified and in some cases covered by an oxide film - meets another warmer metal vein that can flow around it. The cold joint usually brakes along the previous interface of flows when relatively low tension stresses normal to it or shear stresses parallel to it are applied.

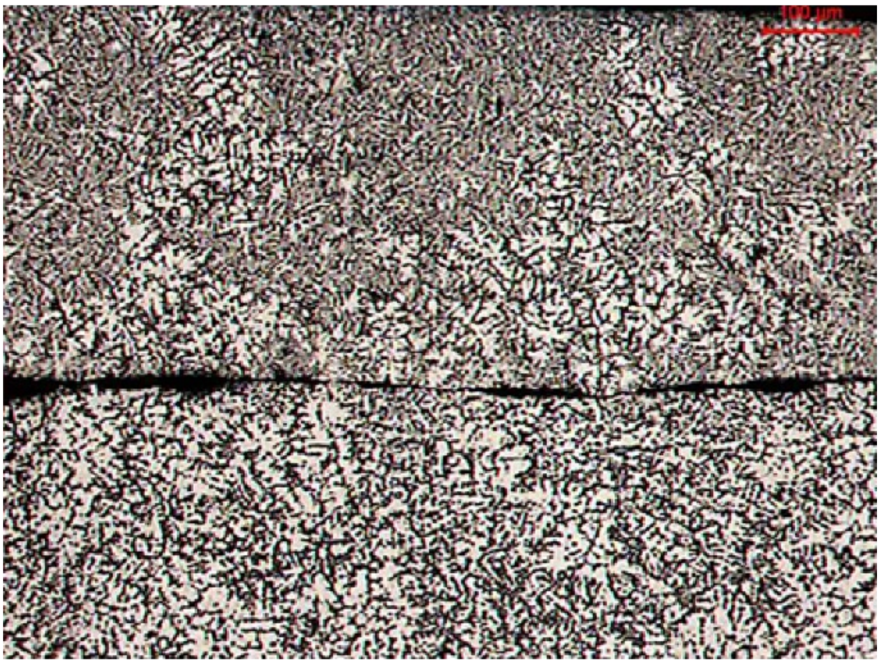


Figure A.8 — Micrograph of a cold joint

A.1.3.2 Lamination (Type A3.2)

Definition: A lamination is a typical surface defect/imperfection (see A.1.3.1), but in some cases can be also considered as internal defect/imperfection. The lamination is a sort of thin metallic layer (skin) with different microstructure in comparison to the material laying around and partly separated by a thin oxide film [see Bibliography [8-10], [12-16]].

Morphology: This defect/imperfection consists of a thin metallic layer having a separation surface from the bulk metal almost parallel to the component surface, with imperfect adhesion to the inner metal and with finer microstructure. This defect/imperfection presents variable size and can be detected by means of ultrasonic inspections and metallographic tests.

Metallurgical origin: The lamination forms when the metal foil comes into contact with the die surface and cools down with a higher rate than the surrounding regions.

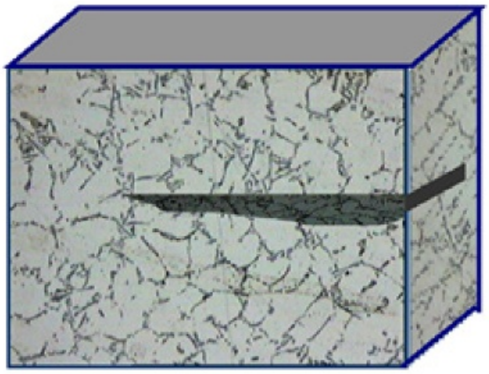


Figure A.9 — Schematics of a lamination

A.1.3.3 Cold shot (Type A3.3)

Definition: Even if a cold shot always originates at the surface of the die, it can be found as internal defect/imperfection when it is trailed by a liquid metal flow. The cold shot is a small amount of metal characterized by microstructural features much finer than the surrounding regions and separated by a thin oxide layer [see Bibliography [8-10], [12-17]].

Morphology: The cold shot looks like a small amount of metal with a spherical or ellipsoidal shape. The size of a cold shot varies between 0,01 mm and 1,0 mm. This defect/imperfection can be detected only by means of metallographic tests.

Metallurgical origin: A cold shot forms when the alloy flows turbulently with a front characterized by a considerable presence of drops (spray effect) and comes into contact with the surface of the die (see A.2.3.3). In such conditions, the molten metal can approach the solidus temperature and rapidly solidifies.

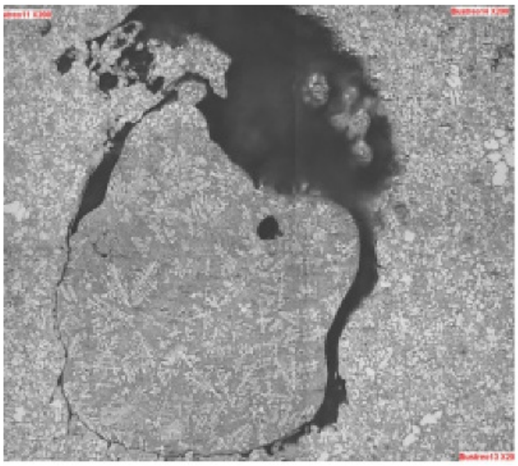


Figure A.10 — Micrograph of a cold shot

A.1.4 Undesired phases

A.1.4.1 Inclusion (Type A4.1)

Definition: Inclusions are typically non-metallic phases and include oxides and dross [see Bibliography [8-10], [12-17]].

Morphology: The inclusion can be in the form of a particle or of a thin film. The size of an inclusion is major than 0,05 mm. This defect/imperfection can be detected by means of ultrasonic and radiographic inspections and metallographic tests.

Metallurgical origin: In Al-alloys the most frequent type of inclusion is the aluminium oxide, i.e. alumina (Al_2O_3). It easily forms when the liquid metal comes into contact with air.

Inclusions can also be other non-metallic phases, such as small portions of refractories (often silicon carbide) or dross. Because of their high hardness, inclusions can cause machining problems.

Figure A.11 — Image of aluminium oxide

A.1.4.2 Undesired structure (Type A4.2)

Definition: These are areas of different microstructure which are undesired mainly for their high hardness, stiffness, brittleness and because they create microstructural discontinuities [see Bibliography [8-13], [15-16]].

Morphology: The morphology of undesired structures cannot be uniquely described and their size depends on the cell size. For example, the SDAS could be outside the acceptable limit for a specific region of the casting. This defect/imperfection can be detected by means of metallographic tests.

Metallurgical origin: Undesired structures can include portions of previously produced castings (for example flash), accidentally left within the die-cavity and then embedded in the successive casting.

Undesired structures represent microstructural discontinuities and could act as crack nucleation and propagation sites during cooling, finishing operations or in-service behaviour.

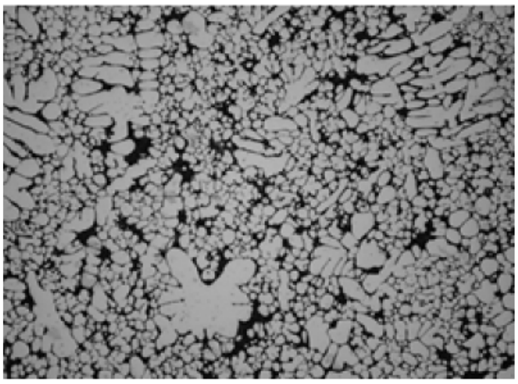


Figure A.12 — Micrograph of a region with large dendrites

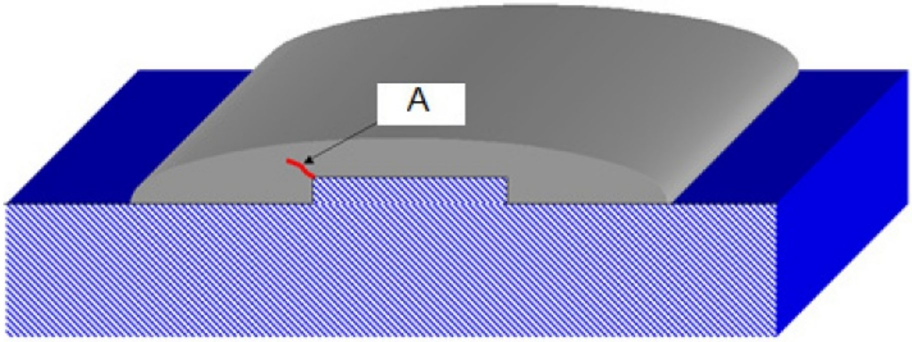
A.1.5 Thermal contraction defects and imperfections

A.1.5.1 Cold crack (Type A5.1)

Definition: A cold crack is a geometrical discontinuity characterized by one dimension far smaller than the two others [see Bibliography [8-10], [12-16]].

Morphology: A narrow void volume lays within the two faced fracture surfaces which define crack. The length of a crack varies between 10 µm to several millimetres. The surfaces often show transcrystalline failure mode as a differentiation of hot cracks / tears. This defect/imperfection can be detected by means of ultrasonic inspections and metallographic tests. It can be detected also by radiographic inspection, if X-Ray shoot and hot tear have the same direction.

Metallurgical origin: Such defect/imperfection forms at relatively low temperature (far from the solidification range) when the greater thermal contraction of the casting with respect to the die is prevented by the die itself. Cracks can often occur in regions of stress localization, either due to macroscopic geometrical reasons or to the presence of microstructural defects/imperfections.



Key

A crack

Figure A.13 — Schematics of a cold crack formation

A.1.5.2 Hot tear, hot crack (Type A5.2)

Definition: A hot tear is a brittle crack formed in liquid portions of the mushy zone in the final stages of solidification [see Bibliography [8-10], [12-16]].

Morphology: The surface of a hot tear typically displays a dendritic morphology and can be heavily oxidized since formed at high temperature. The length of an hot tear varies between 10 µm to several millimetres. The surfaces characteristically show interdendritic failure mode and sometimes may be partially refilled by residual eutectic metal. This defect/imperfection can be detected by means of ultrasonic inspections and metallographic tests. It can be detected also by radiographic inspection, if X-Ray shoot and hot tear have the same direction.

Metallurgical origin: The hot tear usually forms in such alloys characterized by a wide solidification temperature range and in hot spot areas at stresses far below the tensile stress at the temperature. The occurrence of a hot tear is very much influenced by the local geometry and may be additionally influenced by local microstructure.

Figure A.14 — Micrograph of a hot crack

A.2 Surface defects and imperfections

A.2.1 Shrinkage defects and imperfections

A.2.1.1 Sink (Type B1.1)

Definition: A sink is a surface depression related to the presence of sub-surface shrinkage porosity [see Bibliography [8-10], [12], [15]].

Morphology: A sink looks like a surface depression toward the interior of the casting. It extends for several millimetres. This defect/imperfection can be detected by means of visual, liquid penetrant inspections and metallographic tests.

Metallurgical origin: A sink occurs when, during the casting solidification, a hot spot localizes close to the metal/die interface. The skin layer - formed as a consequence of the contact with the die - is not able to sustain stresses arising from the contraction of the sub-surface solidifying region and plastically deforms.

The sink is typically found in components with relatively wide plane surfaces or with sharp cross section changes.

Figure A.15 — External surface of a sink

A.2.2 Gas-related defects and imperfections

A.2.2.1 Blister (Type B2.1)

Definition: The blister is a porosity defect/imperfection due to gases entrapment, with the only difference, in comparison with internal defect/imperfection, that gases are entrapped within a sub-surface region [see Bibliography [8-10], [12], [15]].

Morphology: A blister is a small amount of material that blown up (with respect to the surrounding surface) in correspondence of a sub-surface gas porosity. A blister extends from 100 µm to several millimetres. This defect/imperfection can be detected by means of visual inspections and metallographic tests.

Metallurgical origin: A blister consists of small surface area that blown up when the internal pressure of sub-surface gas-related porosity is high enough to plastically deform the thin metallic layer that covers it. The metal deformation occurs easily at relatively high temperatures, when castings are ejected from the die or during following heat treatments.

Figure A.16 — Example of blisters

A.2.2.2 Pinhole (Type B2.2)

Definition: The pinhole is a smooth-walled cavity, often located in surface or sub-surface of castings, and due to gas entrapment [see Bibliography [8-15]].

Morphology: A pinhole is a smooth-walled cavity, essentially spherical, often located in surface or sub-surface regions. The largest cavities are most often isolated, the smallest appear in groups of varying dimensions (10 µm – 2 000 µm). The interior walls of pinholes can be shiny, more or less oxidized. This defect/imperfection can be detected by means of radiographic (according to EN 12681), ultrasonic inspections and metallographic tests. It may be detected also by penetrant testing and by Eddy current inspections.

Metallurgical origin: Pinholes are caused by gas entrapment in the metal during the course of solidification. Such gases arise from sand cores and are due to moisture, binders, additives containing hydrocarbons, blacking and washes of cores. This phenomenon is aggravated by an insufficient evacuation of gas from the mould cavity.

Figure A.17 — Example of pinholes

A.2.3 Filling-related defects and imperfections

A.2.3.1 Cold joint and vortex (Type B3.1)

Definition: The cold joints are surface wrinkles, slight depressions or simply alterations of castings visual features along the line corresponding to the interface between converging flows. A particular cold joint defect/imperfection is the vortex, which forms on the surface when only one flow rolls itself up and generates a particular spiral distribution of oxide films and microstructures [see Bibliography [8-10], [12], [14-16]].

Morphology: A cold joint presents wrinkled surfaces or linear depressions due to the deformation of the cooler and more viscous flow. The surface of the casting can also be unaltered, but the presence of different microstructures of different flows is visible. The vortex has a characteristic spiral-shaped appearance on the surface of the casting. The cold joint and the vortex can be detected by means of visual inspections and metallographic tests.

Metallurgical origin: A cold joint forms when a relatively cold metal flow - at least partially solidified and in some cases covered by an oxide film - meets another warmer metal vein that can flow around it. As explained in the case of the corresponding internal defect/imperfection (see A.3.1), the metallic discontinuity can cause material detachment along it when even relatively low stress arises.

Figure A.18 — Macrograph showing a vortex

A.2.3.2 Lamination (Type B3.2)

Definition: A lamination is a thin surface metallic layer having a separation surface from the bulk metal almost parallel to the component surface and with imperfect adhesion to the inner metal [see Bibliography [8-10], [12], [15-16]].

Morphology: The lamination seems as a skin with different microstructure and partly separated from the bulk material by an oxide film. This defect/imperfection can be detected by means of visual inspections and metallographic tests.

Metallurgical origin: A lamination forms when a relatively warm vein at low viscosity flows between the steel-die and another cooler and partially solidified flow. Laminations could also form as a result of deformations of the die related to sudden pressure changes. The resulting metallic discontinuity can cause the partial or complete skin detachment along the interface, when even relatively low stresses arise or are externally applied.

Figure A.19 — Surface lamination

A.2.3.3 Cold shot (Type B3.3)

Definition: A cold shot is a small amount of metal characterized by microstructural features much finer than the surrounding regions and separated by a thin oxide layer [see Bibliography [8-10], [12-17]].

Morphology: The cold shot looks like a small amount of metal with a spherical or ellipsoidal shape. The size of a cold shot varies between 0,01 mm and 1,0 mm. This defect/imperfection can be detected by means of visual inspections and metallographic tests. It may be detected also by penetrant testing.

Metallurgical origin: A cold shot forms when the alloy flows turbulently with a front characterized by a considerable presence of drops (spray effect) and comes into contact with the surface of the die (see A.1.3.3). In such conditions, the molten metal can approach the solidus temperature and rapidly solidifies.

Figure A.20 — Macrograph of a surface cold shot

A.2.4 Undesired phases

A.2.4.1 Surface deposit (Type B4.1)

Definition: A surface deposit can be a layer of various chemical composition, thickness, distribution and adhesion, which, for various reasons, deposited on the surface of the casting (without chemical interaction) during the process [see Bibliography [8-10], [16]].

Morphology: A deposit appears as a surface region covered by particles of different chemical composition respect to the casting. A surface deposit usually extends for several millimetres. This defect/imperfection can be detected by means of visual inspections and metallographic tests.

Metallurgical origin: A lubricant excess, which can be transferred from the die to the casting, can cause a surface deposit formation.

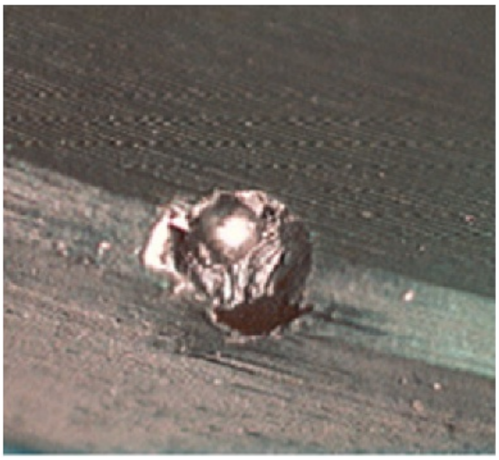


Figure A.21 — Macrograph of a deposit

A.2.4.2 Contaminant or inclusion (Type B4.2)

Definition: A contaminant can be a layer of various chemical composition, thickness, distribution and adhesion, which, for various reasons, deposited on the surface of the casting during the process or later, but in some way related to the process. For inclusion definition, refer to the corresponding internal defect/imperfection (A4.1) [see Bibliography [8-10], [15-16]].

Morphology: When a contaminant defect/imperfection occurs, the surface of the casting appears locally coloured differently from the other portions (or from the usual colour related to the presence of a thin oxide layer). The size of a contaminant or inclusion is major than 0,1 mm. This defect/imperfection can be detected by means of visual inspections and metallographic tests. An inclusion can be detected also by radiographic inspection and by Eddy current inspection.

Metallurgical origin: Contaminants are the result of interaction between metal and substances locally come into contact with it. Even corrosion of the casting can be included into this type of defect/imperfection.

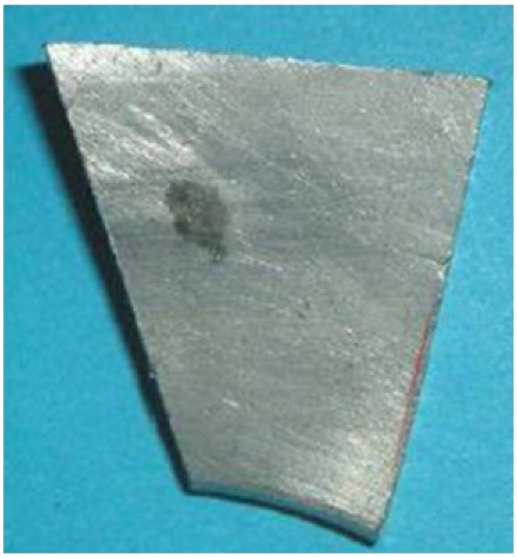


Figure A.22 — Macrograph of a contaminant

A.2.5 Thermal contraction defects and imperfections

A.2.5.1 Cold crack (Type B5.1)

Definition: A cold crack is a defect/imperfection that can widely extend within the casting, from surface to surface. For this reason, cracks have been included both within internal and surface defects/imperfections (see A.5.1) [see Bibliography [8-10], [12-15]].

Morphology: A crack is a geometrical discontinuity characterized by one dimension far smaller than the two others. A narrow void volume lays within the two faced fracture surfaces which define crack. The length of a crack extends from 10 μm to several millimetres. This defect/imperfection can be detected by means of visual, liquid penetrant, Eddy current inspections.

Metallurgical origin: A crack generally originates on a surface or in a sub-surface position, but it can propagate into internal regions of the casting until reaching the other surface/s.

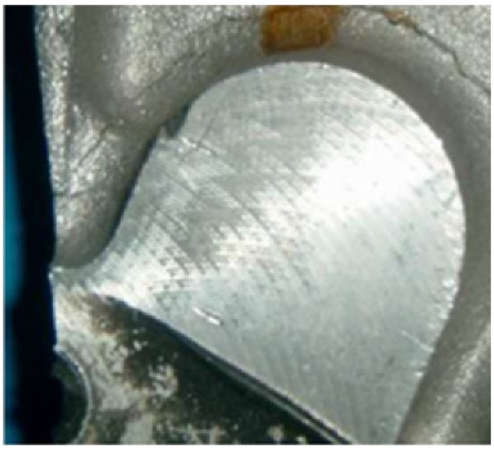


Figure A.23 — Image of a crack

A.2.5.2 Hot tear, hot crack (Type B5.2)

Definition: A hot tear is a defect/imperfection that can widely extend within the casting, from surface to surface. For this reason, hot tears have been included both within internal and surface defects/imperfections (see A.1.5.2) [see Bibliography [8-16]].

Morphology: The surface of a hot tear typically displays a dendritic morphology and can be heavily oxidized since formed at high temperature. The length of a hot tear extends from 10 µm to several millimetres. This defect/imperfection can be detected by means of radiographic and ultrasonic inspections.

Metallurgical origin: The hot tear usually forms in such alloys characterized by a wide solidification temperature range and in hot spot areas at stresses far below the tensile stress at the temperature. The hot tear can also be due of stress concentration for geometrical or microstructural reasons.

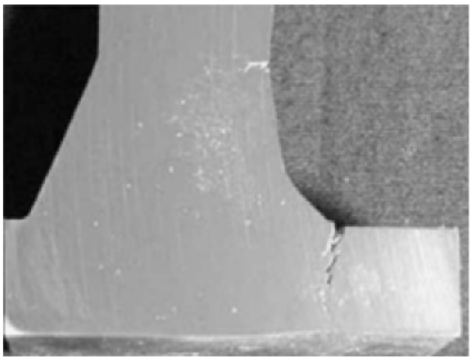


Figure A.24 — Macrograph of a hot crack

A.2.6 Metal/die interaction defects and imperfections

A.2.6.1 Erosion (Type B6.1)

Definition: Erosion is a defect/imperfection that reproduces, in negative, a defect of the die caused by erosive phenomena [see Bibliography [8-10], [16]].

Morphology: Erosion consists of a material excess on the casting caused by the steel removal from the die by erosive wear. The thickness of the erosion defect/imperfection is 1 µm -200 µm. This defect/imperfection can be detected by means of visual inspections and metallographic tests.

Metallurgical origin: The impact of the turbulent flow at high speed and high temperature on the die-cavity can lead to the progressive wear erosion. In addition to the above mentioned factors, erosion is related to the inclination angle of the metal flow with respect to the die surface and to the presence of particles or bubbles inside the liquid metal (cavitation).

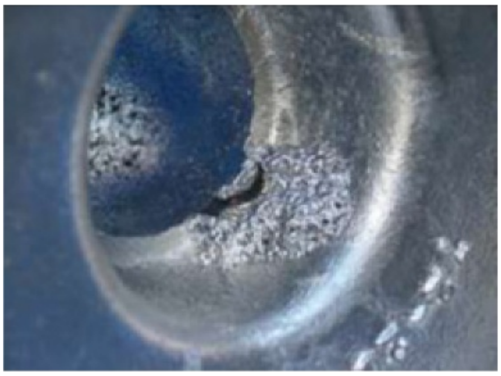


Figure A.25 — Image of a casting defect/imperfection caused by die-erosion

A.2.6.2 Soldering (Type B6.2)

Definition: As for other metal/die interaction defects/imperfections, the metallurgical origin of the die damage (soldering) reflects in the name of the casting defect/imperfection [see Bibliography [8-10], [12], [14-16]].

Morphology: Soldering causes surface roughness or localized lack of material on the casting. The thickness of the soldering defect/imperfection is 1 µm -200 µm. This defect/imperfection can be detected by means of visual inspections and metallographic tests.

Metallurgical origin: The common metallurgical origin of soldering is the formation of Al- and Fe-based intermetallic phases on the die surface and following adhesion of the aluminium alloy on them. Soldering often promptly occurs in regions of the die exposed to liquid metal at relatively high temperature and flow rates. Soldering can also easily take place in the zones of the die where thermal fatigue or erosion phenomena previously occurred.

Figure A.26 — Example of soldering effects on the die

A.2.6.3 Thermal fatigue marks (Type B6.3)

Definition: Thermal fatigue is the name commonly given to narrow relieves related to corresponding damage of the die [see Bibliography [8-10], [12-16]].

Morphology: The defect/imperfection consists of a set of narrow relieves on the surface of the casting, sometimes referred also as crocodile skin. The thickness of the thermal fatigue defect/imperfection is 1 µm - 200 µm. This defect/imperfection can be detected by means of visual, inspections and metallographic tests.

Metallurgical origin: As the time of service of the die increases, small cracks can form on its edges or surface, due to the repetition of stress-strain cycles (induced by the rapid heating and cooling stages). The liquid metal filters into cracks and gives rise to the relieves on the surface of the casting. This kind of defect/imperfection appears on the casting independently from the specific process or relative parameters.

Figure A.27 — A casting defect/imperfection caused by the presence of thermal fatigue cracks on the die

A.2.6.4 Ejection mark (Type B6.4)

Definition: The ejection mark is a defect/imperfection related to the presence of an undercut in the die, that could be a result of modifications of the die-geometry (for example due to one of the described previously erosion/soldering phenomena) [see Bibliography [8-10], [16]].

Morphology: The ejection mark appears as a plastic deformation of the casting that extends along the direction of the ejection from the die. This defect/imperfection can be detected by means of visual inspections and metallographic tests.

Metallurgical origin: When the ejection occurs at relatively high temperature, the presence of even a small undercut on the die causes the deformation of the casting around the undercut in the ejection direction.

Figure A.28 — Image of an ejection mark

A.2.6.5 Corrosion of the die (Type B6.5)

Definition: This defect/imperfection consists of surface roughness of the casting due to damage of the die surface, attacked by the environment (corrosion) [see Bibliography [8-10], [16]].

Morphology: The surface of the product is characterized by high roughness, more evident in correspondence of the severely corroded areas of the die cavity. The thickness of the defect/imperfection caused by the corrosion of the die is 1 μm-200 μm. This defect/imperfection can be detected by means of visual inspections and metallographic tests.

Metallurgical origin: The corrosion of the die is caused by the interaction with the environment and can be homogeneous or localized. An extremely severe corrosion of the die, either homogeneous or localized, can thus lead the casting to be out of tolerance or to have localized excess of material.

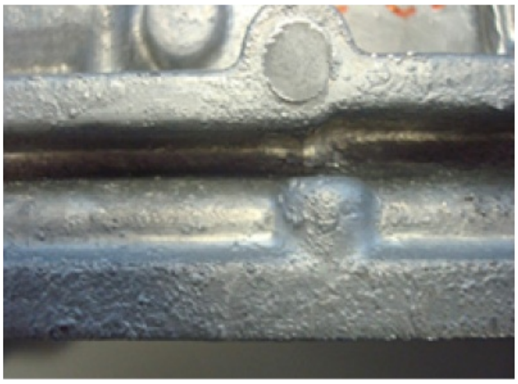


Figure A.29 — Image of a casting obtained with a corroded die

A.3 Geometry defects and imperfections

A.3.1 Lack of material - Incompleteness (Type C1.1)

Definition: An incomplete casting presents a local lack of material with respect to the geometry of the die cavity [see Bibliography [8-10], [12], [14-16]].

Morphology: The lack of material can be in order of several millimetres or centimetres. This defect/imperfection can be detected by means of visual inspections.

Metallurgical origin: Due to an excessively high viscosity, a front portion of the metal flow can stop before the die cavity has been completely filled.

Figure A.30 — Example of incomplete casting

A.3.2 Excess of material - Flash (Type C2.1)

Definition: A flash is an excess of material due to metal infiltration inside a thin gap between the die parts cavity [see Bibliography [8-10], [12], [15-16]].

Morphology: The flash is a thin layer of material in excess, whose geometry roughly reproduces that of the die separation surface. The excess of material can be in order of several millimetres or centimetres. This defect/imperfection can be detected by means of visual inspections.

Metallurgical origin: The flash is due to an insufficient clamping force of the machine, which cannot counterbalance the alloy pressure. Flashes are originated also by a different die thermal expansion.

Figure A.31 — Example of flash

A.3.3 Out of tolerance - Deformation (Type C3.1)

Definition: A casting with deformation presents a geometrical non-conformity to its design geometry, even in absence of local excess or lack of material cavity [see Bibliography [8-10], [12], [14-16]].

Morphology: The deformation of the casting is major than the established tolerances (see EN ISO 8062-1, CEN ISO/TS 8062-2, EN ISO 8062-3, UNI 10569). This defect/imperfection can be detected by means of visual inspections and of metrology testing.

Metallurgical origin: The formation of the defect/imperfection is related to the thermal contraction during cooling that causes local stress inside the casting. The defect/imperfection is more pronounced in castings ejected by the die at high temperature and presenting drastic thickness changes.

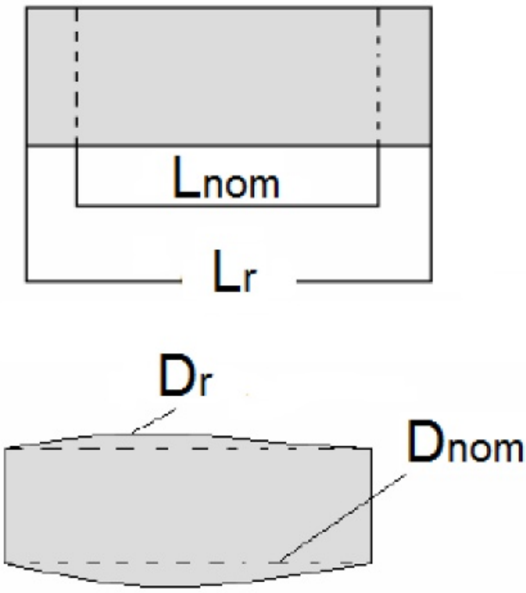


Figure A.32 — Schematics of out of tolerances castings

Annex B
(informative)

Translations of defects and imperfections terminology

In Table B.1, translations of defects and imperfections terminology are presented.

Table B.1 — Translations of defects and imperfections terminology

CODE	ENGLISH	ITALIAN	FRANCAIS	DEUTSCH	ESPAÑOL
A1.1	Macro-shrinkage	Macro-porosità	Souffloures, retassures	Makroporosität, Lunker	Macroporosidad
A1.2	Interdendritic shrinkage	Porosità interdendritica	Microretassures	Interdendritische Porosität	Porosidad interdendritica
A1.3	Layer porosity	Porosità planare	Microretassures centralés des pieces	Schichtporosität	Porosidad planearea
A2.1	Air entrapment porosity	Porosità da aria intrappolata	Porositè d'air enprisoné	Luftporosität	Porosidad de aire atrapado
A2.2	Hydrogen porosity	Porosità da idrogeno	Porosité de gaz Dissous dans le metal	Wasserstoffporosität	Porosidad de hidrógeno
A2.3	Vapour entrapment porosity	Porosità da umidità residua	Porositè	Porosität durch Wasserdampf	Porosidad de humedad restante
A2.4	Lubricant /release agent entrapment porosity	Porosità da lubrificante	Porositè de gaz de poteyage	Gasporosität durch Trennmittel	Porosidad de lubricante
A3.1	Cold joint	Giunzione fredda	Reprise	Kaltfließstelle	Unión
A3.2	Lamination	Sfogliatura	Friass	Schülpe	Foliación
A3.3	Cold shot	Goccia fredda	Goutte froide	Kaltlauf	Gota fría
A4.1	Inclusion	Inclusione	Inclusion	Einschluss	Inclusión
A4.2	Undesired structure	Struttura non desiderata	Structure ne pas demandée	Gefügestörung	Estructura no deseada
A5.1	Cold crack	Cricca a freddo	Fissure	Riss, Kaltriß	Grieta
A5.2	Hot tear, hot crack	Cricca a caldo	Fissure à chaud	Warmriss	Grieta en caliente
B1.1	Sink	Ricalo	Retassure	Einfallstelle	Hundimiento
B2.1	Blister	Blister	Cloque, soufflure	Blister, Blase	Burbuja
B2.2	Pinhole	Soffiatura	Soufflure ou trou, trou d'aiguille	Pinhole, Poren (Folie)	
B3.1	Cold joint and vortex	Giunzione fredda e vortice	Reprise	Kaltfließstelle mit Wirbel	Unión y remolino
B3.2	Lamination	Sfogliatura	Eclatement	Abblätterung / Schülpe	Foliación
B3.3	Cold shot	Goccia fredda	Goutte froide	Kaltlauf	Gota fría

B4.1	Surface deposits	Depositi	Dépot	Schlackerückstände	Depósitos
B4.2	Contaminant or inclusion	Contaminazione o inclusione	Trace de lubrifiant, trace de poteyage ou inclusion	Verunreinigung oder Einschluss	Contaminación o inclusión
B5.1	Cold crack	Cricca a freddo	Fissure	Riss, Kaltriß	Grieta
B5.2	Hot tear, hot crack	Cricca a caldo	Fissure à chaud	Warmriss	Grieta en caliente
B6.1	Erosion	Erosione	Erosion	Erosion	Erosión
B6.2	Soldering	Metallizzazione	Etamage	Verschweißung, Klebestelle	Metalización
B6.3	Thermal fatigue	Crettature da fatica termica	Craquelure	Brandrisse	Grieta por fatiga térmica
B6.4	Ejection mark	Segno di espulsione	Arrachement	Ziehriefen	Marca de expulsión
B6.5	Corrosion of the die	Corrosione dello stampo	Corrosion de moule	Ausspülungen und Korrosion	Corrosión del molde
C1.1	Uncomplete casting	Getto incompleto	Malvenue	Unvollständiges Gussteil	Pieza incompleta
C2.1	Flash	Bava	Bavure	Gesenkgrat/Gußgrat	Rebaba
C3.1	Deformation	Getto deformato	Deformation	Deformation	Pieza deformada

Annex C
(informative)

Examples of detection techniques and size of defects and imperfections

In the following table, some examples of detection techniques and size of defects and imperfections are presented.

Table C.1 — Examples of detection techniques and size of defects and imperfections

9	Type of defect and imperfection	NDT	DT	Size
A1.1	Macro-shrinkage	RT, UT	MA	> 0,5 mm
A1.2	Interdendritic shrinkage	(RT), UT, (LT)	MA	10 µm – 150 µm (as SDAS)
A1.3	Layer porosity	RT, UT	MA	10 µm – 100 µm
A2.1	Air entrapment porosity	RT, UT	MA	0,01 mm – 2 mm
A2.2	Hydrogen porosity	(RT), UT	MA	0,05 mm – 0,5 mm
A2.3	Vapour entrapment porosity	(RT), UT	MA	0,5 mm – 3 mm
A2.4	Lubricant/release agent entrapment porosity	(RT), UT	MA	0,5 mm – 3 mm
A3.1	Cold joint	(UT)	MA	–
A3.2	Lamination	UT	MA	–
A3.3	Cold shot	(UT)	MA	0,01 mm – 1,0 mm
A4.1	Inclusion	UT, RT	MA	> 0,05 mm
A4.2	Undesired structure	–	MA	> 30 µm
A5.1	Cold crack	(RT), UT	MA	Length: 10 µm to several millimetres
A5.2	Hot tear, hot crack	(RT), UT	MA	Length: 10 µm to several millimetres
B1.1	Sink	VT	MA	Several millimetres
B2.1	Blister	VT	MA	100 µm to several millimetres
B2.2	Pinhole	RT, UT, PT, (ET)	MA	0,01 mm – 2,0 mm
B3.1	Cold joint and Vortex	VT	MA	–
B3.2	Lamination	VT	MA	–
B3.3	Cold shot	VT, PT	MA	0,01 mm – 1,0 mm
B4.1	Surface deposit	VT	MA	Several millimetres
B4.2	Contamination or inclusion	VT, (PT, ET)	MA	> 0,1 mm
B5.1	Cold crack	VT, PT, ET, (RT)	MA	Length: 10 µm to several millimetres

B5.2	Hot tear, hot crack	VT, PT, ET, (RT)	MA	Length: 10 µm to several millimetres
B6.1	Erosion	VT	MA	Thickness: 1 µm – 200 µm
B6.2	Soldering	VT	MA	Thickness: 1 µm – 200 µm
B6.3	Thermal fatigue	VT	MA	Thickness: 1 µm – 200 µm
B6.4	Ejection mark	VT	MA	–
B6.5	Corrosion of the die	VT	MA	Thickness: 1 µm – 200 µm
C1.1	Incomplete casting	VT	–	Several millimetres or centimetres
C2.1	Flash	VT	–	Thickness: milliimetres; extension: centimetres
C3.1	Deformation	VT, DI	–	> tolerance

NDT = Non Destructive Testing
RT = Radiographic testing
VT = Visual testing
UT = Ultrasonic testing
PT = Penetrant testing
DT = Destructive Testing
ET = Eddy-current testing
MA = Metallographic analysis
LT = Leak testing
DI = Dimensional inspection

The testing techniques indicated in parentheses can be eventually used in some cases.

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