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Metallic coatings — Physical vapour-deposited coatings of aluminium — Specification and test methods

Revêtements métalliques — Revêtements d'aluminium appliqués par vide — Spécification et méthodes d'essai

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Foreword

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

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

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

ISO 22779 was prepared by Technical Committee ISO/TC 107, *Metallic and other inorganic coatings*, Subcommittee SC 3, *Electrodeposited coatings and related finishes*.

Introduction

Aluminium coatings may be applied to a variety of substrates by physical vapour-deposition techniques to improve resistance to corrosion, as an alternative to cadmium, and to provide dissimilar metal compatibility. The vapour-deposition process does not introduce hydrogen into the substrate and is, thus, especially useful for applying a corrosion-resistant aluminium coating to high-strength steels that are susceptible to hydrogen embrittlement. Hydrogen, however, may still be introduced into the substrate during fabrication, cleaning, pickling and other treatments, and care must be exercised to prevent hydrogen from being introduced prior to vapour deposition.

The corrosion resistance of physical vapour-deposited aluminium coated articles may be further enhanced by applying chromate conversion coatings, anodizing and other supplementary treatments.

Metallic coatings — Physical vapour-deposited coatings of aluminium — Specification and test methods

WARNING — The use of this International Standard may involve hazardous materials, operations and equipment. This standard does not address all the safety problems associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices, and to determine the applicability of regulatory limitations prior to use.

1 Scope

This International Standard specifies requirements for aluminium coatings applied by physical vapour-deposition techniques to mild steels, low-alloy steels, high-strength steels, corrosion-resisting steels, aluminium alloys, titanium alloys and other materials, as appropriate.

Physical vapour-deposited coatings of aluminium are not suitable for steels having tensile strengths greater than 1 400 MPa, because of the possibility of hydrogen embrittlement due to corrosion in service or storage, or as a result of excessive cathodic protection.

2 Normative references

The following referenced documents are indispensable for the application 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 1463, *Metallic and oxide coatings — Measurement of coating thickness — Microscopical method*

ISO 2064, *Metallic and other inorganic coatings — Definitions and conventions concerning the measurement of thickness*

ISO 2080, *Electroplating and related processes — Vocabulary*

ISO 2360, *Non-conductive coatings on non-magnetic electrically conductive basis materials — Measurement of coating thickness — Amplitude-sensitive eddy-current method*

ISO 2819, *Metallic coatings on metallic substrates — Electrodeposited and chemically deposited coatings — Review of methods available for testing adhesion*

ISO 2859 (all parts), *Sampling procedures for inspection by attributes*

ISO 3497, *Metallic coatings — Measurement of coating thickness — X-ray spectrometric methods*

ISO 3543, *Metallic and non-metallic coatings — Measurement of thickness — Beta backscatter method*

ISO 3882, *Metallic and other inorganic coatings — Review of methods of measurement of thickness*

ISO 3892, *Conversion coatings on metallic materials — Determination of coating mass per unit area — Gravimetric methods*

ISO 4518, *Metallic coatings — Measurement of coating thickness — Profilometric method*

ISO 4519, *Electrodeposited metallic coatings and related finishes — Sampling procedures for inspection by attributes*

ISO 9220, *Metallic coatings — Measurement of coating thickness — Scanning electron microscope method*

ISO 9227, *Corrosion tests in artificial atmospheres — Salt spray tests*

ISO 9587, *Metallic and other inorganic coatings — Pretreatments of iron or steel to reduce the risk of hydrogen embrittlement*

ISO 9588, *Metallic and other inorganic coatings — Post-coating treatments of iron or steel to reduce the risk of hydrogen embrittlement*

ISO 10074, *Specification for hard anodic oxidation coatings on aluminium and its alloys*

ISO 10546, *Chemical conversion coatings — Rinsed and non-rinsed chromate conversion coatings on aluminium and aluminium alloys*

ISO 12686, *Metallic and other inorganic coatings — Automated controlled shot-peening of metallic articles prior to nickel, autocatalytic nickel or chromium plating, or as a final finish*

ISO 16348, *Metallic and other inorganic coatings — Definitions and conventions concerning appearance*

EN 12508, *Corrosion protection of metal and alloys — Surface treatment, metallic, and other inorganic coatings — Vocabulary*

IEC 60454, *Specifications for pressure-sensitive adhesive tapes for electrical purposes — Part 2: Methods of test*

3 Terms and definitions

For the purposes of this document, the terms and definitions in ISO 2064, ISO 2080, ISO 2859, ISO 4519 and EN 12508 apply.

4 Information to be supplied by the purchaser to the processor

When ordering articles for physical vapour deposition of aluminium in accordance with this International Standard, the purchaser shall provide the following information in writing in the contract or purchase order, or in the engineering drawing:

a) the designation (see Clause 5);

b) the specification and metallurgical condition of the basis metal, any process-temperature limitations [see 6.1.2 f)] and shot-peening requirements [see 6.1.3 c)];

c) the significant surface, including the coating of holes, recesses and presence of rack marks (see 6.1 and 6.3.1);

d) details of any sensitive material and whether ultra-high-purity argon is required (see 6.1.2);

e) the requirement for any consolidation, for example, by glass-bead peening (see 6.4.1);

f) the requirement for coating thickness (see 5.4 and Table 1) and for a chromate conversion coating (see 5.5 and 6.4.2);

g) the requirement for abrasion-resistant anodic oxide coating (see 6.4.3)

h) the requirement for a supplementary treatment, such as paint, and details of the specification for the organic finish (see 5.5 and 6.4.4);

i) the requirement for coating adhesion (see 6.3.3 and Annex C).

j) the requirement for special test specimens and for the type of test method, for example, destructive or non-destructive (see 6.6);

k) sampling and inspection requirements (see Clause 7 and Annex D).

5 Designation

The designation shall appear on engineering drawings, in the purchase order, the contract or in the detailed product specification. The designation specifies the basis material, the requirements for stress relief before vapour deposition, the nominal composition and thickness of the vapour-deposited aluminium coating, the type of chromate conversion coating and other supplementary treatment, and the heat treatment to reduce susceptibility to hydrogen embrittlement.

5.1 General

The designation shall comprise the following:

a) the term: vapour-deposited coating;

b) the number of this International Standard, ISO 22779;

c) a hyphen;

d) the chemical symbol of the basis metal;

e) a stroke (/);

f) symbols for the aluminium coating, as well as any coatings that may be applied prior to and after deposition, separated by strokes for each stage in the coating sequence in the order of application. The coating designation shall include the thickness of the coating, in micrometres.

5.2 Basis metal

The basis metal shall be designated by its chemical symbol, or its principal constituent, if it is an alloy. For example:

— Fe for iron and steel;

— Zn for zinc alloys;

— Cu for copper and copper alloys,

— Al for aluminium and aluminium alloys;

— Ti for titanium and titanium alloys.

The specific alloy may be identified by its standard designation (for example, its UNS number, or its national or regional equivalent) placed between the symbols, < >, for example, Fe<G434000>. See Reference [4] in the Bibliography.

5.3 Pre-process stress-relief heat treatment

Stress-relief heat treatment prior to coating may be required for some basis materials. Brackets shall be placed around the letters SR, the temperature in degrees Celsius and the time in hours. The temperature shall be in parentheses after the letters SR; for example [SR(210)1].

5.4 Type and thickness of aluminium

The aluminium coating shall be designated by its chemical symbol, Al, followed by a number giving the minimum local thickness of the coating, in micrometres. For example, Al10, designates an aluminium coating that is 10 µm thick. The thickness of vapour-deposited aluminium coatings shall be in accordance with Table 1.

Allowances for the thickness of the aluminium coating should be made by adjusting the dimensional tolerances during the manufacture of threaded items, and those with close tolerances.

Table 1 — Minimum thickness requirements for physical vapour-deposited aluminium coatings

Application	Minimum local thickness µm
General-purpose coatings for corrosion protection and outdoor use.	25 and greater
Coatings for corrosion protection in indoor applications, or where dimensional tolerances will not allow the application of a coating with a minimum thickness of 25 µm.	13 to < 25
Coatings where dissimilar metal compatibility is required for close tolerances or on threaded items.	8 to < 10

5.5 Chromate conversion coatings and other supplementary treatments

The type of chromate conversion coating and other supplementary treatments shall be designated by the symbols given in Tables 2 and 3.

Table 2 — Symbols for chromate conversion coatings

Code	Type Name	Typical appearance	Coating mass per unit area g/m^2
A [a]	Clear	Transparent, clear to bluish	⩽ 0,5
B [b]	Bleached	Transparent with slight iridescence	⩽ 1,0
C	Iridescent	Yellow iridescent	< 0,5 to < 1,5
D	Opaque	Olive-green	> 1,5
F	Black	Black	⩽ 0,5 to ⩽ 1,0

[a] Chromium in hexavalent form may or may not be present.
[b] B is a two-stage process.

Table 3 — Supplementary treatments other than conversion coatings

Code	Type of treatment
T1	Application of paints, varnishes, powder coatings or similar coating materials
T2	Application of organic or inorganic sealants.
T3	Dyeing
T4	Application of grease or oil, or other lubricants
T5	Application of wax
T6	Hard anodizing (see ISO 10074)

NOTE The function of chromate conversion coatings and other supplementary treatments is to retard or prevent the formation of white corrosion products on surfaces exposed to corrosive atmospheres, and to delay the appearance of red corrosion of aluminium coatings on steel. The iridescent yellow to olive drab chromate films are satisfactory for the application of subsequent paint coatings, but bleached or leached chromate films are not recommended as a supplementary finish with vapour-deposited aluminium coatings.

Chemical conversion coatings that do not contain hexavalent chromium are commercially available. Some contain trivalent chromium; others are chromium-free. Substitutes shall meet the corrosion requirements given in Table 4.

5.6 Post-coating heat treatment

Heat treatment to reduce the susceptibility of high-strength steels to hydrogen embrittlement may be required in some circumstances (see Clause 8). Brackets shall be placed around the letters ER, the temperature in degrees Celsius and the time in hours. The temperature shall be in parentheses after the letters ER; for example [ER(400)12].

5.7 Examples of coating designations

Example of a physical vapour-deposited aluminium coating 8 µm thick on steel (Fe), with a supplementary chromate conversion coating that is iridescent yellow (C):

Physical vapour-deposited coating ISO 22779 – Fe/Al8/C

Example of a coating 5 µm thick on steel, with a supplementary chromate conversion coating that is transparent or colourless (A) and that shall receive a subsequent organic sealant (T2):

Physical vapour-deposited coating ISO 22779 – Fe/Al5/A/T2

Example of a coating on high-strength steel that is to be stress relieved at 150 °C for 2 h before applying an aluminium coating 25 µm thick, that is to be hard anodized (T6):

Physical vapour-deposited coating ISO 22779 – Fe/[SR(150)2]/Al25/T6

6 Requirements

6.1 General

6.1.1 Basis metal

This International Standard does not specify requirements for the condition, finish and surface roughness of the basis metal prior to physical vapour deposition of aluminium. However, additional information concerning surface condition, equipment and process parameters for physical vapour deposition of aluminium is given in Annex A.

6.1.2 Equipment and materials

a) The equipment, process and materials used to produce physical vapour-deposited aluminium shall be capable of producing a uniform coating, covering completely all significant surfaces, including roots of threads, recesses, sharp corners, holes and other areas specified in the drawing, contract or purchase order.

NOTE Suitable rotating and revolving racks and fixtures may be used to ensure that all significant surfaces are cleaned and coated to the specified thickness limits.

b) High-purity argon (at least 99,995 % pure) shall be used during substrate conditioning and coating, as required. For sensitive material, ultra-high-purity argon (at least 99,998 % pure) shall be used.

c) The equipment shall be capable of producing a vacuum of 7×10^{-4} Pa, or better, in the coating chamber.

Where water-cooled surfaces are present in the chamber, including chamber walls, then a means of heating the circulating water is to be used, to ensure that the chamber surfaces are warm enough to prevent condensation when open to the atmosphere.

d) The aluminium metal used as a source material shall contain not less than 99,95 % aluminium by mass. The composition of aluminium shall be determined by using chemical or other acceptable techniques. The referee method is the mass spectrometry method.

e) Only items made of a similar basis metal shall be processed together.

f) The equipment and process shall be such that any temperature rise in the items will have no adverse effects on the properties of the basis metal or the coating, or on the adhesion characteristics between the basis metal and the coating [see 4 b)].

6.1.3 Surface preparation

a) Steels of tensile strength 1 000 MPa and greater shall be cleaned before the application of the coating, preferably using non-electrolytic alkaline and anodic alkaline cleaners to avoid the risk of creating hydrogen embrittlement problems as a result of the cleaning procedure. For titanium and titanium alloys, and for other materials, appropriate cleaning procedures, or procedures as specified in the drawing, contract or purchase order shall be followed.

b) Surfaces to be coated shall be smooth and free from oxides, tool marks, pitting, intergranular attack, or other defects.

c) Abrasives used on any metal or alloy shall not have been used on any dissimilar metals or alloys. Separate abrasive cleaning media shall be used for different alloy families, for example, iron and its alloys, aluminium and its alloys, etc. After abrasive cleaning, residues shall be removed from the surfaces of articles prior to subsequent processing.

d) Any shot peening of the basis metal or substrate shall be in accordance with ISO 12686 before final cleaning and the application of the coating [see 4 b)].

6.2 Stress-relief heat treatment before coating

Steel parts that have an ultimate tensile strength of 1 000 MPa and greater and that contain tensile stresses caused by machining, grinding or cold-forming operations shall be given a stress-relief heat treatment prior to cleaning and metal deposition. The stress-relief heat treatment shall be as specified in ISO 9587, or as specified by the purchaser.

6.3 Coating requirements

6.3.1 Appearance

The coating shall be present on all significant areas and shall be smooth, continuous, uniform, adherent, fine-grained and free from stains, burns, blisters, pits, nodules, cracks, porosity, non-coated areas, edge build-up or other defects. The aluminium coating shall show no indication of contamination or improper operation of equipment, such as powdered or darkened areas. The coating shall extend into holes and recesses to a distance as specified in the drawing, contract or purchase order [see 4 c)].

All masking material is to be removed from the non-significant surfaces, and the masked areas shall be clean and free from any defect and aluminium coating. The line of demarcation between the coated and non-coated areas shall be clear-cut. Lifting of the deposit at the edge shall not be acceptable.

Approved samples of artefacts shall be used to control the appearance of the final finish (see ISO 16348).

NOTE Unavoidable rack marks may be permitted if specified in the drawing, contract or purchase order, or with the prior agreement of the purchaser.

6.3.2 Thickness

The coating thickness specified in the designation shall be the minimum local thickness. The minimum local thickness shall be measured at any point on the significant surface that can be touched by a ball 20 mm in diameter. Thickness shall comply with the requirements in Table 1.

The minimum local thickness of the vapour-deposited aluminium coating shall be measured by one of the following methods: ISO 1463, ISO 2360, ISO 3497, ISO 3543, ISO 3882, ISO 3892, ISO 4518 or ISO 9220. The referee methods are specified in ISO 1463, ISO 3497, or ISO 9220. For the determination of the average thickness of the aluminium coating (ISO 3892), see Annex B.

6.3.3 Adhesion

The coating shall adhere to the basis metal without chipping, flaking, or other coating damage and shall conform to the minimum requirements given in Annex C.

6.3.4 Coating composition

The coating shall contain not less than 99,9 % aluminium by mass. The referee method is the mass spectrometry method.

6.4 Supplementary treatments

Prior to the application of any supplementary coating, the aluminium-coated surface may require solvent degreasing. No other form of cleaning shall be allowed.

6.4.1 Treatment with glass beads

If required, the physical vapour-deposited coating may be peened with glass beads [see 4 e)].

NOTE The process can improve the compactness of the coating, give additional corrosion resistance and provide a check for the adhesion of the coating. For example, peening may be carried out by using glass beads 50 µm to 100 µm in diameter, at a pressure of $2{,}8 \times 10^5$ Pa to produce a satin finish on the surface. Thicker coatings deposited at relatively high pressure often develop a coarse-grained structure which can be converted to a fine-grained structure by glass-bead peening.

6.4.2 Chromate conversion coating

Unless otherwise specified, the chromate conversion coating shall be applied in accordance with ISO 10546 [see 4 f)].

Alkaline chromate processes and any chromate process containing phosphate shall not be used for treating vapour-deposited aluminium coatings.

The chromate films shall be adherent, continuous and free from any flaws and defects.

6.4.3 Anodizing

If specified, aluminium coated items may be anodized to enhance abrasion resistance. The thickness of the aluminium shall be at least 20 µm to permit anodizing in accordance with ISO 10074 [see 4 g)].

6.4.4 Organic coatings

If specified, physical vapour-deposited items shall be given an organic protective coating in accordance with the requirements specified in the drawings, contract, or purchase order [see 4 h)].

6.5 Corrosion testing in neutral salt spray

When tested in accordance with the neutral salt spray test (NSS) specified in ISO 9227, the articles shall show no evidence of corrosion of the basis metal when exposed for the test duration given in Table 4 (see D.5).

Table 4 — Duration of salt spray testing for physical vapour-deposited aluminium coatings with organic finishes

Minimum local thickness of coating µm	Test duration h	
	Without chromate conversion coating [a]	With chromate conversion coating [a]
25 and greater	504	672
13 to < 25	336	504
8 to < 13	168	336

[a] See the last paragraph of 5.5 for the use of non-chromate type conversion coatings.

For applications where chromated surfaces are not to be subsequently painted, accelerated tests for corrosion resistance shall be carried out in accordance with ISO 9227. The test shall commence 24 to 36 h after chromate filming, and no corrosion product of the aluminium shall be visible on the chromate-filmed articles after 96 h exposure to the test environment, when visually examined with normal or corrected vision.

The duration and results of artificial-atmosphere corrosion tests may bear little relationship to the service life of the coated article and, therefore, the results obtained should not be regarded as a direct guide to the corrosion resistance of the tested coatings in all environments where these coatings may be used.

6.6 Special test specimens

Special test specimens may be used to measure adhesion, thickness, porosity, corrosion, hardness and other properties, when the coated articles are of a size or shape that is not suitable for the test, or it is not practical to submit the coated articles to destructive tests because the articles are few in number or too expensive [see 4 j)].

If test specimens are to be used, their number, shape and size shall be specified in the drawing, contract or order.

If separate test specimens are to be used to represent the coated articles in a test, the specimens shall be of the same nature, same surface condition, of the same material and in the same metallurgical condition as the article they represent, and shall be placed in the same production lot of, and be processed along with, the coated article they represent.

A test specimen used to represent an article in a coating thickness test shall be introduced into the process at the point where the coating or coatings are applied, and it shall be carried through all steps that might influence the coating thickness.

When both destructive and non-destructive tests exist for the measurement of a characteristic, the purchaser shall specify which is to be used and which test is to be considered as destructive or non-destructive, because a test may destroy the coating but it may be in a non-critical area.

NOTE When a test specimen is used as a coated article in a thickness test, the specimen will not necessarily have the same thickness distribution as the article, unless the specimen and the article are of the same general size and shape. Therefore, before coated articles may be accepted on the basis of a thickness test performed on the representative test specimens, the relationship between the thickness on the specimen and the thickness on the article is to be established. The criterion of acceptance will be the thickness on the specimen that corresponds to the required thickness on the article.

7 Sampling

A random sample shall be selected from the inspection lot in accordance with ISO 2819 and ISO 4519. The articles shall be inspected for conformance to the requirements of Annex D [see 4 k)].

8 Rejection

If the deposited aluminium coating does not meet the thickness or adhesion requirements, then the items may be coated a second time in accordance with the requirements of this International Standard.

If the coating is required to be stripped, the method of removal shall not damage the substrate.

If the coating is stripped by a wet process, then steel items shall be treated in accordance with ISO 9588 immediately after stripping. Items of steel of tensile strength 1 000 MPa and greater shall not be chemically stripped more than once, or coated more than twice. For parts treated in accordance with ISO 9588 after stripping with a wet process, the effectiveness of the embrittlement-relief heat treatment may be determined by test methods specified by the purchaser, or by test methods described in appropriate International Standards. For example, ISO 10587 describes a test method for testing threaded articles for residual hydrogen embrittlement-relief heat treatment, and ISO 15724 for measuring relative diffusible hydrogen concentration in steels.

Annex A
(informative)

Additional information concerning equipment, substrate preparation and process parameters

A.1 General

All cold-working processes, for example, forming, straightening, grinding and machining, where required, are to be completed before any preparation, stress relieving and coating, unless otherwise specified in the drawing, contract or purchase order.

All heat treatment operations, including those designed to reduce the susceptibility to hydrogen embrittlement (see 6.2 and Clause 8) as a consequence of cleaning operations, are to be completed prior to the deposition of aluminium.

Due allowance should be made for surface preparation (especially cleaning) and the application of a uniform coating thickness, in order to obtain the specified surface finish and dimensional tolerance specified in the drawing, contract or purchase order.

All surfaces are to be free from contaminants, such as soap, drawing compounds, oil, grease, machining fluid, polishing compounds, discolouration, oxide scale, or other foreign matter, so as to produce a chemically clean surface. Drying by means of chlorinated solvents is not allowed.

Careful control should be exercised for cleaning of partially closed fabrications and lapped joints to reduce the risk of residue retention. Care should also be taken during the abrasive cleaning of thin sections, to avoid distortion.

Areas that are not required to be coated are to be kept free from aluminium by masking prior to the application of the coating. Aluminium or corrosion-resisting steel masking, foil or plugs are to be used to cover areas where the coating is not required. Organic masking materials that are unstable at high temperatures are not to be used.

Contamination of cleaned items, for example, by handling with bare hands, is to be avoided by the use of clean, dry cotton gloves.

NOTE Difficulty may be experienced in coating small holes and recesses to a specified depth.

A.2 Equipment

The equipment consists of a coating chamber with associated pumps, controls and power supplies containing the following:

a) A means of producing energetic bombardment of the substrate prior to coating and at a suitable intensity throughout deposition of the growing film.

b) A means of producing a coating flux of aluminium, such as an evaporative or sputtering source. According to the technique used, it may be necessary to include a shutter, which may be interposed between the aluminium source and the articles to be coated, except during coating.

NOTE 1 A shutter may be necessary to reduce radiant substrate heating from the aluminium source.

c) A means of holding and manipulating the articles to ensure specified coating uniformity.

d) A means of ensuring that the substrate temperature of the articles is controlled within the specified limits.

NOTE 2 The substrate temperature is controlled by suitable modification of the process parameters.

A.3 Substrate conditioning

After cleaning and drying, as necessary, articles are to be transferred, as soon as possible, into the coating chamber using suitable gloves.

The coating chamber is then pumped to the vacuum specified in 6.1.2 c).

To ensure adequate coating adhesion, articles are then subjected to substrate conditioning to remove absorbed and chemically bound contaminants. Substrate conditioning may be achieved by intimate contact with a glow-discharge plasma (sputter cleaning), bombardment with energetic ions, radicals or atoms, or by reactive plasma cleaning or by other suitable methods. Certain conditioning treatments may require the coating chamber to be back filled with argon or another gas of sufficiently high purity. In addition, manipulation of the items to ensure complete exposure may be required.

On completion of the specified substrate conditioning, transition to the coating deposition stage of the process should be smooth and uninterrupted.

NOTE The chamber is not to be vented to the atmosphere after substrate conditioning prior to coating. Should this occur, the substrate conditioning stage is to be repeated. In some circumstances, it may be necessary to unload and reclean the articles before restarting the process.

A.4 Aluminium coating

The coating process is to be carried out in the evacuated coating chamber in which the articles have been conditioned. At the conclusion of the substrate conditioning, a smooth transition is effected by introducing the aluminium coating flux, for example by opening the shutter and adjusting the process conditions.

It is essential that a sufficiently energetic ion, or radical, or atom bombardment of the growing film occurs throughout the deposition process according to the technique used, for example by glow discharge. Where necessary, the articles are rotated and revolved to ensure uniform coating deposition.

The aluminium source shutter (if fitted) is then closed, the aluminium sources switched off and the coated articles and sources allowed to cool before air is admitted to the coating chamber. The articles are then removed from the coating chamber and the masking material is removed from the articles prior to examination.

The substrate conditioning techniques and the coating conditions will vary with the nature, size, and shape of the items to be coated. These variable factors are to be determined experimentally for each type of article, to ensure that the requirements for thickness and adhesion of the coating are met.