
Guidelines for the selection of coating types, tests and methods of assessing the performance of coated aluminium in architectural applications

Lignes directrices pour la sélection des types de revêtements, essais et méthodes d'évaluation des performances de l'aluminium revêtu dans les applications architecturales

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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.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

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For an explanation on the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT) see the following URL: www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 79, *Light metals and their alloys*, Subcommittee SC 2, *Organic and anodic oxidation coatings on aluminium*.

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Guidelines for the selection of coating types, tests and methods of assessing the performance of coated aluminium in architectural applications

1 Scope

This document establishes a system to select coating types for architectural applications depending on environment. It gives guidelines for the selection of tests and methods of measuring performance in terms that are of direct interest to the building designer.

This document is applicable to organic and anodic oxidation (AAO) coatings on aluminium, including those produced from liquid and powder paints, and combined coatings of organic and anodic oxidation coatings. It is designed to be applicable to novel coatings developed in the future.

2 Normative references

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

ISO 7583, *Anodizing of aluminium and its alloys — Terms and definitions*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 7583 and the following apply.

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

- IEC Electropedia: available at <http://www.electropedia.org/>
- ISO Online browsing platform: available at <http://www.iso.org/obp>

3.1

abrasive wear

wear process of a material caused by cutting or scratching actions of hard bodies or hard particles

[SOURCE: ISO 4378-2:2017, 3.3.1.2]

3.2

adhesive wear

wear process due to adhesion and extraction of material out of the body surface

[SOURCE: ISO 4378-2:2017, 3.3.1.3]

3.3

accelerated test

test undertaken under conditions designed to speed material deterioration

[SOURCE: ISO 23936-2:2011, 3.1.1]

3.4

architectural applications

external and internal building applications for coated aluminium products where both appearance and long life are important

3.5

coating

covering on a substrate, which has protective, decorative or specific technical properties

3.6

coil coating

coating process whereby the coating material is applied continuously to a coil of metal which may be rewound after the film has dried

[SOURCE: ISO 4618:2014, 2.56]

3.7

designer

person or organization responsible for stating the form and specification of a building or parts of a building

3.8

durability

ability of a coating to withstand fabrication and installation procedures and a service environment without excessive degradation of the decorative and other specific properties of the finish

3.9

inorganic coating

coating (3.5) of a coated product consisting primarily of inorganic, non-metallic material

3.10

organic coating

coating (3.5) of a coated product consisting primarily of organic material

3.11

paint

liquid or powder containing pigments, which, when applied to a substrate, forms a film having protective, decorative or specific technical properties

[SOURCE: ISO 4618:2014, 2.184, modified — The definition has been changed so that it is restricted to liquid and powder coating materials and not to opaque films.]

3.12

simulation

use of a similar or equivalent system to imitate a real system so that it behaves like or appears to be the real system

[SOURCE: ISO 16781:2013, 2.9]

3.13

sol-gel processing

conversion of a chemical solution or colloidal suspension (sol) to an integrated network (gel) which can then be further densified

[SOURCE: ISO/TS 80004-8:2013, 6.4.5]

3.14

time-of-wetness

period during which a surface is covered by adsorptive and/or liquid films of aqueous solution

[SOURCE: ISO 9223:2012, 3.5, modified — The definition has been generalized so as not to be specific to metals and corrosion.]

3.15**underfilm corrosion**

corrosion of a metal surface taking place beneath a coating

EXAMPLE Filiform corrosion and the corrosion that can occur beneath blistering.

3.16**visible defect**

unacceptable physical imperfection or flaw in the surface coating detracting from the specified reference material or from the product's functions

[SOURCE: ISO 16348:2003, 2.4]

4 General**4.1 Selection of methods to protect metals against corrosion**

ISO 11303:2002 gives guidelines for the selection of methods of protection against the atmospheric corrosion of metals and alloys. It is applicable for technical equipment and products made of structural metals, including aluminium alloys, and used under atmospheric conditions. It identifies the main considerations in the decision-making process:

- the structural metal;
- the design of the structural element;
- the active agent, e.g. chloride ions;
- the condition of action, e.g. ambient temperature.

It uses the atmospheric corrosion classification of ISO 9223:2012. The principal factor in the selection process is the service life of the component or product, which is derived in relation to its most important functional property, e.g. colour.

This document is concerned with aluminium alloys as the structural metal, although it gives no guidance on alloy selection. The design of the structural element is also outside its scope. It is concerned with the selection of coatings depending on the active agents and conditions of action in atmospheric environments with regard to functional properties. However, it includes no quantitative information that relates the quality degree of the coating to service life. ISO 15686-1 gives general principles of service life planning.

4.2 System for selecting coating types for architectural applications

With reference to the guidelines of ISO 11303:2002, the following steps can be followed to select a coating type for a specific architectural application.

- Identify active agents and conditions of activity of the environment.
- Rate the intensity of the agents. [Clause 5](#) provides guidance for the main agents: acidic pollution, UV (ultra-violet) radiation and chloride deposition.
- Weigh the contributions of the agents according to the conditions of activity, e.g. time-of-wetness, ambient temperature, wet/dry cycling frequency, the frequency of cleaning or washing by rain.
- Using the information of [Clause 7](#), select the coating types most likely to be suitable. Refer to the specifications for coated aluminium listed in [Clause 6](#) for more information on specific coatings.
- Eliminate any coatings on the basis of other factors such as requirements for the design of the structural elements including colour and reflectivity, and costs.

- Undertake comparative tests to identify the coatings most suitable for the service environment. Tests and methods of measuring performance are described in [Clauses 8](#) and [10](#), while the applicability of tests for different environments is covered in [Clause 9](#).

5 Types of environment

A main function of the coating is to preserve the original appearance of the coated product. Thus, the coating should not degrade so that it becomes unsightly. An example is the effect of UV radiation on organic coatings and dyed AAO coatings, which can cause a change in appearance. Furthermore, the coating should prevent the corrosion of the aluminium substrate. Thus, degradation of the coating, even if it is not noticeable, can be the precursor to aluminium corrosion which can affect the appearance of the product. Note that EN 1999-1-1:2007+A1, Eurocode 9, gives basic design rules to avoid loss of load-bearing capacity due to corrosion for buildings and structures made of wrought aluminium alloys.

ISO 9223:2012 gives six classes of outdoor and indoor environments based on corrosivity alone. ISO 12944-2:1998 includes the same categories but adds further examples. [Table 1](#) gives those categories and includes descriptions from both those standards.

The corrosivity categories of ISO 9223:2012 are defined by the first-year corrosion effects on standard specimens of uncoated aluminium, carbon steel, zinc and copper, which are assessed in terms of the most significant atmospheric agents influencing the corrosion of the metals and alloys. The agents considered were the time-of-wetness, and sulfur dioxide (SO₂) and chloride pollution levels. The standard includes data defining different levels of exposure to these agents. The levels of time-of-wetness extend from not more than 10 hours per year to more than 5 500 hours per year. The levels of SO₂ deposition rate extend from not more than 4 mg/(m²·d) to more than 200 mg/(m²·d). The levels of chloride deposition rate extend from not more than 3 mg/(m²·d) to more than 300 mg/(m²·d). ISO 9223:2012 also includes data for other important pollutants although they are not used as classification criteria.

ISO 12944-2:1998 is concerned with painted steel structures.

For the purposes of this document, the categorization of ISO 9223:2012 has certain deficiencies as follows.

- It is based on the corrosion of uncoated metals.
- It does not fully differentiate the effect of chloride ions from other pollutants.
- It does not include acidic pollutants other than sulfur dioxide.
- It does not consider climatic variations in UV radiation.

A significant factor affecting the corrosion of some metals and particularly steel is the chloride content of the environment. The main sources of chlorides are the sea and de-icing of roads. Airborne salinity is strongly dependent on the variables influencing the transport inland of sea-salt, such as wind direction, wind velocity, local topography and distance of the exposure site from the sea. Surfaces that are sheltered and not rain-washed in marine atmospheres where chlorides are deposited and accumulated can experience a higher corrosivity due to the presence of hygroscopic salts. Aluminium is much less affected by chlorides than steel, unless there is associated acidity or alkalinity.

The corrosivity of an atmosphere towards metals is not necessarily comparable to its severity in promoting the degradation of non-metallic coatings, which can affect the aesthetic properties of the product. However, coatings can be degraded by acids and alkalis, and associated time-of-wetness. The wetting of surfaces is caused by many factors, for example, dew, rainfall, melting snow, a high humidity level and condensation. Chemicals from the atmosphere can dissolve in surface films of water and become more concentrated as the water evaporates. Thus, although time-of-wetness is important, so is wet/dry cycling. Particulates on a surface can absorb water creating a poultice with persistent wetness depending on rain washing and drying.

Table 1 — Typical environments related to corrosivity categories

| Corrosivity category | Corrosivity | Outdoor | Indoor |
|----------------------|-------------|---|---|
| C1 | Very low | Dry- or cold-zone atmospheric environment with very low pollution and time-of-wetness. EXAMPLE Certain deserts, central Arctic/Antarctica. | Heated spaces with low relative humidity (RH) and insignificant pollution. EXAMPLE Offices, shops, schools, hotels, museums. |
| C2 | Low | Temperate-zone atmospheric environment with low pollution. EXAMPLE Rural areas, small towns. Dry- or cold-zone atmospheric environment with short time-of-wetness. EXAMPLE Deserts, subarctic areas. | Unheated spaces with varying temperature and RH. Low frequency of condensation and low pollution. EXAMPLE Depots, sports halls. |
| C3 | Medium | Temperate-zone atmospheric environment with medium pollution or some effect of chlorides. EXAMPLE Urban areas, coastal areas with low deposition of chlorides. Subtropical- and tropical-zone atmosphere with low pollution. | Spaces with moderate frequency of condensation and moderate pollution from production processes. EXAMPLE Food-processing plants, laundries, breweries, dairies. |
| C4 | High | Temperate-zone atmospheric environment with high pollution or substantial effect of chlorides. EXAMPLE Polluted urban areas, industrial areas, coastal areas without spray of salt water or exposure to strong effect of de-icing salts. Subtropical-zone and tropical-zone atmosphere with medium pollution. | Spaces with high frequency of condensation and high pollution from production processes. EXAMPLE Chemical plants, swimming pools, coastal ship and boatyards. |
| C5 | Very high | Temperate- and subtropical-zone atmospheric environment with very high pollution and/or significant effect of chlorides. EXAMPLE Industrial areas, coastal areas, sheltered position on coastline. | Spaces with very high frequency of condensation and/or with high pollution from production processes. EXAMPLE Mines, caverns for industrial purposes, unventilated sheds in subtropical and tropical zones. |
| CX | Extreme | Subtropical- and tropical-zone (very high time-of-wetness) atmospheric environment with very high pollution including accompanying and production factors and/or strong effect of chlorides. EXAMPLE Extreme industrial areas, coastal and offshore areas, occasional contact with salt spray. | Spaces with almost permanent condensation or extensive periods of exposure to extreme humidity effects and/or with high pollution from production processes. EXAMPLE Unventilated sheds in humid tropical zones with penetration of outdoor pollution including airborne chlorides and corrosion-stimulating particulate matter. |

The degradation of organic coatings is not only dependent on the amount of UV exposure but also the presence of water and oxygen. Whereas atmospheric oxygen levels may not be expected to vary significantly; time-of wetness as determined by the ambient temperature and relative humidity (RH) can have an important effect on degradation due to UV radiation. Inorganic materials are generally unaffected by UV radiation.

Inorganic materials can be degraded by the presence of water, particularly as an aqueous solution of an aggressive chemical. Considering acidic pollutants, the main sources of sulfur dioxide are emissions

from industrial plants using coal or oil. Traffic is the main source of nitrogen dioxide emissions. High levels of nitric acid are associated with high concentrations of nitrogen dioxide, organic compounds and UV light. The decreasing sulfur dioxide levels in many parts of the world and the elevated levels of nitrogen oxides caused by increasing traffic, together with ozone and particulates, has created a new multi-pollutant environmental situation. In other parts of the world, in relation to the rapid development of industry, the corrosive effect of sulfur dioxide pollution is intensifying and still dominating. Ozone is formed in the atmosphere by interactions between sunlight, oxygen and pollutants. The concentrations are higher in polluted rural atmospheres and lower in high-traffic urban areas. Particulates including aerosols arise from high-concentration traffic areas and industrial activities. They can contain high concentrations of corrosion-active components such as sulfate, nitrate and chloride anions. The burning of coal and wood is a major source of soot. There is also diesel soot from road vehicles.

EN 1396:2015 has certain advantages over ISO 9223:2012. It is concerned with painted aluminium and consequently categorizes end-use environments according to UV radiation intensity, as well as potential corrosivity (see Table 2). The indices are defined in terms of the performance of variously coated test panels during outdoor exposure testing carried out in compliance with EN 13523-19 and evaluated according to EN 13523-21. UV radiation indices correspond to colour change and retained gloss over two years of outdoor exposure. Corrosivity indices correspond to specific amounts of underfilm corrosion after specific times of outdoor exposure rather than rate data for uniform corrosion as used by ISO 9223:2012.

Table 2 — Corrosivity and UV radiation indices for different environments (EN 1396:2015)

| Environment | Corrosivity index | UV radiation index (R_{UV}) |
|--|-------------------|---------------------------------|
| High UV radiation with severe conditions Tropical (high temperature, high humidity) outdoor areas | 3 | 4 |
| High UV radiation outdoor areas | 2 | 4 |
| Very severe coastal marine (less than 3 km from the sea, depending also on the topography) Severe industrial – extreme conditions | 3 | 3 |
| Rural or urban light industrial (or light marine) outdoor areas | 2 | 3 |
| Wet corrosive indoor areas | 3 | 2 |
| Dry and wet non-corrosive indoor areas | 1 | 2 |

EN 1396:2015 defines the UV radiation indices geographically and on the basis of altitude as follows.

- R_{UV2} . Regions located north of about latitude 45 °N with an altitude not greater than 900 m.
- R_{UV3} . Regions located south of about latitude 45 °N and north of about latitude 37 °N with an altitude not greater than 900 m.
- R_{UV4} . Regions located south of about latitude 37 °N. Every region with an altitude greater than 900 m.

Note that these criteria relate to the northern hemisphere. Because of the symmetry of the northern and southern hemispheres, the situation is equivalent in the southern hemisphere.

It also defines coating performance requirements appropriate for each UV radiation index. This enables the indices to be used for indoor as well as outdoor environments.

However, EN 1396:2015 includes a relatively small number of distinct categories for outdoor exposure. There are only two each for corrosivity and UV radiation compared with the six of ISO 9223:2012 for corrosivity alone.

The standards JIS H 8601:1999 and JIS H 8602:2010 relate specifically to anodized aluminium and combined coatings on aluminium. They classify outdoor environments into three classes:

- a) severe environment with strong UV radiation;

- b) severe environment;
- c) normal environment.

These are very broad classifications in comparison with those of [Table 1](#).

6 Classification of coatings

6.1 Specifications for coated aluminium products

The main objectives of coating aluminium for architectural applications are to modify the appearance of the aluminium to generate an aesthetic effect and to preserve the initial appearance of the product over a long service life.

The following international, national and voluntary product standards specify different types of coated aluminium.

- ISO 7599;
- ISO 28340;
- EN 1396;
- EN 12206-1;
- GB 5237.2;
- GB 5237.3;
- GB 5237.4;
- GB 5237.5;
- DIN 17611;
- JIS H 8601;
- JIS H 8602;
- BS 3987;
- BS 4842;
- AAMA 611;
- AAMA 612;
- AAMA 2603;
- AAMA 2604;
- AAMA 2605;
- GSB AL 631;
- Voluntary specification for paint coatings of architectural aluminium materials, Japan Aluminium Products Association (JAPA), Tokyo;
- Voluntary specification for baked paint coatings of architectural aluminium alloy materials, Japan Society for Finishing Technology (JSFT), Tokyo;
- Specifications for the QUALANOD quality label for sulphuric acid-based anodizing of aluminium, Qualanod, Zurich;

- Specifications for a quality label for liquid and powder organic coatings on aluminium for architectural applications, Qualicoat, Zurich.

6.2 Descriptions of coatings and coating processes

This document is cognisant of EN 15530, which gives general guidelines to standards' writers on the environmental aspects of aluminium products, including those for building and construction, with their associated coating processes.

This document covers mainly paint coatings, AAO coatings and combined coatings. Other coatings not specifically covered may include those produced by methods such as sol gel processing and electrophoretic coating onto non-anodized aluminium. Paint coatings are generally applied by spray deposition onto profiles while roll-coating is used most frequently to apply liquid paints onto aluminium strip during coil coating. Combined coatings produced by the electrodeposition of organic material onto anodized aluminium and AAO coatings are produced using immersion processes.

The production of translucent coatings can be preceded by a pretreatment to modify the appearance of the aluminium. Such pretreatments include finishing, buffing, shot blasting, brushing, etching and brightening.

The colouring of AAO coatings can be accomplished by dyeing with an organic or inorganic dye, or by electrodepositing a metal into the coating that generates colour by light scattering and absorption. The final step in an anodizing line is a sealing process that reduces the porosity and absorption capacity of the AAO coating. Sealing processes include immersion in a demineralized-water solution at a temperature of at least 96 °C, immersion in a special nickel fluoride-based solution at a temperature not higher than 35 °C, exposure to steam or deposition of a sol-gel coating. The environmental impact of these requires careful consideration, balancing the contributions of energy consumption, chemical manufacture and effluent processing.

Pretreatment processes before the application of a paint coating are important for corrosion protection and paint adhesion. They include anodic oxidation using sulfuric or phosphoric acid and conversion processes using chemicals based on chromates, fluorotitanates, phosphates or silanes. The environmental impact of hexavalent chromium is well-known and the industry is moving away from its use. Pretreatment films are covered by the paint coating and can become exposed only when degradation is occurring.

The organic coatings of paints and combined coatings may include inorganic components, e.g. metallic paints. The organic materials are hydrocarbon derivatives and the coatings have to be cured, which is an energy-intensive process.

The coatings consisting of organic materials are susceptible to the effects of UV radiation which may degrade their appearance. AAO coatings consist mainly of aluminium oxide and hydroxide which are unaffected although can include organic material such as dyes. As aluminium oxide and hydroxide are amphoteric, AAO coatings are susceptible to chemical attack by acidic and alkaline solutions which can not only degrade the appearance of the coating but reduce its thickness. There is a fundamental difference between the materials of the different types of coating. Organic coatings resemble polymers or plastics, while AAO and inorganic coatings have more in common with the material of rocks or glass.

AAO coatings are produced by oxidation of the aluminium so are integral with the aluminium and perfectly adherent to it. By contrast, organic coatings are deposited onto the pretreated aluminium surface. Conversion coatings are precipitated from solution onto the aluminium generally involving a reaction with solvated aluminium species. Deposited coatings can lose adhesion to the aluminium.

6.3 Classifications of anodic oxidation coatings

AAO coatings are classified by the different product standards on the basis of coating thickness where the number associated with the "AA" classification indicates the minimum average thickness in µm (see [Table 3](#)). The higher coating thicknesses are recommended for the more aggressive conditions. This is based on the fact that the degree of protection of the aluminium against corrosion depends primarily

on the thickness of the coating. However, anodizing requires significant amounts of electrical energy, which are proportional to the coating thickness, so there is an environmental incentive not to over-anodize. There is little effect on performance from the choice of alloy within the range of alloys used for architectural applications. But there can be a slight deleterious effect of electrolytic colouring to produce a dark colour. The classification does not include factors that relate to the degradation of the AAO coating itself such as bloom formation, chalking or rate of thickness loss.

Table 3 — Classification of AAO coatings based on coating thickness

| Standard | JIS H 8601:1999 | GB 5237.2:2008 | DIN 17611:2011 | BS 3987:1991 | Qualanod:2010 | AAMA 611-14 |
|--|----------------------------------|---|---|--------------------------|---|---|
| Coating thickness class | AA25, AA20, AA15 for outdoor use | AA25, AA20 for severe, rugged outdoor use | AA25 for especially aggressive conditions | AA25 for outdoor use | AA25, AA20, AA15 for outdoor use | Minimum 18 µm for outdoor use with periodic maintenance |
| | | | AA20 for polluted outdoor conditions | | | |
| | | AA15 for non-polluted outdoor and wet indoor conditions | | | | |
| | AA15 for outdoor use | AA10 for dry indoor conditions | | AA10, AA5 for indoor use | Minimum 10 µm for indoor use or outdoor use with regularly scheduled cleaning and maintenance | |
| | AA10, AA6, AA5 for indoor use | AA10 for indoor or outdoor use | | | | |
| NOTE ISO 7599:2010 uses the "AA" classification system but does not specify classes for particular applications. | | | | | | |

6.4 Classifications of paint coatings

Paint coatings are classified by different product standards on the basis of coating quality but there is not necessarily a direct correspondence between the quality classes of the different standards. Coating quality is variously defined often in considerable detail.

EN 12206-1:2004, GB 5237.4:2008, GB 5237.5:2008 and BS 4842:1984 include no classification of coatings.

EN 1396:2015 classifies coatings into four levels:

- category 1 for further painting after fabrication;
- category 2 for the following interior applications: dry and wet non-corrosive areas; wet corrosive areas;
- category 3 for the following exterior applications: rural; or urban or light industrial (or mild marine); tropical (high temperatures, high humidity); high UV;
- category 4 for the following applications: severe industrial — extreme conditions; very severe coastal marine (less than 3 km from the sea, depending also on the landscape); high UV plus severe conditions (tropical and marine).

JAPA 2010 has three categories based on the severity of the environment.

JSFT 2005 has two categories determined by the resin of the coating material.

The Qualicoat classification is based on the performance of classes 1, 2 and 3 over one, three and ten years respectively of South Florida exposure and a wide range of laboratory tests including mechanical, chemical, corrosion and artificial weathering, as well as coating thickness measurement. The outdoor exposure performance is assessed by measuring gloss retention and colour change.

GSB's classification is similar to that of Qualicoat, except the South Florida exposure periods are determined by specific amounts of UV radiation, i.e. 300 MJ/m², 840 MJ/m² and 1 400 MJ/m² over approximately one, three and five years respectively. It also includes an additional classification based on underfilm corrosion occurring over three years exposure to industrial, maritime climatic conditions preferably at Hoek van Holland.

AAMA also classifies coatings according to South Florida exposure performance and mechanical, chemical and corrosion laboratory tests. It requires the different classes of coatings to be subjected to one, five and ten year exposure and assesses performance by colour change, gloss retention, chalking and erosion (thickness loss).

6.5 Classifications of combined coatings

Combined coatings are also classified by the different product standards on the basis of coating quality, but there is not necessarily a direct correspondence between the quality classes of the different standards.

ISO 28340:2013 specifies four quality classes.

GB 5237.3:2008 specifies two classes: "A" for use in severe environments; "B" and "S" for use in ordinary environments.

JIS H 8602:2010 has four levels: "A1" for use in marine environments with much UV radiation; "A2" for use in marine environments; "B" for use in ordinary environments; "C" for indoor use. Note the emphasis on UV radiation which can affect the organic coating and marine environments where salt can promote corrosion of the aluminium substrate.

AAMA 612 includes no classification of coatings.

6.6 Comparison of the classifications

There is a significant difference between the classification of AAO coatings and organic coatings and even subtle differences between the systems for organic coatings. AAO coatings are classified by perceived levels of corrosion protection provided by different thickness coatings but without clear relationships to weathering conditions. Resistance to UV radiation is the main criterion for organic coatings, although resistance to underfilm corrosion is sometimes included. Both of these are assessed from outdoor exposure tests.

7 Coating selection for different environments

[Clause 5](#) reveals the difficulties in classifying atmospheres in relation to their ability to degrade coated aluminium. However, for the purposes of this document, a guideline system can be achieved where the three agents UV radiation, acid pollution and chloride levels are taken separately for anodized aluminium.

[Clause 6](#) provides guidance on the classification of coatings. However, direct comparability is possible only for AAO coatings because all the classifying systems use coating thickness as the determining criterion. The criteria vary for paint coatings so the guideline system for such coatings cannot be well defined.

Guidelines for the selection of coatings are given in [Tables 4](#) and [5](#) with further descriptions below. These guidelines assume that the coatings conform to a product specification for that particular quality class and receive optimum in-service maintenance (see [Annex A](#)), which can lead to a service life in excess of 20 years. [Tables 4](#) and [5](#) give the minimum quality level for particular environments. It has to

be stressed that the information of [Tables 4](#) and [5](#) only contain guidance because it is not supported by objective evidence.

The AAO coating should be selected with particular regard to the most significant single agent at the outdoor location (see [Table 4](#)). However, consideration should also be given to the conditions of action. UV radiation has no effect on clear anodic oxidation coatings.

Table 4 — Guidelines on the selection of the minimum thickness class of anodic oxidation coating subject to different levels of single environmental agents

| Single agent | Anodic oxidation coatings (classified by AA class) |
|--|--|
| Pollution (outdoor or indoor) | |
| Extreme industrial areas | AA25 |
| Polluted urban areas, industrial areas | AA20 |
| Indoor industrial facilities with high levels of pollution from production processes | AA20 |
| Urban areas | AA15 |
| Indoor spaces with moderate pollution from production processes | AA15 |
| Rural areas, small towns | AA10 |
| Indoor spaces with low pollution | AA10 |
| Dry and wet non-corrosive indoor areas | AA5 |
| Chloride levels (marine environments) | |
| Coastal areas, occasional contact with salt spray | AA15 |
| Coastal areas without spray of salt water, low deposition of chlorides | AA10 |
| UV radiation | |
| High UV radiation | AA5 |

AAO coatings are susceptible to degradation by acidity present in the atmosphere when the coating surface is wet. Heavily polluted industrial areas are particularly damaging. High ambient temperatures and wet/dry cycling promote attack. Thus, AAO coatings with a high thickness class should be selected for humid environments with significant temperature variation and heavy industrial or urban pollution. In order to minimize the risk of crazing, AAO coatings with hydrothermal sealing and a high thickness class should be selected for dry environments with significant temperature variation and heavy industrial or urban pollution.

In the absence of acidic pollution, AAO coatings exhibit good resistance to the effects of salty water. However, if the environment and its acidity are such to lead to rapid localized dissolution of a coating, then the presence of chloride ions can promote localized attack (pitting) of the aluminium substrate. AAO coatings with a high thickness class should be selected for marine environments if there is significant acidic pollution and temperature variation. The choice of appropriate AAO coatings thickness class would then depend on the aggressive nature of the environment. This can also be determined by consulting the existing national standards.

The guidelines for the selection of paint and combined coatings are based on multiple environmental agents with the categories of [Table 1](#). [Table 5](#) gives the guidelines for protective paint systems which includes pretreatment and [Table 6](#) gives the guidelines for combined coatings. Note that mechanical damage to paint coatings can enable rapid attack in industrial, urban or marine environments. However, due to the presence of AAO coatings, combined coatings are not susceptible to mechanical damage extending to the substrate and to diffusing species reaching the substrate.

Table 5 — Guidelines on the selection of protective paint coating subject to different levels of multiple environmental agents

| Multiple agents (see Table 1 for corrosivity categories) | Paint coating system |
|--|----------------------|
| CX and C5 with high UV radiation. CX indoor | High quality |
| C4 with high UV radiation. C4 and C5 indoor | Medium quality |
| C3, C2 and C1. C3 indoor | Low quality |
| C2 and C1 indoor | Low quality |

Table 6 — Guidelines on the selection of combined coatings subject to different levels of multiple environmental agents

| Multiple agents (see Table 1 for corrosivity categories) | Combined coating (classified following ISO 28340:2013) |
|--|--|
| CX and C5 with high UV radiation. CX indoor | 4 |
| C4 with high UV radiation. C4 and C5 indoor | 3 |
| C3, C2 and C1. C3 indoor | 2 |
| C2 and C1 indoor | 1 |

8 Durability tests

8.1 General

This clause includes brief descriptions of a number of test methods. However, they do not include full descriptions of the scopes or limitations of the methods. The applicability of any particular method can be determined only by reference to the particular standard.

8.2 Mechanical durability

8.2.1 General

This subclause explains the mechanical properties of coatings. These include tensile and compressive properties, impact resistance, abrasive wear and erosive wear. The subclause explains their relevance to fabrication processes and to architectural applications.

[Table 7](#) shows how different types of test for mechanical durability are included in various product standards. As AAO coatings are relatively hard and brittle, they are often chosen for applications where the resistance to wear is important. In comparison, organic coatings are softer and more flexible, and thus can be susceptible to damage by indentation or impact. However, paint coatings can be more tolerant of bending of the underlying aluminium.

Some product standards have requirements to withstand sawing, milling and drilling operations. However, no standard methods are described so such requirements are excluded here.

8.2.2 Deformation

Coated aluminium can be deformed during fabrication processes after the coating process. Thus, coating flexibility without cracking or peeling is important. When coated aluminium is deformed, e.g. when it is bent, the metal elongates at least at one surface. However, the coating has different tensile properties compared with the metal so that it does not elongate similarly. If it is less flexible than the metal, there might be cohesive failure within the coating, i.e. it cracks, or adhesive failure of the coating from its substrate. If bending puts a surface of the metal into compression, the coating can produce wrinkles.

Table 7 — The occurrence of mechanical durability tests in product standards^a

| Product standards | Deformation | | | Indenta- tion | Wear | | | | Erosion | |
|---------------------------------------|-------------|---------|-------------------|------------------|----------|------------------------|---------------------------|---------|-------------------------|-----------------|
| | Bend | Cupping | Rapid (impact) | | Buchholz | Abra- sive wheel | Glass- coated paper | Scratch | Pencil hard- ness | Falling sand |
| Anodic oxidation coatings | | | | | | | | | | |
| ISO 7599:2010 | 0 | | | | 0 | | | | 0 | 0 |
| GB 5237.2:2008 | | | | | | | | | 0 | |
| DIN 17611:2011 | | | | | | | | | | |
| JIS H 8601:1999 | | | | | 0 | | | | 0 | 0 |
| BS 3987:1991 | | | | | | 0 | | | | |
| AAMA 611-14 | | | | | | 0 | | | | |
| Qualanod 2010 | | | | | 0 | 0 | | | | |
| Paint coatings | | | | | | | | | | |
| EN 1396:2015 | 0 | 0 | 0 | | | | | 0 | | |
| EN 12206-1:2004 | 0 | 0 | 0 | | | | | | | |
| GB 5237.4:2008 | 0 | 0 | 0 | 0 | | | | | 0 | |
| GB 5237.5:2008 | | | 0 | | | | | 0 | 0 | |
| BS 4842:1984 | | | | | | | 0 | | | |
| AAMA 2603- 13, 2604-13, 2605-11 | | | 0 | | | | | 0 | 0 | |
| GSB 2013 | 0 | 0 | 0 | | | | | | | |
| JAPA 2010 | | | | | | | | 0 | | |
| JSFT 2005 | | | 0 | | | | | 0 | | |
| Qualicoat 2010 | 0 | 0 | 0 | 0 | | | | | | |
| Combined coatings | | | | | | | | | | |
| ISO 28340:2013 | | | | | | | | 0 | 0 | 0 |
| GB 5237.3:2008 | | | | | | | | 0 | 0 | |
| JIS H 8602:2010 | | | | | | | | | | |
| AAMA 612-02 | | | 0 | | | | | 0 | 0 | |

^a The occurrence is indicated in the table by the symbol 0.

The following International Standards include methods to test the deformation (tensile/shear) properties of coatings:

- ISO 1519;
- ISO 1520;
- ISO 3211;
- ISO 6272-1;
- ISO 6272-2;
- ISO 6860.

The two ISO 6272 tests involve rapid deformation of the coated aluminium caused by the impact of a falling weight whereas the other tests involve the progressive deformation of the coated aluminium by

making it conform to a shape, e.g. a mandrel or a die. ISO 3211 specifies a bend test similar to ISO 6860. The applied stress in a bend test is distributed linearly along the mandrel, whereas the applied stress in a cupping test is more concentrated.

These tests can constitute reasonable simulations of conditions experienced by coated products.

AAO coatings are not only less flexible than aluminium metal but also much less flexible than most organic coatings. They generally fail by cracking perpendicular to the substrate. The cracks are more noticeable for thicker coatings. There is evidence that the cracks produced by coil anodizing have no effect on the corrosion protection properties of the coating.

Paint coatings generally fail adhesively. This can affect the appearance of the coated aluminium and the associated exposure of bare aluminium can provide sites for corrosive attack.

During deformation, the AAO coating of combined coatings is likely to fail before the overlying organic coating. However, adhesive failure of the organic coating from the AAO coating is less likely than if the substrate were the metal because the organic coating is "pinned" to the AAO coating between the cracks.

The degree of polymerization of an organic coating can affect the results of an impact test.

The test methods listed above can be applied to any of the coating types.

8.2.3 Indentation (hardness)

Coated aluminium can be damaged during fabrication or in service by accidental compression of the coating. A sharp point can penetrate the coating exposing bare aluminium and thus enabling corrosive attack.

The following International Standards include methods to test the indentation or compressive properties of coatings:

- ISO 1522;
- ISO 2815;
- ISO 4516;
- ISO 14577-4.

Many of these tests involve the use of a load to force an indenter or wheel into the surface of coated aluminium, and the dimension of the indentation mark is measured. Plastic deformation is necessary for a mark to be maintained. The principle of ISO 1522 is different. It is that the amplitude of oscillation of a pendulum touching a surface decreases more rapidly the softer the surface. It depends on both the elastic and viscoelastic properties of the surface.

These tests can constitute reasonable simulations of conditions experienced by coated products.

AAO coatings have greater compressive strength than aluminium alloys. Thus, the AAO coating might support a high load whereas the aluminium cannot and is compressed. Consequently, microhardness tests, where the indentation depth is very shallow, are applied to anodized aluminium. The indenter is pressed onto the surface or the cross-section of the coating. Such tests are described in ISO 4516 and ISO 14577-4. AAO coatings suffer plastic deformation at high loads and do not exhibit significant elastic or viscoelastic properties. The method of ISO 1522 is not appropriate.

Organic coatings can have a lower compressive strength than aluminium and can exhibit significant elastic or viscoelastic properties. Thus, microhardness tests require low loads and are designed accordingly (see ISO 14577-4). The methods of ISO 1522 and ISO 2815 are appropriate for organic coatings.

The applicability of any of these methods to all the different types of coating is restricted because of the different properties of the coatings.

8.2.4 Abrasive and adhesive wear

Abrasive wear involves abrasive materials harder than the coating and perform a cutting or scratching action on the surface of the coating. Adhesive wear involves abrasive materials generally softer than the coating. Coated aluminium can be damaged during fabrication or in service by accidental damage to the coating that degrades its appearance or exposes the underlying aluminium. A coating can also be damaged by repeated actions such as the manual handling of a door handle.

The following International Standards include methods to test the resistance of coatings to abrasive or adhesive wear:

- ISO 1518-1;
- ISO 7784-1;
- ISO 7784-2;
- ISO 7784-3;
- ISO 8251:2011;
- ISO 11998;
- ISO 12137;
- ISO 15184.

ISO 1518-1 specifies a method involving penetration by scratching by a stylus with a specified load. ISO 7784-1 and ISO 8251:2011 describe methods using abrasive paper attached to a rotating wheel. ISO 7784-2 is similar but uses an abrasive rubber wheel. ISO 15184 uses pencils with tips of different hardness to see which scratches the coating surface. The methods of ISO 7784-3 and ISO 12137 are primarily intended to assess whether superficial abrasion of a coating leads to any change in its appearance. The former uses a rubbing device while the latter uses a stylus.

As shown in [Table 7](#), certain voluntary standards include a test for AAO coatings where abrasive-coated paper is repeatedly drawn across the surface to assess the abrasion resistance of the surface of the coating. A deposit on the abrasive paper indicates that the abrasive is harder than the AAO coating. It is believed that softer coatings are more susceptible to chalking during weathering.

The method of ISO 11998 can be used to assess the amount of coating lost due to repeated cleaning procedures.

These tests can constitute reasonable simulations of wear conditions experienced by coated products.

Any of these methods can, in principle, be applied to any of the coating types. However, as AAO coatings are very much more resistant than organic coatings, the choice of abrasive material and loading becomes important. Abrasive wear requires the selection of an abrasive material that is harder than the coating. Thus, an abrasive suitable for use on an organic coating is not likely to be suitable for an AAO coating. However, it is possible that the same material is appropriate to assess adhesive wear of an AAO coating.

8.2.5 Erosion

Coated products can suffer erosive wear in environments where they are exposed to wind-borne particles such as found in desert regions and near coasts, and in dust storms.

The following International Standard includes methods to test the resistance of coatings to erosive wear:

- ISO 8251.

ISO 8251:2011 includes two erosion methods. One uses a jet of abrasive particles to erode the surface of a coating. The other uses sand falling under gravity to erode the surface.

These tests might constitute reasonable simulations of conditions experienced by coated products.

Although the methods of ISO 8251:2011 are intended for use with AAO coatings, they can, in principle, be applied to any of the coating types. However, as AAO coatings are very much more wear resistant than organic coatings, the choice of test conditions can be important. ISO 28340:2013 specifies these tests for combined coatings and thus constitutes guidance on how these tests can be applied to paint coatings. The falling sand test occurring in the AAMA product standards (see [Table 7](#)) is specified for organic coatings in ASTM D968-93(2001).

8.3 Chemical durability

8.3.1 General

This subclause covers methods to test the chemical resistance of coatings and methods to test the degree to which coatings protect the aluminium from corrosion. The attack is caused by chemical or electrochemical means. Note the difference between chemical resistance and corrosion protection. Corrosion is a scientific term for the electrochemical process that leads to the degradation of conductors such as metals. Therefore, AAO, paint and combined coatings cannot be corroded; the term chemical resistance is appropriate.

During fabrication or service, coated aluminium might be exposed to various liquids. These can include aqueous solutions or non-aqueous liquids such as cleaning media and water containing dissolved chemicals from other parts of a building or from the atmosphere. Cleaning media might be acidic or alkaline. Run-off from mortar or cement used in building construction is alkaline. Environmental pollutants are generally acidic, although sea water is very slightly alkaline. These chemicals can react with the coating, causing a change in the appearance of the coated aluminium. In extreme cases, they can dissolve some of the coating.

Corrosion can occur if the coating has been damaged or penetrated to the extent that a corrosive solution can reach the aluminium substrate. With correct choice of alloy, aluminium corrosion does not lead to structural failure of the component. However, it can mar the appearance of the product. This can take the form of blistering or adhesive failure if underfilm corrosion can propagate, or pitting.

Different coatings react differently to different chemicals. AAO coatings have relatively low resistance to strong alkalis and acids. For example, a test for the resistance to sodium hydroxide solution can be applied to organic and AAO coatings. However, their performance would be so different that the user would have to carefully consider his requirements. Another example is that organic solvents can be used to clean anodized aluminium because the coating is chemically resistant. Organic solvents can be used to assess the degree-of-cure of organic coatings.

[Table 8](#) shows how the different types of test for chemical durability are included in various product standards.

8.3.2 Immersion tests

The following International Standards include methods to test the chemical durability of coated aluminium by immersion in a liquid or a solution of a chemical or chemicals:

- ISO 3210;
- ISO 2812-1;
- ISO 2812-2;
- ISO 2812-5.

ISO 2812 specifies generic immersion methods that can be applied to any coating type. Depending on the conditions employed, they might constitute reasonable simulations, possibly accelerated, of conditions experienced by coated products.

Table 8 — The occurrence of chemical durability tests in product standards^a

| Product standards | Immersion (solutions) | | | | Spot or ring (solutions) | | | Poul-tice | Absorbent medium | | Spray | | | Vapour or gases | | | | | | | |
|--------------------------------|-----------------------|--------------------------------|------|------------------------------|--------------------------|---|-----------------|-----------|------------------|---|--------|----------|-----------|-----------------|------|------|---------------------|-----------|-----|-----------------|------------------|
| | HNO ₃ | H ₂ SO ₄ | NaCl | Boiling or pressurized water | Deter-gent | CrO ₃ and H ₃ PO ₄ | Win-dow cleaner | | HCl | NaOH or Na ₂ CO ₃ | Mortar | Sol-vent | Mois-ture | NSS | AASS | CASS | QUV/ASS or QUV/CASS | Humid-ity | HCl | SO ₂ | HNO ₃ |
| Anodic oxidation coatings | | | | | | | | | | | | | | | | | | | | | |
| ISO 7599:2010 | | | | | | 0 | | | | | | | | 0 | 0 | | | | | | |
| GB 5237.2:2008 | | | | | | 0 | | 0 | | | | | | | 0 | | | | | | |
| DIN 17611:2011 | | | | | | 0 | | | | | | | | | | | | | | | |
| JIS H 8601:1999 | | | | | | 0 | | 0 | | | | | | 0 | 0 | 0 | | | | | |
| BS 3987:1991 | | | | | | 0 | | | | | | | | | | | | | | | |
| AAMA 611-14 | | | | | | 0 | | | | | | | | 0 | | | | | | | |
| Qualanod 2010 | 0 | | | | | 0 | | | | | | | | | 0 | | | | | | |
| Paint coatings | | | | | | | | | | | | | | | | | | | | | |
| EN 1396:2015 | | | | | | | | | | | | | | | 0 | | | | 0 | 0 | 0 |
| EN 12206-1:2004 | | | | 0 | | | | | | 0 | | | | | 0 | | | | 0 | 0 | 0 |
| GB 5237.4:2008 | | | | 0 | | | | 0 | | 0 | | | | | 0 | | | | 0 | 0 | 0 |
| GB 5237.5:2008 | | | | 0 | | | | 0 | | 0 | | | | | 0 | | | | 0 | 0 | 0 |
| BS 4842:1984 | | | | 0 | | | | | | 0 | | | | | 0 | | | | 0 | 0 | 0 |
| AAMA 2603-13, 2604-13, 2605-11 | | | | 0 | | | | 0 | | 0 | | | | | 0 | | | | 0 | 0 | 0 |
| GSB 2013 | | | | 0 | | | | | | 0 | | | | | 0 | | | | 0 | 0 | 0 |
| JAPA 2010 | | | | 0 | | | | | 0 | | | | | | 0 | | | | 0 | 0 | 0 |
| JSFT 2005 | | | 0 | 0 | | | | | | 0 | | | | | 0 | | | | 0 | 0 | 0 |
| Qualicoat 2012 | | | 0 | 0 | | | | | | 0 | | | | | 0 | | | | 0 | 0 | 0 |

^a The occurrence is indicated in the table by the symbol 0.

Table 8 (continued)

| Product standards | Immersion (solutions) | | | | Spot or ring (solutions) | | | Poul-tice | Absorbent medium | | Spray | | | Vapour or gases | | | | | | |
|-------------------|-----------------------|--------------------------------|------|------------------------------|--------------------------|---|-----------------|-----------|------------------|---|--------|----------|-----------|-----------------|------|------|---------------------|-----------|-----|-----------------|
| | HNO ₃ | H ₂ SO ₄ | NaCl | Boiling or pressurized water | Deter-gent | CrO ₃ and H ₃ PO ₄ | Win-dow cleaner | | HCl | NaOH or Na ₂ CO ₃ | Mortar | Sol-vent | Mois-ture | NSS | AASS | CASS | QUV/ASS or QUV/CASS | Humid-ity | HCl | SO ₂ |
| ISO 28340:2013 | | | | 0 | | | | 0 | 0 | 0 | 0 | | 0 | 0 | 0 | | | | | |
| GB 5237.3:2008 | | | | 0 | | | | 0 | 0 | 0 | | | | | 0 | | | | | |
| JIS H 8602:2010 | | | | 0 | | | | 0 | 0 | 0 | | | | | | 0 | | | | |
| AAMA 612-02 | | | | 0 | | | | 0 | 0 | 0 | | | | 0 | | | | | | 0 |

Combined coatings

^a The occurrence is indicated in the table by the symbol 0.

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The method of ISO 3210 involves immersion in an acid solution of chromic and phosphoric acids. Experience has taught practitioners that the test assesses the quality of AAO coatings sealed using certain procedures. This test is not a simulation and, as the solution composition bears no similarity to any service environment, it is not appropriate to apply the test to organic coatings.

The Qualanod specification includes a nitric acid immersion test for anodized aluminium. It is believed that this acid has particular characteristics that enable it to distinguish certain qualities of anodizing. The test has no particular significance for organic or combined coatings.

The product standards include various methods involving immersion in boiling or pressurized water. They are intended to test the adhesion of the coating.

The JFST specification includes a sulfuric acid immersion test for paint coatings. This solution is used as representative of acidic environments.

The Qualicoat specification includes the Machu test which involves immersion in an acidic solution based on sodium chloride. The method includes scoring through the coating to the substrate.

The AAMA specifications include immersion in a detergent solution to see whether adhesive failure occurs.

8.3.3 Spot and ring tests

The following International Standard includes methods to test the chemical durability of coated aluminium by applying a small quantity of a liquid or a solution of a chemical or chemicals to the surface of the coated aluminium:

— ISO 2812-4.

Such methods can be more convenient to use an immersion test. In some cases, there is no need to cut a test sample from a coated profile so, for a good quality product, spot and ring tests are non-destructive.

ISO 2812-4 specifies a generic method that can be applied to any coating type. Depending on the conditions employed, it might constitute a reasonable simulation, possibly accelerated, of conditions experienced by coated products.

The ISO 28340:2013 product standard and the Chinese and AAMA ones for paint coatings include hydrochloric acid spot tests. Hydrochloric acid contains chloride ions and acidity which are features that can be encountered in external applications although not at such high concentrations. The solution can cause changes to the appearance of a coating and corrosion of the aluminium substrate. The methods can be applied to AAO coatings although they are less resistant to acids than organic coatings.

Many product standards include alkaline spot tests involving sodium hydroxide or sodium carbonate solutions. These are convenient alkalis; coatings in service might be exposed to alkaline solutions originated from mortar or cement used in the construction of a building. These solutions can cause changes to the appearance of a coating and corrosion of the aluminium substrate. The methods can be applied to AAO coatings although they have particularly poor resistance to alkaline solutions compared with organic coatings.

The AAMA 2605-05 specification includes methods to assess whether window cleaner solution affects the appearance of a paint coating and/or the adhesion to its substrate. The window-cleaner test simulates exposure for an extended period of time. Whereas it might be relevant to test whether the appearance of an AAO coating could be affected by such solutions, the question of adhesion is not relevant because adhesive failure cannot occur.

8.3.4 Poultrice or pat tests

The following International Standard includes a method to test the chemical resistance of coated aluminium by applying a poultice, paste or similar wet material to the surface of the coated aluminium:

- ISO 2812-5.

Depending on the conditions employed, poultice or pat tests might constitute a reasonable simulation, possibly accelerated, of conditions experienced by coated products.

ISO 2812-5 specifies a method, using a temperature-gradient oven, for determining the resistance of an individual-layer or multi-layer system of coating materials to the effects of liquids or paste-like products. It can be applied to any coating type.

As shown in [Table 8](#), various product standards include methods to test the resistance of organic coatings to mortar. As AAO coatings have little resistance to attack by alkaline solutions, these tests are not appropriate for AAO coatings.

8.3.5 Tests using an absorbent medium

The following International Standard includes a method to test the chemical resistance of coated aluminium by applying to the surface of the coated material an absorbent material impregnated with a liquid or a solution of a chemical or chemicals:

- ISO 2812-3.

ISO 2812-3 specifies a method, using an absorbent medium, for determining the resistance of coating materials to the effects of liquids or solutions including simulants of exudates from plants, animals and birds. It can be applied to any coating type.

As shown in [Table 8](#), various product standards include methods to test the resistance of organic coatings to organic solvents using absorbent media. The purpose of these tests is to assess the degree of cross-linking of the organic coating. AAO coatings do not depend on cross-linking and, furthermore, they are very resistant to degradation by organic solvents.

The GSB product specification includes a method to assess the suitability of coated aluminium for storage under the influence of condensation and temperature in closed/wrapped conditions. It can constitute a reasonable simulation of conditions experienced by coated products, and is thus also applicable to AAO and combined coatings.

8.3.6 Spray tests

The following International Standards cover methods to carry out salt spray tests:

- ISO 9227:2012;
- ISO 11997-1;
- ISO 11997-2;
- ISO 14993.

There are three methods specified in ISO 9227:2012, the neutral salt spray (NSS) test, the acetic acid salt spray (AASS) test and the copper-accelerated acetic acid salt spray (CASS) test. They are regarded as corrosion tests. The NSS test involves the least aggressive environment while the addition of cupric chloride in the CASS test solution promotes rapid corrosive attack of the aluminium. These can be suitable accelerated methods depending on the environment.

The methods of ISO 11997 and ISO 14993 involve defined cycles of wet, dry, humidity and, for part 2, UV exposure using a specified solution. The salt fog is not acidified. They are intended to be more realistic simulations of outdoor weathering than the methods of ISO 9227:2012. However, even for these

methods, valid comparisons with outdoor exposure cannot be expected because of the wide range of parameters involved during weathering.

The ISO 28340:2013 and JIS H 8602:2010 product specifications include methods of cyclic corrosion testing where either the AASS or CASS test is used for wet exposure.

Where tests are to be applied to paint coatings, a cross-cut incision is generally made through the coating to the aluminium substrate. For AAO and combined coatings, this is not done because of the hardness of the AAO coating. These are fundamentally different ways of carrying out the test. They are based on the premise that paint coatings have lower indentation resistance and might be damaged during fabrication, installation or service whereas AAO and combined coatings are very much more resistant to any indentation damage that could lead to exposure of the aluminium. On the other hand, AAO coatings can crack as a result of deformation leading to weak sites exposing the aluminium. Thus, failure of paint coatings leads to underfilm corrosion whereas failure of AAO coatings leads to pitting corrosion.

8.3.7 Tests involving exposure to vapours or gases

The following International Standards include methods to determine the resistance of coated aluminium to the effects of vapours or gases including humidity:

- ISO 3231;
- ISO 4623-2;
- ISO 6270-1;
- ISO 11503.

The principle of the procedure specified in ISO 3231 is to expose a coated test panel to specified humid atmospheres containing sulfur dioxide. The effects of exposure are evaluated by criteria agreed in advance between the interested parties, these criteria being usually of a subjective nature. This method can be applied to any coating type.

ISO 4623-2 specifies a method to test for filiform corrosion resistance. Scribed, painted samples are placed for a period of time in a chamber with an atmosphere saturated with hydrochloric acid gas. Afterwards, they are placed for a further period in a chamber that is set to a specific temperature and humidity. Assessment involves quantifying the characteristics of any filiform threads produced. The method, without scribing, can be applied to combined coatings and AAO coatings although these have been found to have good filiform corrosion resistance.

ISO 6270-1 specifies a method involving conditions of high humidity. It provides an indication of the performance likely to be obtained under severe conditions of exposure where continuous condensation occurs on the surface. The procedure may reveal failures of the coating (including blistering, staining, softening, wrinkling and embrittlement) and deterioration of the substrate. The method of ISO 11503 covers intermittent condensation. These methods can be applied to AAO coatings although any degradation is likely to manifest itself differently from that of organic coatings.

Certain product standards include methods of exposing coated aluminium to nitrogen oxides enclosed above a nitric acid solution. These are primarily intended to induce colour change in organic coatings.

8.4 Radiation and heat resistance

This subclause includes procedures for carrying out tests where coated aluminium is exposed to artificially-produced electromagnetic radiation under ambient laboratory conditions. The radiation does not truly simulate sunlight. Also, unlike artificial weathering (see below), the tests do not include any attempt to simulate the environment, e.g. the humidity, although samples might become warmer during the test. Also, the radiation does not necessarily reproduce that from artificial lighting. Where the test involves heat, then depending on the conditions, it can be a reasonable simulation of conditions encountered by the coated aluminium in service.

Table 9 shows how the different types of test for radiation resistance are included in various product standards.

The following International Standards include methods of assessing light fastness and resistance to UV radiation:

- ISO 2135;
- ISO 3248;
- ISO 6581.

ISO 2135:2017 says that carbon- or xenon-arc lamps are suitable light sources. Neither is the type commonly used indoors in fluorescent tubes. Xenon-arc lamps produce light with a spectrum more similar to sunlight. ISO 6581 specifies a mercury-arc lamp. It is a comparative test requiring a control specimen. Both tests employ intense radiation to give a result in a relatively short period of time. This is particularly the case for the ISO 6581 method, which leads to a rise in the surface temperature of the test samples of up to 100 °C.

Table 9 — The occurrence of radiation and weathering tests in product standards^a

| Product standards | Radiation resistance | | | Artificial weathering | | | Natural weathering | |
|----------------------------------|----------------------|-------------|------|-----------------------|-----------|-----------------|--------------------|-------------|
| | Xenon-or carbon-arc | Mercury-arc | Heat | Carbon-arc | Xenon-arc | UV/condensation | Sunlight (UV) | Corrosivity |
| Anodic oxidation coatings | | | | | | | | |
| ISO 7599:2010 | 0 | 0 | | | | | | |
| GB 5237.2:2008 | | 0 | | | | | | |
| DIN 17611:2011 | | | | | | | | |
| JIS H 8601:1999 | | | | | | | | |
| BS 3987:1991 | | 0 | | | | | | |
| AAMA 611-14 | | | 0 | | | | 0 | |
| Qualanod 2010 | 0 | | | | | | 0 | 0 |
| Paint coatings | | | | | | | | |
| EN 1396:2015 | | | | | | 0 | 0 | 0 |
| EN 12206-1:2004 | | | | | | 0 | 0 | |
| GB 5237.4:2008 | | | | | 0 | 0 | 0 | |
| GB 5237.5:2008 | | | | | 0 | | 0 | |
| BS 4842:1984 | | | | 0 | | | 0 | |
| AAMA 2603-13, 2604-13, 2605-11 | | | | | | | 0 | |
| GSB 2013 | | | | | | 0 | 0 | 0 |
| JAPA 2010 | | | | 0 | | | | |
| JSFT 2005 | | | | 0 | | | 0 | |
| Qualicoat 2012 | | | | | 0 | | 0 | |
| Combined coatings | | | | | | | | |
| ISO 28340:2013 | | | | 0 | 0 | | 0 | 0 |
| GB 5237.3:2008 | | | | | 0 | | | |
| JIS H 8602:2010 | | | | 0 | 0 | | | |
| AAMA 612-02 | | | 0 | | | | 0 | |

^a The occurrence is indicated in the table by the symbol 0.

Although these methods are specified for coloured AAO coatings, they can be applied to organic coatings. The Chinese product standards include a radiation test using a mercury-arc lamp.

ISO 3248 specifies a method to determine the effect of heat on the appearance, cohesion and adhesion of paints. The product standards AAMA 611-14 and AAMA 612-02 include a heat test which has the aim of inducing crazing of an AAO coating by heating the anodized aluminium. Differential thermal expansion

contributes to this. It can be relevant particularly for dark coloured anodized aluminium exposed in an environment where high ambient temperatures are encountered. It is not relevant to test for thermal crazing of paint coatings because they are sufficiently flexible to expand with the aluminium substrate.

8.5 Weathering resistance

8.5.1 Resistance to artificial weathering

The following International Standards include methods of carrying out artificial weathering procedures:

- ISO 16474-1;
- ISO 16474-2;
- ISO 16474-3;
- ISO 16474-4.

Artificial weathering procedures involve cyclic exposure of the coated aluminium to a source of radiation and a wet or condensing environment. [Table 9](#) shows that different product standards select methods with different radiation sources. Results from organic coatings can be different depending on the method.

ISO 16474-1 provides information and general guidance relevant to the selection and operation of the methods of exposure described in detail in subsequent parts. It also provides information on the interpretation of data from artificial accelerated weathering or artificial accelerated irradiation exposures. These methods are also applicable to AAO coatings.

8.5.2 Resistance to natural weathering

The following International Standards include guidance on conducting weathering tests by the outdoor exposure of coated products:

- ISO 2810;
- ISO 8565.

ISO 8565 establishes general requirements for stationary corrosion testing of metals, and metallic and other inorganic coatings under atmospheric conditions carried out in the open air or under shelters. It can also be applied to the testing of complex specimens and assemblies of metallic materials. AAO coatings are inorganic coatings.

ISO 2810 specifies the conditions which need to be taken into consideration in the selection of the type of natural weathering and the natural weathering procedure to be used to determine the resistance of paint coatings. Natural weathering includes direct weathering or weathering behind window glass and is used to determine the resistance of coatings to the sun's radiation and the atmosphere. Although the standard was written for paint coatings, it is applicable to combined coatings and many of its recommendations can be applied for AAO coatings.

As shown in [Table 9](#), standards specify outdoor exposure tests generally in South Florida or Hoek van Holland or both and are concerned with the effects of sunlight and corrosive atmospheres. They do not necessarily follow the guidance of ISO 2810.

9 Selection of test methods to enable the comparison of different coating types for service in different environments

This clause is concerned with the selection of test methods that enable different coating types to be compared. It is not concerned with the quality of a product with a particular type of coating because that is covered by the different product standards.

This clause identifies methods of testing durability. [Clause 10](#) covers the methods of measuring performance. As different coating types are being compared, the concept of acceptance limits is not necessarily relevant; the object is to discover which type has the best performance.

For outdoor applications, outdoor exposure testing is the preferred method. Sites should be selected to be representative of the service location and with reference to [Clause 5](#). Well characterized outdoor exposure testing sites include South Florida and Hoek van Holland. South Florida provides high exposure to UV light and, if required, water but not to pollutants that might cause degradation of the coating or, potentially, corrosion of the aluminium. On the other hand, Hoek van Holland combines marine and industrial pollutants but with limited exposure to sunlight. The method of performing outdoor exposure testing is specified in the following International Standard:

- ISO 2810.

Although outdoor exposure testing is the preferred method of comparing the different coating types, the service lifetime of coated aluminium in architectural applications can be very long. Thus, it is often impractical to make durability assessments by exposing test pieces to real service environments. No methods have been established that use electrooptical or spectroscopic techniques to detect the early stages of degradation after short times of exposure to real service environments. Such methods could have the advantage of enabling the prediction of service performance from tests with a duration of weeks rather than years. This deficiency should be rectified as such methods would give greater confidence in the utility of coated aluminium products.

There are laboratory methods that expose materials to active agents or conditions of activity or both. These do not necessarily simulate service environments and, in some cases, can be quite dissimilar.

The following International Standards specify methods that can be used to compare the response of different coating types to UV radiation with or without moisture and heat:

- ISO 16474-1;
- ISO 16474-2;
- ISO 16474-3;
- ISO 16474-4.

The following International Standard specifies methods that can be used to compare the response of different coating types to an atmosphere containing sulfur dioxide, which represents industrial pollution. There is no International Standard specifying a comparable method that can represent urban pollution:

- ISO 3231.

The following International Standards specify methods that can be used to compare the response of different coating types to marine or salty environments in some cases combined with UV radiation or acidity:

- ISO 4623-2;
- ISO 11997-1;
- ISO 11997-2.

The following International Standards specify methods that can be used to compare the response of different coating types to conditions without the presence of the main active agents. The conditions can represent time-of-wetness, wet/dry cycling or ambient temperature:

- ISO 3248;
- ISO 6270-1;
- ISO 11503.

The following International Standards specify methods that can be used to compare the response of different coating types under specific conditions of exposure to chemicals that can be encountered during indoor as well as outdoor service:

- ISO 2812-1;
- ISO 2812-2;
- ISO 2812-3;
- ISO 2812-4;
- ISO 2812-5;
- ISO 11998.

Mechanical durability is important in situations of product abuse, e.g. impact and bending, as well as specific exposure environments depending on the application for the coated product, e.g. wear and erosion. In indoor applications, products that are regularly handled by people, e.g. door handles, railings, can become degraded by adhesive wear processes and might also be affected by salt solution from people's hands. Performance in external environments where there is wind-borne abrasive material, e.g. near deserts or sandy beaches or subject to dust storms, involves erosive wear.

The following International Standards specify methods that can be used to compare the response of different coating types under different conditions of mechanical stress:

- ISO 6272-1;
- ISO 6272-2;
- ISO 6860;
- ISO 7784-1;
- ISO 7784-2;
- ISO 8251:2011.

The methods of the two ISO 7784 standards can assess abrasive or adhesive wear resistance depending on the nature of the coating. ISO 8251 includes a number of methods; the falling sand method is preferred for these comparative purposes.

No methods are included for indentation or scratch resistance because the differing properties of organic and AAO coatings make such distinctions unnecessary.

10 Methods of measuring performance

10.1 General

Methods of measuring performance are independent of coating type. They assess characteristics that are of interest to the customer. For architectural applications, the customer has a direct interest in the appearance of the coated aluminium. This relates to appearance as the starting condition, which includes uniformity and/or consistency. Furthermore, it relates to the appearance after any fabrication and installation procedures. And the customer is concerned that the appearance is maintained, with proactive intervention if necessary, to an acceptable degree during service. Thus, cleaning procedures are important in extending a product's life during service, and recommendations are included in [Annex A](#).

Where a durability test is applied to coated material, the customer is interested in any change in appearance that might indicate what is likely to happen during service. Such changes include the fading

of colour and the loss of reflectance (matting, blooming, chalking) particularly if they occur in a non-uniform manner.

Visible imperfections can be produced by durability tests that are similar to those that might arise in service. These include scratches, indentations and corrosion pits in the underlying aluminium.

The customer is also interested in any other sign of degradation induced by the durability test that could indicate a tendency for the appearance to change or act as a precursor to appearance change. Such signs are the degradation of coating integrity. These can include a failure of adhesion or cohesion, a loss of thickness, mass or density, reduced electrical resistance or increased absorptivity.

10.2 Appearance

10.2.1 Visible defects

Many kinds of defects can arise on as-produced coated aluminium. They include marks, scratches, indentations, pick-up, hot spots, excessive roughness, runs, blisters, inclusions, craters, dull spots, pinholes and pits. Only some of these are produced during subsequent fabrication processes or during service and, thus, are of interest if they occur during durability tests. The main ones are marks, scratches, indentations, dull spots, blisters and pits. Underfilm corrosion as blisters or filaments (filiform corrosion) typically occur on aluminium with a paint coating while pitting corrosion is typical of anodized aluminium.

The following International Standards give methods that can be used in making an assessment of visible defects on the significant surfaces of coated material. In addition, some methods can be used to rate pitting or to assess underfilm corrosion on aluminium:

- ISO 4628-1;
- ISO 4628-2;
- ISO 4628-8;
- ISO 4628-10;
- ISO 8993;
- ISO 8994;
- ISO 10289.

These methods are applicable to all coating types although, as described above, are not likely to be needed for all.

10.2.2 Colour

A number of tests including outdoor exposure can lead to a change in the colour of a test piece. In particular, the effects of UV light combined with other environmental factors can lead to fading. Certain standards specify assessment on the basis of visual comparison with a reference, e.g. ISO 2135. The following International Standards include quantitative colorimetric methods:

- ISO 11664-3;
- ISO 11664-4.

The ISO 11664 series are concerned with colorimetry generally. ISO 11664-3 specifies methods of calculating the tristimulus values of colours for which the spectral distributions are provided. ISO 11664-4 specifies the method of calculating the coordinates in the CIE 1976 L *a*b* colour space. It includes two methods for determining perceived colour differences in this space. It is applicable to tristimulus values calculated using certain standard colorimetric systems.

Spectral photometric characteristics can be measured with a spectrophotometer and tristimulus values with a tristimulus colorimeter.

Certain product standards include methods for the visual assessment of products before they are put into service. Albeit non-quantitative, such methods can be useful to assess any non-uniform appearance of coated material after durability tests.

10.2.3 Reflectance

Various tests can lead to a change of reflectance of a test piece. Such effects include chalking which, although by different mechanisms, can affect organic and AAO coatings. They also include blooming which can affect AAO coatings. Furthermore, cracking, crazing and delamination of coatings can lead to an apparent change in reflectance. The following International Standards include methods that can be used to measure reflectance:

- ISO 2813;
- ISO 4628-6;
- ISO 4628-7;
- ISO 6719;
- ISO 7668;
- ISO 7759;
- ISO 10215;
- ISO 10216.

In the methods to determine specular gloss or reflectance, the different angular geometries are suitable for coatings that are differently glossy or matt. Note that the methods of ISO 2813 are not suitable for metallic paints while those of ISO 7668 are mainly intended for clear anodized aluminium. Similarly, ISO 7668 is suitable for combined coatings unless the organic coating is pigmented, in which case ISO 2813 is appropriate.

ISO 6719 specifies a method of measuring the total and diffuse luminous reflectance characteristics of aluminium surfaces using integrating-sphere instruments. The method is also applicable to the measurement of specular reflectance, specularity and diffuseness. The method is unsuitable for use with lighting reflectors. ISO 7759 specifies a method for the measurement of the reflectance characteristics of high-gloss anodized aluminium surfaces. The method described is also suitable for the measurement of the reflectance characteristics of other high-gloss metal surfaces but not for diffuse-finish metal surfaces. These methods are suitable, as appropriate, for organic coatings.

ISO 4628-6 provides pictorial reference standards for designating the degree of chalking of paint coatings. It also describes a method by which the degree of chalking is rated. ISO 4628-7 describes a method suitable, in particular, for rating the degree of chalking on white or coloured coatings on rough surfaces such as minerals. These methods are suitable, as appropriate, for use with combined coatings and AAO coatings. However, chalking can be assessed by an instrumental method of determining reflection characteristics.

Certain product standards include methods for the visual assessment of products before they are put into service. Albeit non-quantitative, such methods can be useful to assess any non-uniform appearance of coated material after durability tests.