Via email to steven.cliff@arb.ca.gov

February 10, 2023

Hon. Steven S, Cliff, Ph.D., Executive Officer
California Air Resources Board
1001 I Street
Sacramento, CA 95814

Re: CARB CrVI ATCM Update – Follow-up to January 27 Board Meeting

Executive Officer Cliff –

The Metal Finishing Association of Southern California [MFASC], the Metal Finishing Association of Northern California [MFANC] and the National Association for Surface Finishing [NASF] appreciate the consideration the members of the California Air Resources Board are giving to our industry's concerns with the current draft of the update to the air toxic control measure for hexavalent chromium [CrVI] for chromium electroplating and chromic acid anodizing operations.

Our industry does not propose to avoid regulation for chromium plating and anodizing facilities. We remain committed to emissions-based regulations that will result in meaningful emissions reductions and believe that the update to the air toxic control measure [ATCM] for CrVI plating can be crafted to achieve this objective.

Board Member Comments

We offer to engage in furtherance of the comments and requests the Board made in its January 27 hearing, and note the comments made by individual board members. These include Chair Randolph's concern that the smallest facilities with the smallest emissions face the earliest ban, Board Member Balmes' emphasis on the low emissions from decorative plating and the necessity for more time for decorative plating to transition to alternatives, and Board Member Berg's support for the update providing decorative CrVI platers with a choice between a ban or SCAQMD Rule 1469 – type requirements.

Decorative Applications that Require Hexavalent Chromium Applications

As we have confirmed with the CARB team subsequent to the board meeting, we offer this information as staff responds to the board's request that it consider decorative plating for products where CrVI provides functionality, health and safety protection, or compliance with customer specifications.

There are applications that the current draft defines as "decorative" where CrVI is needed for purposes that trivalent cannot provide, including functionality, corrosion protection, wear resistance, hardness, product performance or health and safety protection based on customer specifications and industry standards. We have identified the following categories to-date and there are certainly more:

- Medical equipment
- Dental equipment
- HVAC
- Food surfaces
- Golf clubs
- Scuba gear
- Breathing apparatus
- Kitchen and restaurant equipment

Many of these critical applications and others address significant health and safety concerns posed by particularly corrosive environments or product quality performance demands.

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Customer and Industry Specifications
Our discussions with a number of our member facilities confirm that, unfortunately, the details of the engineering specifications are not available to us as they are prohibited pursuant to customer-required nondisclosure agreements [NDAs].

However, support for the necessity of decorative CrVI plating can be confirmed by customer specifications that necessitate CrVI plating such as: AMS 2460[1], B650[2], B456[3], and B177[4], and QQC-320[5].

Support is also found in a number of publicly available documents including: two analyses of alternatives to CrVI plating that support the statement that trivalent chromium plating is an inadequate replacement[6,7]; and four certificates of conformance that confirm the product performance requirements that plating must meet and necessitate CrVI[8,9,+0].

The necessity for decorative CrVI plating is also evidenced by the specific decorative CrVI plating exemptions the European Union [EU] has provided as it works aggressively to ban CrVI processes. The EU still provides numerous exemptions for many decorative applications. For example, a reference in a document that is in the EU REACH docket states that:

> *"The majority of the European sanitary ware manufacturing sector has already applied for, and in some cases received, authorisation under EU REACH to continue using Cr(VI) for another 10+ years, due largely to quality problems with the principal alternatives and the time needed to remedy them. Manufacturers outside of the EU are free to use Cr(VI) without similar regulatory controls and already supply a significant proportion of the GB and EU markets. This means that any switch to inferior alternatives to Cr(VI)-based electroplating would result in a loss of customers and market share to those firms still supplying higher quality Cr(VI)-based products."*
>
> Source: TCL Manufacturing Ltd, Analysis of Alternatives and Socio-Economic Analysis, June 28, 2022, Page 112: https://consultations.hse.gov.uk/crd-reach/reach-afa-022-01/supporting_documents/REACH%20%20AFA02201%20CrO3%20Analysis%20of%20Alternatives%20%20%20Socioeconomic%20Analysis%20Public.pdf

Suggested Revisions to CrVI ACTM

Definition of Decorative Chrome Plating
With this information, we suggest that the definition of "decorative chrome plating" in Section 93102.3 of the draft update should be revised to accurately state the purpose of the process. It is not limited to the terms of the current draft: "provide a bright surface with wear and tarnish resistance." The revised section would read as follows:

> (30) "Decorative Chrome Plating" means the process by which a thin layer of chromium (typically 0.003 to 2.5 micrometers) is applied to provide functionality, corrosion protection, wear resistance, hardness, product performance, or health and safety protection and is electrodeposited on that Base Material. In this process, the Base Material serves as the cathode in the electrolytic cell and the solution serves as the electrolyte. Typical current density applied during this process ranges from 540 to 2,400 Amperes per square meter (Amp/m^2) for total plating times ranging between 0.5 to 5 minutes."

Additional Time for Decorative Hexavalent Chromium Plating
The draft update should also be revised so that decorative chrome plating as now defined would be subject to each of the numerous requirements that are proposed for Functional Chrome Plating. The key revision would be to Section 93102.3, as follows:

> (46) "Functional Chrome Plating" means Hard Chrome Plating~~, and~~ Chromic Acid Anodizing ***and Decorative Chrome Plating***.

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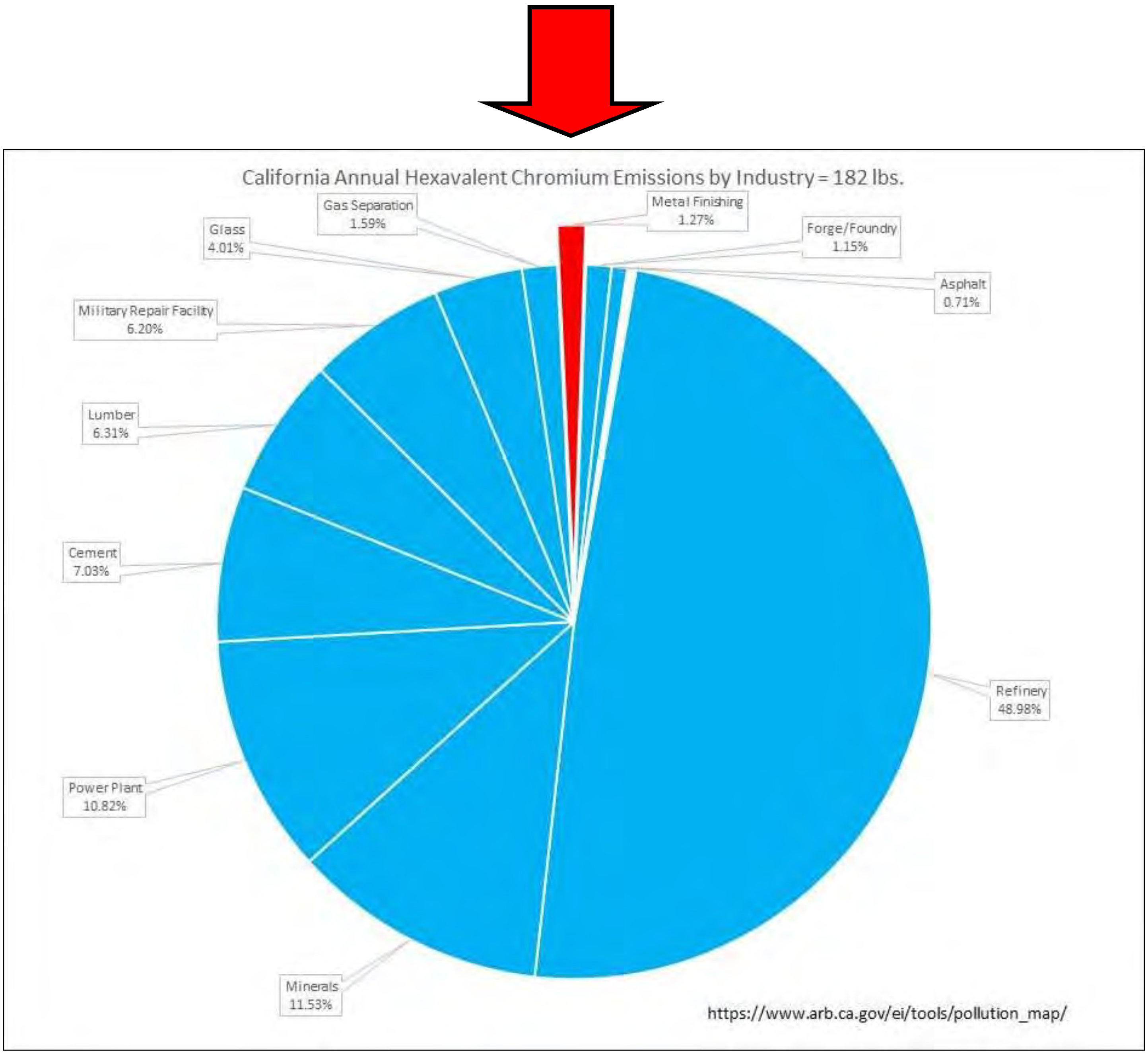
The Board on January 27 also requested that staff consider an appropriate period of time that would enable decorative CrVI plating to transition to alternatives while the environment is protected from fugitive emissions.

The approximately 50 facilities in this category pose a relatively small risk compared to hard chromium and chromic acid anodizing. Decorative CrVI plating represents only 3.7% of total CrVI emissions from the surface finishing industry, which itself is less than 1% of total statewide CrVI emissions.

Decorative Chrome Plating is only 3.7% of this 1.27% Slice of the CrVI Stationery Source Emissions



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These are the smallest facilities with the smallest emissions. Most of them are subject to SCAQMD Rule 1469 and have been investing tens of thousands of dollars to comply with the requirements of that rule and prevent fugitive emissions.

The necessity for additional time beyond the proposed July 1, 2027 ban date is supported by information submitted into the record through written public comments as well as testimony at the January 27 hearing. These demonstrate that customers are not at present willing to accept alternatives to CrVI and that there needs to be a focused effort to overcome this obstacle. Our industry commits to work with CARB and our customers to continue the transition to alternatives where appropriate. The well-intentioned offers of financial assistance for facilities unfortunately will not change customer demand.

New Requirements for Decorative Chromium Plating
The draft update should be revised to address these concerns by revising Section 93102.4, as follows:

> (b) Phase out that applies to all Existing Facilities that use Hexavalent Chromium.
> (1) Decorative Chrome Plating. No Person shall use any Hexavalent Chromium for the purposes of Decorative Chrome Plating in California after ~~***January 1, 2027***~~ ***January 1, 2039.***

In addition, the draft update should be revised so that the requirements proposed for hard chrome plating would apply to decorative chrome plating until January 1, 2039. These include the operation requirements of Section 93102.5, source test requirements of Section 93102.7, chemical fume suppressant provisions of Section 93102.8, parameter monitoring requirements of Section 93102.9, inspection and maintenance requirements of Section 93102.10, operation and maintenance plan requirements of Section 93102.11, recordkeeping requirements of 93102.12, and reporting requirements of Section 93102.13.

Technology Review for Decorative Chromium Plating
Also, the technology review proposed in subdivision (3) of Section 93102.4 should be revised to specifically include decorative chrome plating:

> Technology Reviews. CARB shall conduct two technology reviews that evaluate the development of technologies to replace Hexavalent Chromium in ***Decorative Chrome Plating***, Hard Chrome Plating and Chromic Acid Anodizing operations. Each technology review shall include a summary of the status of the development and availability of alternative technologies.
> CARB staff will complete first technology review by January 1, 2032, and the second technology review by January 1, 2036.

Source Testing
Finally, as our industry has been stating throughout the development of the update, the two-year frequency mandated by the source test requirements of Section 93102.7 is not supported by the record. The SCAQMD Rule 1469 appropriately sets forth a frequency based on the facility's permitted annual ampere hours, either 60 months or 84 months following a source test that demonstrates compliance with all applicable requirements.

The revisions would be:

> (3) All Functional Chrome Plating Facilities that use Hexavalent Chromium must conduct a Source Test on all Tier III Tanks every ~~***2 calendar years after the previous source test***~~:
> - ***For facility-wide permitted annual ampere hours over 1,000,000: 60 months from the day of the most recent source test that demonstrates compliance with all applicable requirements after the date of the previous Source Test.***
> - ***For facility-wide permitted annual ampere hours over 1,000,000 or less: 84 months from the day of the most recent source test that demonstrates compliance with all applicable requirements after the date of the previous Source Test.***

In conclusion, we look forward to discussing these issues and suggested revisions at your convenience. They are intended to be specific to, and responsive to, the direction the board provided to staff on January 27 to consider products that are decorative CrVI plated for functionality and health and safety purposes, and to consider a reasonable period of time for decorative chrome plating to transition to alternatives while providing for the protection of health, safety and the environment.

Sincerely,

Bobbi Burns
Bobbi Burns, MFANC President, 510-659-8764

Bryan Leiker
Bryan Leiker, MFANC & MFASC Executive Director, 818-207-1021

Vince Noonan
Vince Noonan, MFASC President, 800-227-9242

Jeff Hannapel
Jeff Hannapel, The Policy Group, on behalf of NASF, 202-257-3756

Enclosures

C: Members, California Air Resources Board

Footnotes:

[1] AMS 2460 [Attachment One]

[2] AMS B650: https://www.astm.org/b0650-95r18.html

[3] AMS B456: https://www.astm.org/b0456-17.html

[4] AMS B177: https://www.astm.org/b0177_b0177m-11r21.html

[5] QQC-320 [Attachment Two]

[6] Analysis [Attachment Three – Analysis – Dornbracht]

[7] Analysis [Attachment Four – Analysis: Ideal Standard]

[8] Certificate of Conformance [Attachment Five – COC: eu compliant 2000R]

[9] Certificate of Conformance [Attachment Six – COC: eu compliant 1180R]

[+] Certificate of Conformance [Attachment Seven – COC: eu compliant 21600]

[o] Certificate of Conformance [Attachment Eight - COC: eu compliant 826026]

SAE Aerospace An SAE International Group	AEROSPACE MATERIAL SPECIFICATION	SAE AMS2460	REV. A
		Issued 2007-07 Revised 2013-03 Superseding AMS2460	

Plating, Chromium

RATIONALE

AMS2460A results from a Five Year Review and includes additional details for basis metal quality and for stress relief of steel parts before plating.

NOTICE

ORDERING INFORMATION: The following information shall be provided to the plating processor by the purchaser:

1) Purchase Orders shall specify not less than the following:
   - AMS2460A
   - Part number and quantity of pieces to be plated
   - Class of plating. See 1.4.1.
   - For Class 1 plating, type of surface luster. See 1.4.2 and 3.5.1.2.
   - Plating thickness. See 3.4.1.
   - Underplating, if different from 3.3.2
   - Basis metal to be plated
   - Tensile strength or hardness of the basis metal
   - Pre-plate stress relief (time and temperature) if different from 3.2.1, or instructions that pre-plate stress relief has already been performed prior to submitting parts to the plating processor, or statement that pre-plate stress relief is not required
   - Plating coverage; special features, geometry or processing present on parts that requires special attention by the plating processor
   - Hydrogen embrittlement relief to be performed by the plating processor (parameters or requirements document), if different from 3.3.4
   - Peening requirements, if peening is required to be performed by the plating processor. See 3.1.3 and 8.4.1.
   - If tests for hardness, porosity, or hydrogen embrittlement are required for lot acceptance. See 4.2.1.
   - If adhesion is to be evaluated by grinding. See 3.4.2.1. and responsibility (plating processor or part fabricator) to perform this evaluation.

2) Parts manufacturing operations such as heat treating, forming, joining, and media finishing can affect the condition of the substrate for plating, or if performed after plating, could adversely affect the plated part. The sequencing of these types of operations should be specified by the cognizant engineering organization or purchaser and is not controlled by this specification, except as noted herein. Requirements for basis metal quality (3.1.1), peening (3.1.3), and preplating stress relief (3.2.1) require special coordination with the plating processor.

TO PLACE A DOCUMENT ORDER: Tel: 877-606-7323 (inside USA and Canada)
Tel: +1 724-776-4970 (outside USA)
Fax: 724-776-0790
Email: CustomerService@sae.org
SAE WEB ADDRESS: http://www.sae.org

SAE values your input. To provide feedback on this Technical Report, please visit http://www.sae.org/technical/standards/AMS2460A

1. SCOPE

1.1 Purpose

This specification covers the requirements for electrodeposited chromium plating.

1.2 Application

This plating has been used typically as a decorative finish, to improve corrosion resistance, to increase wear resistance, to extend tool and die life, to maintain accuracy of gauges, and to recondition worn or undersized parts, but usage is not limited to such applications. While this document is primarily intended to address electrodeposition on steels, the process has been performed on aluminum, heat resistant alloys, high nickel alloys, super alloys, and other metals. The requirements of this specification are equivalent to AMS-QQ-320 but generally more stringent than AMS2406A. Thin Dense Chrome plating should be specified by reference to AMS2438.

1.2.1 Restriction

Application of chromium plating to steel parts having a hardness of 48 HRC (ultimate tensile strength of 238 ksi [1641 MPa]) or higher shall not be performed unless authorized by the design documentation of the cognizant engineering organization. (See 4.2.3.1 and 8.4.2.) Application of chromium plating for repair of steel parts having a hardness of 48 HRC(ultimate tensile strength of 238 ksi (1641 Mpa) or higher requires a special design evaluation and shall not be performed unless specific approval has been received from the cognizant engineering organization

1.3 Safety-Hazardous Materials

While the materials, methods, applications and processes described or referenced in this specification may involve the use of hazardous materials, this specification does not address the hazards which may be involved in such use. It is the responsibility of the user to ensure familiarity with the safe and proper use of any hazardous materials, to take precautionary measures to ensure the health and safety of all personnel involved.

1.4 Classification

1.4.1 Classes

Electrodeposited chromium plating shall be one of the following classes.

Class 1 - Corrosion protective plating. See 8.4.3.

Class 2 - Engineering plating. See 8.4.4.

1.4.2 Appearance

Class 1 plating shall have one of the following types of lusters, as specified.

Type I - Bright finish

Type II - Satin finish.

2. APPLICABLE DOCUMENTS

The issue of the following documents in effect on the date of the purchase order forms a part of this specification to the extent specified herein. The supplier may work to a subsequent revision of a document unless a specific document issue is specified. When the referenced document has been cancelled and no superseding document has been specified, the last published issue of that document shall apply.

2.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or 724-776-4970 (outside USA), www.sae.org.

AMS2403 Plating, Nickel, General Purpose

AMS2406 Plating, Chromium, Hard Deposit

AMS2438 Plating, Chromium, Thin, Hard, Dense Deposit

AMS2759/9 Hydrogen Embrittlement Relief (Baking) of Steel Parts

AMS-QQ-C-320 Chromium Plating, Electrodeposited

AMS-QQ-N-290 Nickel Plating (Electrodeposited)

2.2 ASTM Publications

Available from ASTM International, 100 Barr Harbor Drive, P.O. Box C700, West Conshohocken, PA 19428-2959, Tel: 610-832-9585, www.astm.org.

ASTM B 253 Standard Guide for Preparation of Aluminum Alloys for Electroplating

ASTM B 487 Measurement of Metal and Oxide Coating Thickness by Microscopic Examination of a Cross Section

ASTM B 499 Measurement of Coating Thick nesses by the magnetic Method: Nonmagnetic Coatings on Magnetic Base Metals

ASTM B 504 Measuring the Thickness of Metallic Coatings by the Coulometric Method

ASTM B 556 Thin Chromium Coatings by the Spot Test, Guideline for Measurement of

ASTM B 567 Method for Measurement of Coating Thickness by Beta Backscatter Method

ASTM B 568 Measurement of Coating Thickness by X-Ray Spectrometry

ASTM B 571 Qualitative Adhesion of Metallic Coatings

ASTM B 748 Measurement of Thickness of Metallic Coatings by Measurement of Cross Section with a Scanning Electron Microscope

ASTM B 764 Simultaneous Thickness and Electrochemical Potential Determination of Individual Layers on the Multilayer Nickel Deposit (STEP Test)

ASTM E 384 Test Method for Microhardness of Materials

ASTM F 519 Mechanical Hydrogen Embrittlement Testing of Plating Processes and Service Environments

2.3 Aerospace Industries Association Publications

Available from Aerospace Industries Association, 1000 Wilson Boulevard, Suite 1700, Arlington, VA 22209-3928, Tel: 703-358-1000, www.aia-aerospace.org.

NASM1312-12 Fastener Test Methods, Thickness of Metallic Coatings

3. TECHNICAL REQUIREMENTS

3.1 Material

3.1.1 Basis Metal Quality

The basis metal (parts) shall be submitted to the plating processor free from visible defects such as blemishes, prior pitting from corrosion, nicks, scratches, burrs or other geometrical or base metal defects that could be detrimental to the appearance or performance of the plating. The plating processor shall perform such cleaning and plating procedures as necessary to yield a deposit that conforms to the specified requirements.

3.1.2 Parts dimensions should be such that, after plating, specified tolerances will be met (See 8.2).

3.1.3 Peening

When specified, parts shall be peened prior to plating. Unless otherwise specified, such peening shall be accomplished on all surfaces for which the plating is required and on all immediately adjacent surfaces that contain notches, fillets or other abrupt changes of section size (See 8.4.1). Peening shall be performed by or on behalf of the part fabricator, unless specifically delegated to the plating processor

3.2 Preparation

3.2.1 Stress Relief Treatment

Unless otherwise specified, steel parts 34 HRC (ultimate tensile strength 152 ksi [1048 MPa]) and higher and that have been machined, ground, cold formed, or cold straightened after heat treatment shall be cleaned to remove surface contamination and thermally stress relieved before plating. Acid cleaning shall not be used. See 8.4.2.3. (Residual tensile stresses have been found to be damaging during electrofinishing.) Temperatures to which parts are heated shall be such that maximum stress relief is obtained while still maintaining hardness of parts within drawing limits. Unless otherwise specified, the following treatment temperatures and times shall be used:

3.2.1.1 For parts, excluding nitrided parts, having a hardness of 55 HRC and above, including carburized and induction hardened parts, stress relieve at 275 °F ± 25 (135 °C ± 14) for 5 to 10 hours.

3.2.1.2 For parts having a hardness less than 55 HRC, stress relieve at 375 °F ± 25 (191 °C ± 14) for a minimum of 4 hours. Nitrided parts fall into this category. Higher temperatures shall be used only when specified or approved by the cognizant engineering organization.

3.2.1.3 For peened parts: If stress relief temperatures above 375 °F (191 °C) are elected, the stress relieve shall be performed prior to peening or the cognizant engineering organization shall be consulted and shall approve the stress relief temperature.

3.2.2 Cleaning

The plating shall be applied over a surface free from water breaks. The cleaning procedure shall not produce pitting, intergranular attack, or hydrogen embrittlement of the basis metal and shall preserve dimensional requirements. See 8.4.2.

3.2.3 Electrical Contact Points

For parts which are to be plated all over, locations shall be acceptable to purchaser. For parts which are not to be plated all over, locations shall be in areas on which plating is not required.

3.2.4 Aluminum alloys shall be zincate treated in accordance with ASTM B 253 or other method acceptable to purchaser prior to plating.

3.3 Procedure

3.3.1 Parts shall be plated by electrodeposition of chromium plating onto a properly prepared surface. Procedures and operating parameters shall be adequate to meet the properties and quality requirements of this specification.

3.3.2 Underplating

Unless otherwise specified, the following apply:

3.3.2.1 Class 1 plating shall be applied over an intermediate plating of nickel in accordance with AMS2403 or AMS-QQ-N-290 on steel, zinc, and copper alloys.

3.3.2.2 Class 2 plating shall be deposited directly on the basis metal without a preliminary plating of another metal, except parts made from maraging steel, or corrosion resistant steel, or aluminum alloy may receive a preliminary deposit of nickel or other suitable metal to a thickness not greater than 0.0002 inch (5 µm).

3.3.2.3 Underplate shall not be substituted for any portion of the specified chromium plate thickness.

3.3.3 Plating re-start procedures, if used, shall be approved by the cognizant engineering organization. See 4.4.3.

3.3.4 Hydrogen Embrittlement Relief (Baking)

Hydrogen embrittlement relief baking applies only to steel alloys unless otherwise specified by the cognizant engineering authority. At the option of the processor, hydrogen embrittlement relief baking may be performed on other families of alloys. If performed on other alloy families, all hydrogen embrittlement relief baking operations shall be documented. Hydrogen embrittlement relief baking shall be in accordance with AMS2759/9, except as shown in Table 1. Depending on the metallurgical condition of the parts at time of plating (i.e., alloy, hardness, prior heat treatment - carburized, induction hardened, etc.), the cognizant engineering authority may elect to prescribe hydrogen embrittlement relief baking temperatures and times different from those shown in Table 1.

TABLE 1 - HYDROGEN EMBRITTLEMENT RELIEF (BAKING) REQUIREMENTS (1)

Ultimate Tensile Strength Inch/Pound Units	Ultimate Tensile Strength SI Units	Hardness	Time in Hours at 375 °F (191 °C)
160 ksi to 182 ksi, excl.	1103 MPa to 1255 MPa, excl.	36 to 39 HRC	3
182 ksi to 221 ksi, excl.	1255 MPa to 1518 MPa, excl.	40 to 45 HRC	8
221 ksi, and higher	1518 MPa, and higher	46 HRC and higher	23

(1) NOTE: All times shown are minimum times. For high strength steels 40 HRC (ultimate tensile strength 182 ksi [1255 MPa]) and higher, it may be beneficial, and the processor is permitted, to extend the baking time to 23 hours to ensure complete relief from hydrogen embrittlement.

3.4 Properties

The plating shall conform to the following requirements:

3.4.1 Thickness

Thickness shall be as specified on the drawing, determined in accordance with any of the following methods as applicable: ASTM B 487, ASTM B 499, ASTM B 504, ASTM B 556, ASTM B 567, ASTM B 568, ASTM B 748, ASTM B 764 or by other method acceptable to the purchaser. NASM1312-12 may be used for thickness measurement of plated fasteners. ASTM B 556 (spot test) may be used for Class 1 plating, when a destructive procedure is applicable.

3.4.1.1 All surfaces of the part, except those which cannot be touched by a sphere 0.75 inch (19 mm) in diameter, shall be plated to the specified thickness. Unless otherwise specified, surfaces such as holes, recesses, threads and other areas where a controlled deposit cannot be obtained under normal plating conditions, may be under the specified limit provided they show visual plating coverage. The plate shall be substantially uniform in thickness on significant surfaces except that build-up at exterior corners or edges shall be permitted provided finished drawing dimensions are met.

3.4.1.2 Class 1

Unless otherwise specified, the minimum thickness of Class 1 chromium plating shall be 0.00001 inch (0.25 μm).

3.4.1.3 Class 2

The thickness of Class 2 plating shall be as specified by the purchaser. If the as-plated thickness is not specified, the minimum thickness shall be 0.002 inches (51 μm) plus any grinding or finishing allowance such that the minimum thickness of the finished part is 0.002 inches (51 μm).

3.4.2 Adhesion

The plating and any underplate shall be tightly adherent to the substrate as determined in accordance with ASTM B 571, knife-chisel or bend test with no mandrel. When examined at a magnification of approximately 4X, neither the chromium plating nor any electrodeposited underplate(s) shall show separation from the basis metal or from each other. The formation of cracks in the plating or the basis metal which do not result in flaking, peeling, or blistering of the plating shall not be cause for rejection.

3.4.2.1 Class 2 Adhesion Evaluation – Optional Method

When specified, Class 2 plating may be evaluated by grinding as an alternative to the bend test or knife-chisel test. The plating shall withstand the grinding operations with no evidence of delamination of plated layers or separation from the basis metal.

3.4.3 Hardness (Class 2 Only)

When tested in accordance with ASTM E 384 using a Vickers indentor and 100 gram load, the minimum hardness of a cross section Class 2 plating shall be 600 Vickers Hardness Number (HVN) if the plating is finished to a semi-bright or matte luster. If the plating is finished to a bright pebbly bright lusters, the minimum hardness shall be 850 HVN. Any Alternative hardness requirement or test method shall be as specified by the cognizant engineering organization. There is no hardness requirement for Class 1

3.4.4 Porosity (Class 2 Only)

Class 2 plating shall be porosity free to the extent that it protects the basis metal from corrosion due to pits, pores, or cracking. Criteria for evaluating this characteristic shall be as shown in 3.4.4.1 and 3.4.4.2. There is no porosity requirement for Class 1 – (See 8.4.3)

3.4.4.1 Class 2 plating, when subjected to the test specified in 3.4.4.2, shall show no more than 15 isolated blue spots or pits, none larger than 0.03 inch (0.8 mm) in diameter, in a total of 150 square inches (967 cm^2) of test area. In addition no more than five isolated spots or pits are permitted, none larger than 0.03 inch (0.8 mm) in any 30 square inches (193 cm^2) of test area. Isolated linear indications are acceptable. Linear cracking or crazing indications occurring over 5% or more the surface area are not acceptable. Panel edges, identification markings, and electrical contact locations are exempt from these requirements.

3.4.4.2 Potassium Ferricyanide (Ferroxyl) Porosity Test

Plated low alloy steel parts or low steel specimens shall be evaluated. See 4.3.3.2. Note: Panels subjected to distortion or flexing during processing can exhibit cracking or crazing type indications, so care should be exercised to prevent such false indications. All specimen surfaces shall be cleaned to remove any oil or grease. Contamination removal shall be accomplished with a solvent acceptable to the purchaser. A sheet of filter paper or other suitable adsorbent paper, saturated in the ferroxyl solution shall be applied for 10 minutes to the flat surface of the specimen or the article. Complete contact of the filter paper with the chrome plated test specimen shall be ensured using strokes with a soft bristle brush. Filter paper shall be kept saturated during the duration of the 10 minute test. Pits, pores, or cracking of the chrome are revealed by dark blue spots or lines. For a permanent record, the filter paper may be dried. The approximate solution composition shall be as follows:

Potassium ferricyanide ($K_3Fe(CN)_6$) 1 gm
Sodium Chloride (NaCl) 10 gm
Water (distilled or deionized) to make 1 liter

3.4.5 Hydrogen Embrittlement

The plating process shall not cause hydrogen embrittlement in steel parts determined in accordance with 4.3.3.3 or alternative acceptable to the cognizant engineering organization. Control of and testing for hydrogen embrittlement shall include all aspects of the process including stripping, surface preparation, reagent or electro cleaning, electrodeposition of the chromium onto the basis steel using acceptable bath chemistries, and the subsequent hydrogen embrittlement relief (baking) operation. Care should be exercised to control all aspects of the chromium plating process. See 8.4.2 and 4.6.1.1.

3.5 Quality

3.5.1 Plating, as received by purchaser, shall be smooth, continuous, adherent, free from delamination within the plating, uniform in appearance, fine grained, and shall be free from blisters, nodules, excessive pits, and other imperfections detrimental to usage of the plate. Slight staining or discoloration is permissible. The plating shall show no indication of contamination or improper processing such as excessively powdered or darkened plating, excessive edge build up, or other defects.

3.5.1.1 Boundaries of Class 2 plating between plated and unplated area shall be free from beads, nodules, jagged edges or other irregularities.

3.5.1.2 Luster

Class 1, Type I plate shall be fully bright in appearance. Class 1, Type II plate shall be a satin finish in appearance. Unless otherwise specified either a fully bright or a dull matte finish shall be acceptable for Class 2 plate. See 8.4.

4. QUALITY ASSURANCE PROVISIONS

4.1 Responsibility for Inspection

The processor shall supply all samples for processor's tests and shall be responsible for the performance of all required tests. When parts or special specimens are to be tested, the parts or special test specimens shall be provided by the purchaser. Purchaser reserves the right to sample and perform any testing deemed necessary to ensure that processing conforms to specified requirements.

4.2 Classification of Tests

4.2.1 Acceptance Tests

Thickness (3.4.1), adhesion (3.4.2), and quality (3.5) are acceptance tests and shall be performed on parts or samples representing parts from each lot. When specified by the purchaser, hardness of Class 2 plating (3.4.3), porosity of Class 2 plating (3.4.4), and hydrogen embrittlement (3.4.5) are also acceptance tests.

4.2.2 Periodic Tests

Periodic (Production Control) are tests performed on a regular monthly basis and are intended to control the quality of the production process. Thickness (3.4.1), adhesion (3.4.2), hardness of Class 2 plating (3.4.3), porosity of Class 2 plating (3.4.4), and tests of cleaning and plating solutions are periodic tests and shall be performed at least monthly on each plating bath. Hydrogen embrittlement (3.4.5) is a periodic test and shall be performed at least once each month on each plating bath in which steel parts 36 HRC (ultimate tensile strength 161 ksi [1110 MPa]) and higher are plated.

4.2.2.1 Process Control Records

The supplier shall maintain a record of each processing bath, showing all additions of chemicals or treatments to the bath, the results of all tests and chemical analysis performed, and the quantity of parts plated during operation. These records shall be maintained and made available for review for not less than one year after completion of the contract or purchase order.

4.2.2.2 Interruption of Production

If continuous month to month production ceases for a particular plating bath, the processor is not required to continue periodic production control testing (4.2.2.1). However, all property verification tests of section 3.4 shall be performed on the idled plating bath prior to processing of production parts.

4.2.3 Preproduction Tests

All property verification tests of section 3.4 are preproduction tests and shall be performed prior to production and when the purchaser deems confirmatory testing is required.

4.2.3.1 Steel parts 40 HRC (ultimate tensile strength 182 ksi [1255 MPa]) and higher shall not be plated until approval has been received from the purchaser concerning acceptance of hydrogen embrittlement test results. See 4.4 and 8.4.2.

4.3 Sampling

Sampling for testing shall be not less than the following; a lot shall be all parts of the same part number processed in a continuous operation to the same thickness range, in the same set of solutions, in not longer than 24 consecutive hours, and presented for processor's inspection at one time. Adhesion verified by grinding on parts, thickness, and quality are classified as non-destructive tests. Adhesion verified by knife-chisel or bend test, hardness, porosity, and hydrogen embrittlement render actual parts not useable after testing and are classified as destructive tests.

4.3.1 Nondestructive Tests

Samples shall be randomly selected from all parts in the lot. The minimum number of parts tested shall be as indicated in Table 2.

TABLE 2 - SAMPLING FOR NONDESTRUCTIVE ACCEPTANCE TESTS

Number of Parts in the Lot	Number of Parts to be Tested
15 or less	7 [(1)]
16 to 40	10
41 to 110	15
111 to 300	25
301 to 500	35
501 and over	50

(1) If the number of parts in the lot is less than 7, then all parts shall be tested.

4.3.2 Destructive Tests

Sample quantities shall be as shown in Table 3.

TABLE 3 - SAMPLING FOR DESTRUCTIVE TESTS

Test	Class of Coating	Number of Samples to be Tested	Requirement Paragraph	Specimen Paragraph	Test Method Paragraph
Thickness	1 & 2	4	3.4.1	4.3.3.1	3.4.1
Adhesion	1 & 2	4	3.4.2	4.3.3.1	3.4.2
Hardness	2	4	3.4.3	4.3.3.1	3.4.3
Porosity	2	5	3.4.4	4.3.3.2	3.4.4.1
Hydrogen Embrittlement	1 & 2	4	3.4.5	4.3.3.3	4.3.3.3

4.3.3 Sample Configuration

Separate test specimens may be used under the following circumstances: When plated parts are of a configuration, size, quantity or value as to not be readily adaptable to a specified tests, when nondestructive testing is not practical on actual parts, or when it is not economically acceptable to perform destructive tests on actual parts. When used, separate test specimens shall be made of the same generic class of alloy as the parts as defined in 8.6, distributed within the lot of parts to be cleaned, plated and post treated with the actual parts.

4.3.3.1 Separate test specimens for thickness, adhesion, and hardness tests shall be four (4) samples approximately 1 × 4 × 0.040 inches (25 × 100 × 1 mm).

4.3.3.2 Separate test specimens for porosity test shall be five (5) samples of low alloy steel and approximately 3 × 10 × 0.040 inches (75 × 250 × 1 mm).

4.3.3.3 Hydrogen Embrittlement Test

Test shall be in accordance with the requirements of ASTM F 519 Type 1a.1 using round notched specimens, unless a different specimen is specified by the purchaser, stressed in tension under sustained load. For test purposes, the plating thickness shall be a minimum of 0.002 inch (51 μm) measured on the smooth section of the test specimen, but with visual plating at the root of the notch. Testing beyond the 200 hour test period is not required. The test samples shall be exposed to all steps of the documented plating process including surface preparation (reagent, electro-cleaning or abrasive blasting as applicable), underplate, electrodeposition of the chromium onto the basis metal, and the prescribed baking schedule per Table 1 and AMS2759/9.

4.3.3.4 Periodic and Preproduction Test Specimens for Thickness, Adhesion, Hardness, and Porosity

When Class 2 plating is performed, separate test specimens shall be chromium plated onto bare steel to a nominal thickness of 0.002 inch (51 μm).

4.4 Approval

4.4.1 The process and control factors or a preproduction part, or both, whichever is specified, shall be approved by the cognizant engineering organization before production parts are processed.

4.4.1.1 When specified, records of process control and all pre-production control test results shall be approved by the cognizant engineering organization before production parts are processed.

4.4.2 If the processor makes a significant change to any material, process, or control factor from that which was used for process approval, all preproduction tests shall be performed and the results submitted to the purchaser for process reapproval unless the change is approved by the cognizant engineering organization. A significant change is one which, in the judgment of the cognizant engineering organization, could affect the properties or performance of the parts.

4.4.3 Control factors shall include, but not limited to the following:

Stress relief performed by plating processor (temperature and time)
Surface preparation and cleaning methods
Plating material trade name and manufacturer
Plating bath composition and composition control limits
Plating bath temperature limits and controls
Plating interruption and restart procedures, when applicable
Stripping procedure, when applicable
Rack locations
Current density (amps per part or amps per total surface area of the parts plated at one time in each tank)
Hydrogen embrittlement relief (bake) temperature and time, when applicable
Periodic test plan for process solutions and records. See 4.2.2, 8.5, and 4.2.2.1.

4.5 Reports

The processor shall furnish with each shipment a report stating that the parts have been processed and tested in accordance with the specified requirements and that they conform to the acceptance test requirements. This report shall include the purchase order number, AMS2460A, the part number, lot identification, and quantity.

4.6 Resampling and Retesting

4.6.1 If any acceptance test for quality or thickness, and when specified, adhesion, hardness, or porosity fails to meet specified test requirements, the parts in that lot may be stripped, pretreated, plated and post treated as defined herein and retested. Alternatively, all parts in the lot may be inspected for the non-conforming attribute, and the non-conforming parts may be stripped, pretreated, plated, and post treated as defined herein and then retested. When specified for acceptance testing, if hydrogen embrittlement fails to meet test requirements, retesting in accordance with the procedures of ASTM F 519 is permitted

4.6.1.1 When stripping is performed, the method shall be acceptable to the purchaser and shall not roughen, pit, or embrittle the basis metal or adversely affect part dimensions. When parts have been stripped and replated, the reprocessing shall be documented and the purchaser shall be informed.

4.6.2 If any periodic test fails to meet specified requirements, the process is nonconforming. No additional parts shall be plated until the process is corrected and new specimens are plated and tested. Results of all tests shall be recorded and, when requested, reported. Purchasers shall be notified of all parts coated since the last acceptable periodic test.

5. PREPARATION FOR DELIVERY

5.1 Plated parts shall be handled and packaged in such as manner as will ensure that the required physical characteristics and properties of the plating are preserved.

5.2 Packages of plated parts shall be prepared for shipment in accordance with commercial practice and in compliance with applicable rules and regulations pertaining to the handling, packaging and transportation of the plated parts to ensure carrier acceptance and safe delivery.

6. ACKNOWLEDGEMENT

The processor shall mention this specification number and its revision letter in all quotations and when acknowledging purchase orders.

7. REJECTIONS

Parts on which plating does not conform to this specification or to modifications authorized by purchaser will be subject to rejection.

8. NOTES

8.1 A change bar (|) located in the left margin is for the convenience of the user in locating areas where technical revisions, not editorial changes, have been made to the previous issue of this document. An (R) symbol to the left of the document title indicates a complete revision of the document, including technical revisions. Change bars and (R) are not used in original publications, nor in documents that contain editorial changes only.

8.2 This plating process alters the product dimensions. Compliance with dimensional tolerances affected by the plating process requires communications of manufacturing planning information between the part fabricator and the plating processor. The cognizant engineering organization should specify the stage at which the plating thickness and the product dimensions (e.g., threads, features) apply such as before plating, as-plated, or after metal removal operations that are to follow plating.

8.3 The purchaser is expected to provide the processor with a properly dimensioned part that allows for the change in dimensions expected from this process. The purchaser should also provide any special instructions that may need to be observed concerning plating thickness or plated part dimensions.

8.4 The information in this section is provided for guidance, but does not alter the requirements of this specification.

8.4.1 Peening

A reduction in the fatigue life of chromium plated parts attributed to the chromium adhesion, physical characteristics, mechanical properties, and state of stress, should be expected. Parts designed for unlimited fatigue life under dynamic loads (including Class 2c and 2e of AMS-QQ-C-320) should be peened prior to plating, particularly surfaces for which the plating is required and on all immediately adjacent surfaces that contain notches, fillets or other abrupt changes of section size where stresses may be concentrated. AMS2430, AMS2432, AMS2546, or AMS-R-81841 are recommended peening specifications. eening is normally performed by the part fabricator or their subcontractor, and, unless specifically directed, is not the responsibility of the plating processor.

8.4.2 Hydrogen Embrittlement

Chromium plating and the associated precleaning processes can produce a cracking condition in the base metal known as hydrogen embrittlement. Hydrogen embrittlement sensitivity increases with increasing hardness or strength. Plating of steel parts 48 HRC (ultimate tensile strength 238 ksi [1641 MPa]) and higher requires specific authorization from the cognizant engineering organization that the item is suitable and intended for chromium plating. Plating of steel parts 40 HRC (ultimate tensile strength 182 ksi [1255 MPa]) and higher requires preproduction process approval of hydrogen embrittlement test results. See 4.2.3.1 Plating of steel parts 36 HRC (ultimate tensile strength 161 ksi [1110 MPa]) and higher requires post plating hydrogen embrittlement relief baking. See 3.3.4. Plating of steel parts 34 HRC (ultimate tensile strength 152 ksi [1048 MPa]) and higher with residual stresses requires thermal stress relief prior to plating. See 3.2.1. Additional guidance follows:

8.4.2.1 Control of and testing for hydrogen embrittlement includes all aspects of the process including surface preparation, reagent or electro cleaning, electrodeposition of the chromium onto the basis steel using acceptable bath chemistries, and the subsequent embrittlement relief (baking) operation. Care should be exercised to control all aspects of the chromium plating process.

8.4.2.2 Steel parts 40 HRC (ultimate tensile strength 182 ksi [1255 MPa]) or higher may be alkaline cleaned using anodic current, but cathodic or periodic reverse current should not be used.

8.4.2.3 An acid dip may be used for surface activation or neutralization of residual alkaline cleaner, however the immersion should be minimized, as measured in seconds, to preclude pitting or hydrogen embrittlement.

8.4.2.4 Except as noted in 8.4.2.2, the final step in cleaning should consist of anodically etching the parts in a chromic acid solution of a concentration approximately to that of the chromic acid solution used in the plating bath.

8.4.2.5 For plating nickel alloys, and for plating other alloys on which a deposit of nickel is used as an undercoating for chromium, the final step in cleaning should consist of electrolytically etching the parts in a sulfuric-hydrofluoric acid solution (25% by volume H_2SO_4 and 4.5% by volume HF) or in a 40% by volume solution of sulfuric acid. Current density should not exceed 3 amps per square inch to prevent base metal attack.

8.4.3 Class 1 Chromium Plating

8.4.3.1 The function of the under layer of nickel for Class 1 plating is to provide a pore free continuous underplate for the chromium outer layer. Generally, the thicker the nickel layer, the better the corrosion resistance. The system of an outer layer of chromium over the combined plated nickel and copper are generally used in a combined total thickness of 0.0001 to 0.002 inches (2.5 to 51 μm) depending upon service conditions and the basis metal.

8.4.3.2 Class 1 plating may be processed in the following forms of deposition:

R = Regular or conventional
MP = Microporous
MC = Microcracked

8.4.3.2.1 Generally, a nominal plating thickness, approximately 0.00001 inch (0.25 μm) is used for all forms of the Class 1 chromium deposit. The thickness of Form R plating should not exceed 0.0002 inch (5.1 μm) as the resultant chromium plate tends to crack spontaneously. Form MP deposits should contain a minimum of 64 500 pores per square inch (100 pores per square mm), invisible to the unaided eye. For MC deposits should have more than 750 cracks per inch (80 cracks per millimeter) in any direction over the significant surfaces. MP and MC forms are typically used for applications where retention of oil or lubrication is desired on the chrome surface.

8.4.3.2.2 The determination and acceptance of deposit Form should be accomplished by a method acceptable to the purchaser.

8.4.4 Class 2 Chromium Plating

8.4.4.1 Class 2 plating, also known as "engineering chromium", "industrial chromium", or "hard chromium" is typically used for wear resistance, abrasion resistance, improved frictional properties (lower), and such incidental corrosion barrier protection of parts as the specified thickness of the plating may afford. Class 2 plating is usually applied directly to the basis metal and is finished by grinding to the specified dimensions. It lacks the brightness of Class 1 plating. Additional corrosion resistance can be obtained by use of an undercoat of electrodeposited nickel in thickness of 0.001 to 0.002 inch (25 to 51 μm) on ferrous parts, the minimum thickness to be determined by service conditions. Heavy deposits of the Class 2 plating have been used for buildup of worn or undersized parts, or for salvage purposes, and to provide protection against corrosive chemical environments. Final grinding of the chromium plating can increase the incidence of cracking in the deposit. For greater corrosion resistance, based upon equal thickness, unground deposits should be selected rather than ground deposits. See 8.4.4.4. A reduction in fatigue life of chromium plated parts can be expected and is attributed to the physical and adhesion characteristics of the chromium plate and its state of stress. Plating bath temperature and embrittlement relief (baking) temperature have been found to affect the fatigue performance of Class 2 plating.

8.4.4.2 The following designations are provided for correlation with AMS-QQ-C-320 and QQ-C-320:

Class 2b - Parts below 40 HRC for which shot peening is not required
Class 2c - Parts below 40 HRC for which shot peening is required prior to plating
Class 2d - Parts 40 HRC and higher for which shot peening is not required
Class 2e - Parts 40 HRC and higher for which shot peening is required prior to plating.

8.4.4.3 For Class 2 plating, parts should be plated by electrodeposition of chromium from a chromic acid solution containing added sulfate, fluoride ions, or organic sulfonate catalysts.

8.4.4.4 Recommended maximum thickness of Class 2 plating is 0.015 inches (0.38 mm) except on tools and dies. Recommended minimum thickness of chromium, when used for protection against corrosion is 0.002 inches (51 um) however this does not imply any minimum corrosion resistance. Chromium plating 0.0005 inches (13 μm) or more in thickness is likely to crack the nickel underplating on brass basis metal.

8.4.4.5 When grinding chromium plate, it should be done with a soft wheel, proper coolant, (not dry. Excessive stock removal per pass is to be avoided. Recommended removal rate is 0.0001 inch (2.5 μm) per pass. AMS2440 is recommended to establish proper techniques for grinding of chromium plate.

8.5 ARP4992, "Periodic Test Plan for Process Solutions" is recommended to satisfy the requirements for control of processing solutions.

8.6 Test Specimen Material

When plating basis metals of the following types, the following criteria shall be used for selection of an acceptable generic alloy to represent parts for test purposes. The thickness to be applied to the test specimen shall be either:

1. The nominal thickness range (class or type) specified herein or

2. The thickness range specified by the purchaser or cognizant engineering authority.

8.6.1 Transformation Hardening Steels

These steels include, but are not limited to: (1) Plain carbon steels such ads AISI-SAE 10xx, 11xx, 12xx 15xx types, (2) Low and medium alloy steels (AISI-SAE 1300, 4000, 5000, 6000, 8000, 9000 series alloys and other transformation hardening steels where sufficient carbon or alloy is present to effect a martensitic phase transformation during heat treatment (applicable when martensitic phase transformation properties are the dominate hardening mechanism), and (3) Bearing steels such as 52100. Test specimen material shall be a low alloy steel such as AISI-SAE 4xxx, or 8xxx series. Alternative alloys may be used when agreed upon by purchaser and vendor.

8.6.2 CRES (Corrosion Resistant Steels)

Alloys containing primarily iron and chromium with or without nickel (ferritic, austenitic and martensitic grades) Includes 200, 300, 400 series stainless steels and PH grades stainless steels. Test specimen material shall be a stainless steel of a type and condition at the discretion of the processor.

8.6.3 High Alloy Steels

To include, but not limited to Maraging grades, AF 1410, Aero-Met 100, Hy-Tuf, HP alloys, etc. which rely on multiple strengthening mechanisms. Test specimen material shall be as agreed upon between purchaser and vendor.

8.6.4 Tool Steels

To include by not limited to W, S, F, O, L, D, A, H, and M series tool steels. Test specimens shall be of the same alloy as being plated. Alternative alloys may be used as test samples when agreed upon by purchaser and vendor.

8.6.5 Heat Resistant Alloys

To include Inconels, Hastelloys, René, Waspaloy, AM350, Custom 45x series, Incoloys, Greek Ascoloy, A286, etc. Test specimens shall be from the same alloy as being plated. Alternative alloys may be used when agreed up by purchaser and vendor.

8.6.6 Aluminum Alloys

Test specimens shall be from the same alloy and heat treat condition as being plated.

8.6.7 Titanium Alloys

Test specimens shall be from the same alloy and heat treat condition as being plated.

8.6.8 Copper Alloys

Includes brass, bronze and beryllium copper alloys. Test specimens shall be from the same alloy and temper condition as being plated.

8.7 Note that steel parts 34 HRC (ultimate tensile strength 152 ksi [1048 MPa]) and higher which have been ground, machined, cold formed, or cold straightened after heat treatment, but which have not been stress relieved, are susceptible to hydrogen embrittlement during the plating process. See 3.2.1 and 8.4.2. Failure to stress relieve such parts could result in cracking during cleaning and or plating. Note that the stress relief treatment is different and distinct from post plating hydrogen embrittlement relief (baking) treatment. See 3.3.4.

8.8 Terms used in AMS documents are clarified in ARP1917. ASTM B 374 "Terminology Relating to Electroplating" should be utilized as a reference and referee document when areas of design definition or technical interpretation arise.

8.9 Dimensions and properties in inch/pound units and the Fahrenheit temperatures are primary; dimensions and properties in SI units and Celsius temperatures are shown as the approximate equivalents of the primary units and are presented for information only.

PREPARED BY AMS COMMITTEE "B"

QQ-C-320B
June 17, 1974
SUPERSEDING
Fed. Spec. QQ-C-320A
July 25, 1967

FEDERAL SPECIFICATION

CHROMIUM PLATING (ELECTRODEPOSITED)

This specification was approved by the Commissioner, Federal Supply Service, General Services Administration for use of all Federal agencies.

1. SCOPE AND CLASSIFICATION

1.1 Scope. This specification covers the requirements for electrodeposited chromium plating.

1.2 Classification.

1.2.1 Classes. Electrodeposited chromium plating shall be of the following classes, as specified (see 6.2):

Class 1 - Corrosion protective plating (see 3.3.1)
Class 2 - Engineering plating (see 3.3.2)

1.2.2 Finish. Class 1 plating shall be of the following types of finish, as specified (see 6.2):

Type I - Bright finish
Type II - Satin finish

2. APPLICABLE DOCUMENTS

2.1 The following documents of the issue in effect on date of invitation for bids or request for proposal, form a part of this specification to the extent specified herein.

Federal Specifications

QQ-N-290	Nickel Plating (Electrodeposited)
QQ-S-624	Steel Bar, Alloy, Hot Rolled and Cold Finished (General Purpose)

(Activities outside the Federal Government may obtain copies of Federal Specifications, Standards and Handbooks as outlined under General Information in the Index of Federal Specifications and Standards and at the prices indicated in the Index. The Index, which includes cumulative monthly supplements as issued, is for sale on a subscription basis by the Superintendent of Documents, U.S. Government Printing Office, Washington, DC 20402.

(Single copies of this specification and other Federal Specifications required by activities outside the Federal Government for bidding purposes are available without charge from Business Service Centers at the General Services Administration Regional Offices in Boston, New York, Washington, DC, Atlanta, Chicago, Kansas City, MO, Fort Worth, Denver, San Francisco, Los Angeles, and Seattle.

(Federal Government activities may obtain copies of Federal Specifications, Standards, and Handbooks and the Index of Federal Specifications and Standards from established distribution points in their agencies.)

Military Specifications:

MIL-S-5002	Surface Treatments and Inorganic Coatings for Metal Surfaces of Weapons Systems
MIL-S-13165	Shot Peening of Ferrous Parts
MIL-R-81841	Rotary Flap Peening of Metal Parts

Military Standards:

MIL-STD-105	Sampling Procedures and Tables for Inspection by Attributes
MIL-STD-1312	Fasteners, Test Methods

(Copies of Military Specifications and Standards required by contractors in connection with specific procurement functions should be obtained from the procuring activity or as directed by the contracting officer.)

2.2 Other publications. The following documents form a part of this specification to the extent specified herein. Unless a specific issue is identified, the issue in effect on date of invitation for bids or request for proposal shall apply.

American Society for Testing and Materials (ASTM) Standards:

ASTM B-487	Measurement of Metal and Oxide Coating Thickness by Microscopic Examination of a Cross Section

ASTM B-499	Measurement of Coating Thicknesses by the Magnetic Method: Nonmagnetic Coatings on Magnetic Basis Metal
ASTM B-504	Measuring the Thickness of Metallic Coatings by the Coulometric Method
ASTM B-556	Thin Chromium Coatings by the Spot Test, Guideline for Measurement of
ASTM B-578	Measurement of Microhardness of Electrplated Coatings
ASTM E-8	Tension Testing of Metallic Materials

(Application for copies should be addressed to the American Society for Testing and Materials, 1916 Race Street, Philadelphia, PA 19103.)

3. REQUIREMENTS

3.1 Materials. The materials used shall be such as to produce platings which meet the requirements of this specification.

3.2 General requirements.

3.2.1 High tensile steel parts. Unless otherwise specified (see 6.2), steel parts having an ultimate tensile strength greater than 240,000 psi (1655 MPa) shall not be plated without specific approval of the procuring activity.

3.2.2 Stress relief treatment. All steel parts having an ultimate tensile strength of 150,000 psi (1034 MPa) and above, which are machined, ground, cold formed or cold straightened, shall be baked at a minimum of 375 ±25°F (191 ±14°C) for three hours or more prior to cleaning and plating for the relief of damaging residual tensile stresses. When peening is required (see 3.3.2.3 and 3.3.2.5), thermal stress relief shall be performed prior to shot or rotary flap peening.

3.2.3 Cleaning. Unless otherwise specified (see 6.2), all steel parts shall be cleaned in accordance with MIL-S-5002. Other basis metals shall be cleaned by methods which shall not damage the substrate and shall not interfere with adhesion of the deposit.

3.2.4 Plating application. Unless otherwise specified (see 6.2), the plating shall be applied after all basis metal heat treatments and mechanical operations, such as machining, brazing, welding, forming and perforating of the article, have been completed.

3.2.5 Underplating. Unless otherwise specified (see 6.2), class 1 plating shall be applied over an intermediate plating of nickel in accordance with QQ-N-290 on steel, zinc and zinc-based alloys or copper and copper-based alloys. Unless otherwise specified (see 6.2), class 2 plating shall be deposited on the basis metal without a preliminary plating of another metal. In no case shall any underplate be substituted for any part of the specified chromium thickness.

3.2.6 Embrittlement relief. All coated steel parts having a hardness of Rockwell C40 and higher shall be baked at a minimum of 375 $\pm$25°F (191 $\pm$14°C) for three hours or more, within four hours after plating, to provide hydrogen embrittlement relief (see 6.4). The baked parts, when tested in accordance with 4.5.5, shall not crack or fail by fracture (see 4.4.3.5). Plated springs and other parts subject to flexure shall not be flexed prior to hydrogen embrittlement relief treatment.

3.2.7 Coverage. Unless otherwise specified (see 6.2), the plating shall cover all surfaces including roots of threads, corners and recesses.

3.2.8 Boundaries. Boundaries of class 2 plating which covers only a portion of the surface shall be free from beads, nodules, jagged edges and other irregularities.

3.2.9 Finish. For class 1 plating, the finish or luster shall be as specified (see 1.2.3 and 6.2). Type I of class 1 shall be a fully bright finish, smooth, uniform in appearance and free from frosty areas. Type II of class 1 shall be a satin finish, smooth and uniform in appearance. Unless otherwise specified (see 6.2), either a fully bright or a dull matte finish, smooth and free from frosty areas shall be acceptable for class 2 plating finish.

3.3 Processing.

3.3.1 Class 1 processing. Parts for class 1 deposition shall be plated to specific dimensions as specified (see 3.4.1.1). When specified (see 6.2), parts shall be processed in accordance with procedural instructions for form of chromium deposit (see 6.5).

3.3.2 Class 2 processing. Parts for class 2 deposition shall be plated to specific dimensions as specified (see 3.4.2.1). Unless otherwise specified (see 6.2), steel parts shall be processed in accordance with the procedural instructions of the procuring activity as follows:

3.3.2.1 Class 2a. Parts plated or plated and processed to specific dimensions in accordance with procedures and criteria specified by the procuring activity. Parts not covered by procedural instructions which do not specify baking procedures shall be baked in accordance with 3.2.6 after plating.

3.3.2.2 Class 2b. Plated parts below Rockwell C40 hardness, which are subjected to static loads or designed for limited life under dynamic loads or combinations thereof, need not be peened prior to plating.

3.3.2.3 Class 2c. Plated parts below Rockwell C40 hardness, which are designed for unlimited life under dynamic loads, shall be peened in accordance with MIL-S-13165 or MIL-R-81841 prior to plating. Unless otherwise specified in the applicable drawings, the peening shall be accomplished on all surfaces for which the plating is required and on all immediately adjacent surfaces when they contain notches, fillets or other abrupt changes of section size where stress will be concentrated.

3.3.2.4 Class 2d. Plated parts, Rockwell C40 hardness or above, which are subjected to static loads or designed for limited life under dynamic loads or combinations thereof, shall be baked in accordance with 3.2.6 after plating. The load for the static load test (see 4.5.5, the embrittlement relief test) shall be as specified in the contract, order or applicable drawing (see 6.2).

3.3.2.5 Class 2e. Plated parts, Rockwell C40 hardness or above, which are designed for unlimited life under dynamic loads, shall be peened in accordance with MIL-S-13165 or MIL-R-81841 prior to plating. Unless otherwise specified in the applicable drawings, the peening shall be accomplished on all surfaces for which the plating is required and on all immediately adjacent surfaces when they contain notches, fillets or other abrupt changes of section size where stress will be concentrated. The plated parts shall be baked in accordance with 3.2.6 after plating. The load for the static load test (see 4.5.5, the embrittlement relief test) and the dynamic load conditions shall be as specified in the contract, order or applicable drawing (see 6.2).

3.4 Detail requirements.

3.4.1 Class 1.

3.4.1.1 Thickness. Unless otherwise specified (see 6.2), the minimum thickness of class 1 chromium plating shall be 0.00001 inch or 0.01 mil (0.25 micrometre) on all visible surfaces which can be touched by a ball 0.75 inch (19 mm) in diameter. Unless otherwise specified (see 6.2), holes, deep recesses and other openings, bases of angles, and articles with internal threads from which the external environment is completely excluded and where a controlled deposit cannot be normally obtained shall not be subjected to a thickness requirement but shall show evidence of plating. There shall be no bare areas.

3.4.1.2 Underplating. Class 1 plating is normally used with an underplate system of nickel or copper. Where such requirements exist (see 3.2.5), the underplate thickness shall be in accordance with QQ-N-290. The thickness of the underplate shall not be used in determination of the specified chromium plating thickness.

3.4.1.3 Adhesion. The adhesion of the plating and any underplate shall be such that, when examined at a magnification of approximately 4 diameters, neither the chromium plating nor any electrodeposited underplate(s) shall show separation from the basis metal or from each other at their common interface(s) when subjected to the test described in 4.5.2. The interface between a plating and the basis metal is the surface of the basis metal before plating. The formation of cracks in the plate or the basis metal which does not result in flaking, peeling or blistering of the plate shall not be cause for rejection.

3.4.2 Class 2.

3.4.2.1 Thickness. The minimum, maximum or range of thickness for class 2 plating shall be as specified in the contract, purchase order or on the applicable drawing (see 6.2). If a thickness is not specified, the minimum thickness for the finished part shall be 0.002 inch or 2 mils (51 μm). The thickness requirement for class 2 plating shall apply after all metal finishing and post-plating grinding operations have been completed.

3.4.2.2 Adhesion. The adhesion of the plating and any underplate shall be such that when examined at a magnification of approximately 4 diameters, neither the plating, nor any electrodeposited underplate shall show separation from the basis metal or from each other at their common interface(s) when subjected to the test described in 4.5.2. The interface between a plating and the basis metal is the surface of the basis metal before plating. The formation of cracks in the basis metal or the plate which do not result in flaking, peeling or blistering of the plate shall not be cause for rejection.

3.4.2.3 Hardness. The minimum hardness of a cross-section class 2 plating, when subjected to the microhardness test detailed in 4.5.3, shall be 600 Vickers Hardness Number (VHN) or equivalent if the plating is finished to a semi-bright or matte luster (see 3.2.9). If the plating is finished to a bright or bright pebbly luster, the minimum hardness shall be 850 Vickers Hardness Number (VHN) or equivalent.

3.4.2.4 Porosity. The class 2 plating, by being as free from porosity as possible, shall be capable of protecting the basis metal from corrosion due to pits, pores or cracking. When subjected to the test detailed in 4.5.4, specimens shall show no more than a total of 15 isolated spots or pits, none larger than 1/32 inch (0.79 mm) in diameter, in a total of 150 square inches (967.8 sq. cms) of test area grouped from five or more test pieces; nor more than five isolated spots or pits, none larger than 1/32 inch (0.79 mm) in a total of 30 square inches (193.6 sq. cms) from one or more test pieces, except those areas within 1/16 inch (1.59 mm) from identification markings and contact marks after processing.

3.5 Workmanship.

3.5.1 Basis metal. The basis metal shall be free from visible defects that will be detrimental to the appearance or protective value of the plating. The basis metal shall be subjected to such cleaning and plating procedures as necessary to yield deposits herein specified.

3.5.2 Plating. The plating shall be smooth, fine grained, adherent, uniform in appearance, free from blisters, pits, nodules, excessive edge build-up and other defects. The plating shall show no indication of contamination or improper operation of equipment used to produce the deposit, such as excessively powdered or darkened plating, build-up and other defects. The size and number of contact marks shall be at a minimum consistent with good practice. The location of contact marks shall be in areas of minimum exposure to service environmental conditions where important to the function of the part. Superficial staining which has been demonstrated as resulting from rinsing or slight discoloration resulting from baking operations to relieve embrittlement, as specified above (see 3.2.6), shall not be cause for rejection. All details of workmanship shall conform to the best practice for high quality plating.

4. QUALITY ASSURANCE PROVISIONS

4.1 Responsibility for inspection. Unless otherwise specified in the contract or purchase order, the supplier is responsible for the performance of all inspection requirements as specified herein. Except as otherwise specified in the contract or order, the supplier may use his own or any other facilities suitable for the performance of the inspection requirements specified herein, unless disapproved by the Government. The Government reserves the right to perform any of the inspections set forth in the specification where such inspections are deemed necessary to assure that supplies and services conform to prescribed requirements.

4.2 Classification of inspection. The inspection requirements specified herein are classified as follows:

a. Production control inspection (see 4.3).

b. Quality conformance inspection (see 4.4).

4.3 Production control inspection.

4.3.1 Control records. When specified in the contract or order (see 6.2), the supplier shall maintain a record of each processing bath, showing all additional chemicals or treatment solutions to the unit, the results of all chemical analyses performed, and the quantity of parts plated during operation. Upon request of the procuring activity, such records as well as reports of the test results shall be made available. These records shall be maintained for not less than one year after completion of the contract or purchase order.

4.3.2 Production control. The equipment, procedures and operations employed by a supplier shall be capable of producing high quality electrodeposited platings as specified in this document. When specified by the procuring activity (see 6.2), the supplier, prior to production, shall demonstrate the capability of the process used to show freedom from hydrogen embrittlement damage as indicated by satisfactory behavior of specimens prepared (see 6.2.2) and tested in accordance with 4.3.2.1 to comply to the requirements of MIL-S-5002 for preproduction process qualification.

4.3.2.1 Preproduction control. For preproduction control, four round notched steel specimens shall be prepared in accordance with 4.4.4.3 from four individual heats for a total of 16 specimens, using the specified steel alloy for which preproduction examinations of the process is to be demonstrated. Specimens shall be heat treated to the maximum tensile strength representing production usage. The specimens shall be given the same pretreatments and treatments proposed for production. The specimens shall be subject to the test detailed in 4.5.5. The process shall be considered satisfactory if all specimens show no indication of cracks or failure. The test results and production control information shall be submitted to the procuring activity for approval. Until approval has been received, parts shall not be plated.

4.3.3 Frequency of tests. To assure continuous control of the process as required by MIL-S-5002 and to prevent detrimental hydrogen embrittlement during production, the satisfactory behavior of specimens prepared and tested in accordance with table I shall be made once each month, or more frequently if required by the procuring activity. The results of tests made to determine conformance of electrodeposited platings to all requirements of this specification are acceptable as evidence of the properties being obtained with the equipment and procedures employed.

4.3.4 Production control specimens. Test specimens for production control shall be prepared in accordance with 4.4.4, 4.4.4.1 and 4.4.4.2, as applicable for the thickness, adhesion, hardness and porosity tests detailed in table I. Specimens for the production control embrittlement relief test shall be four round notched steel specimens of alloy steel 4340, conforming to QQ-S-624, heat treated to the maximum tensile strength from one or more heats, and prepared in accordance with 4.4.4.3.

4.4 Quality conformance inspection.

4.4.1 Lot. A lot shall consist of plated articles of the same basis metal composition, class, deposition form and finish, plated and treated under the same conditions and approximately the same size and shape submitted for inspection at one time.

4.4.2 Sampling for visual examination and nondestructive tests. Sampling for visual examination and nondestructive tests shall be conducted as directed by the procuring activity (see 6.2) in accordance with MIL-STD-105 or using table II. A sample of coated parts or articles shall be drawn by taking at random from each lot the number of articles in accordance with MIL-STD-105, Level II, Acceptable Quality Level (AQL) 1.5 percent defective or as indicated in table II. The lot shall be accepted or rejected according to the procedures in 4.4.2.1 for visual examination and 4.4.2.2 for plating thickness (nondestructive tests).

Table I. Production control tests and specimens

Test	For coating classes	Requirement paragraphs	Specimen preparation paragraph 1/	Test reference paragraphs
Thickness	1 and 2	3.4.1.1 and 3.4.1.2 or 3.4.2.1	4.4.4 and 4.4.4.1	4.5.1
Adhesion	1 and 2	3.4.1.3 or 3.4.2.2	4.4.4 and 4.4.4.1	4.5.2
Hardness	2	3.4.2.3	4.4.4 and 4.4.4.1	4.5.3
Porosity	2	3.4.2.4	4.4.4 and 4.4.4.2	4.5.4
Hydrogen embrittlement relief	1 and 2	3.2.6	4.4.4 and 4.4.4.3	4.5.5

1/ Standard alloy steels shall be used for production control specimens. The selection shall be at the option of the supplier; however, alloy steels such as AISI or SAE numbers 4130, 4135, 4140, 4145, 4340, 8645 and 8740 conforming to QQ-S-624 shall be used.

Table II. Sampling for visual examination and nondestructive tests

Number of items in lot inspections	Number of items in samples (randomly selected)	Acceptance number (maximum number of sample items nonconforming to any test)
15 or less	7 1/	0
16 to 40	10	0
41 to 110	15	0
111 to 300	25	1
301 to 500	35	1
501 and over	50	2

1/ If the number of items in the inspection lot is less than 7, the number of items in the sample shall equal the number of items in the inspection lot.

4.4.2.1 Visual examination. Samples selected in accordance with 4.4.2 shall be examined for compliance with the requirements of 3.2.7, 3.2.8, 3.2.9 and 3.5.2 after plating. If the number of nonconforming articles exceeds the acceptance number for the sample, the lot represented by the sample shall be rejected.

4.4.2.2 Thickness of plating (nondestructive tests). Samples selected in accordance with 4.4.2 shall be inspected and the plating thickness measured by the applicable test detailed in 4.5.1 at several locations on each article as defined in 3.4.1.1 and 3.4.1.2 or in 3.4.2.1; as applicable, for compliance with the requirement. Measurements on fastener hardware shall be made on location defined in MIL-STD-1213, Test 12. The part or article shall be considered nonconforming if one or more measurements fail to meet the specified minimum thickness. If the number of defective items in any sample exceeds the acceptance number for the specified sample, the lot represented by the sample shall be rejected. Separate specimens (see 4.4.4.1) shall not be used for thickness measurements unless a need has been demonstrated.

4.4.3 Sampling for destructive tests. A random sample of five plated parts or articles shall be taken from each lot for each destructive test or separately plated specimens shall be prepared in accordance with 4.4.4, 4.4.4.1, 4.4.4.2 and 4.4.4.3 to represent each lot. If the number of articles in the lot is five or less, the number of articles in the sample shall be specified by the procuring activity (see 6.2).

4.4.3.1 Thickness of plating (destructive tests). If sampling and testing for thickness of plating by nondestructive testing is not the option of the supplier, samples selected in accordance with 4.4.3 shall be measured for plating thickness by the applicable tests detailed in 4.5.1 at several locations as defined in 3.4.1.1 and 3.4.1.2 or in 3.4.2.1, as applicable, for compliance with the requirements. Measurements for fastener hardware shall be made at locations defined in MIL-STD-1312, Test 12. If the plating thickness at any place on any article or specimen is less than the specified minimum thickness, the lot shall be rejected. Separate specimens (see 4.4.4.1) shall not be used for thickness measurements unless a need has been demonstrated.

4.4.3.2 Adhesion (destructive tests). The articles or specimens used for the destructive thickness test (see 4.4.3.1), if of suitable size and form, may be used as the test pieces for the adhesion test to determine compliance with the requirements of 3.4.1.3 or 3.4.2.2. Failure of one or more of the test pieces shall constitute failure of the lot.

4.4.3.3 Hardness (destructive tests). When specified in the contract or order (see 6.2), compliance with the requirements for hardness shall be determined. The articles or specimens, used for the destructive thickness test (see 4.4.3.1) if of suitable size and form, may be used for the test pieces for examination to determine compliance with the requirement of 3.4.2.3. Failure of one or more of the test pieces shall constitute failure of the lot.

4.4.3.4 Porosity (destructive tests). When specified in the contract or order (see 6.2), compliance with the requirements for porosity shall be determined. A set of five separate test specimens prepared in accordance with 4.4.4 and 4.4.4.2 in lieu of treated plated articles shall be used to determine compliance with the requirements for porosity (see 3.4.2.4). Failure of one or more of the test specimens shall reject the lot.

4.4.3.5 Hydrogen embrittlement relief (destructive tests). Unless otherwise specified in the contract or order (see 6.2), conformance to the requirements of 3.2.6 for hydrogen embrittlement relief of treated steel parts shall be determined for those parts, comprising a lot, having a tensile strength of or heat treated to a tensile strength level of 240,000 psi (1655 MPa) or above and which will be subjected to a sustained tensile load in use. A random sample of five plated articles shall be taken from each lot or five specimens, prepared in accordance with 4.4.4 and 4.4.4.3 shall be used to represent the lot. When tested as specified in 4.5.5, cracks or failure by fracture shall be cause for rejection. Failure of one or more of the test pieces shall reject the lot.

4.4.4 Quality conformance specimen preparation. When the plated articles are of such form, shape, size and value as to prohibit use thereof, or are not readily adaptable to a test specified herein, or when destructive tests of small lot sizes are required, the test shall be made by the use of separate specimens plated concurrently with the articles represented. The separate specimens shall be of a basis metal equivalent to that of the article represented. "Equivalent" basis metal includes chemical composition, grade, condition and finish of surface prior to plating. For example, a cold-rolled steel surface should not be used to represent a hot-rolled steel surface. Due to the impracticality of forging or casting separate test specimens, hot-rolled specimens may be used to represent forged and cast-steel articles. The separate specimens may also be cut from the scrap casting when ferrous alloy castings are being plated. These separate specimens may be introduced into a lot at regular intervals prior to the cleaning operations, prior to plating and shall not be separated therefrom until after completion of plating. Conditions affecting the plating of specimens, including the spacing, plating media, bath agitation, temperature, etc. in respect to other objects being plated shall correspond as nearly as possible to those affecting the significant surfaces of the articles represented. Separate specimens shall not be used for thickness measurements, however, unless the necessity for their use has been demonstrated.

4.4.4.1 Specimens for thickness, adhesion, and hardness tests. If separate specimens for thickness, adhesion, and hardness tests are required, they shall be strips approximately 1 inch (25 mm) wide, 4 inches (102 mm) long and 0.04 inch (1 mm) thick.

4.4.4.2 Specimens for porosity tests. If separate specimens for porosity tests are required, they shall be panels not less than 10 inches (254 mm) in length, 3 inches (76 mm) in width and approximately 0.04 inch (1 mm) thick.

4.4.4.3 Specimens for embrittlement relief. Separate specimens for embrittlement relief test shall be round notched specimens with the axis of the specimen (load direction) perpendicular to the short transverse grain flow direction. The configuration shall be in accordance with Figure 8 of ASTM E-8 for rounded specimens. Specimens shall have a 60 degree V-notch located approximately at the center of the gage length. The cross section area at the root of the vee shall be approximately equal to half the area of the full cross section area of the specimen's reduced section. The vee shall have a 0.010 ±0.0005 inch (0.254 ±0.0127 mm) radius of curvature at the base of the notch (see 6.2.2).

4.5 Tests.

4.5.1 Thickness. For nondestructive measurement of plating thickness, procedures in accordance with ASTM B-499 (magnetic test method) may be used. For destructive measurement of plating thickness, procedures in accordance with ASTM B-487 (microscopic) or ASTM B-504 (coulometric) may be used. In addition to the above, other procedures embodied in MIL-STD-1312, Test 12, may be used for thickness measurement of plated fastener hardware. Class 1 plating may be measured for thickness in accordance with ASTM B-556 (spot test) within its limitations, as a destructive procedure.

4.5.2 Adhesion. Adhesion may be determined by scooping the surface or shearing with a sharp edge, knife or razor through the plating down to the basis metal and examining at four diameters magnification for evidence of non-adhesion. Alternately the article or specimen may be clamped in a vise and the projecting portion bent back and forth until rupture occurs. If the edge of the ruptured plating can be peeled back or if separation between the plating and the basis metal can be seen at the point of rupture when examined at four diameters magnification, adhesion is not satisfactory.

4.5.3 Hardness. The hardness of class 2 plating shall be determined by a microhardness traverse in accordance with ASTM B-578, except that a Vicker indenter and 100 gram load shall be used. A minimum of three hardness readings shall be made to establish the basis metal hardness in an area at least 0.125 inch (3.175 mm) from the outer surface or at mid radius of the cross section which ever is less. Readings shall be taken at 0.0005 inch (0.013 mm) intervals starting at 0.001 inch (0.025 mm) from the outer surface in a staggered pattern until the pre-established basis metal hardness is reached. The hardness reading may be plotted versus distance from the outer surface. The point at which the hardness shows a vast decrease may be taken as the limits of chromium plating.

4.5.4 Porosity. Prior to determining porosity by the ferroxyl test, the specimen surface shall be cleaned to remove any oil or grease. Contamination removal shall be accomplished with any acceptable solvent in accordance with MIL-S-5002. A sheet of filter paper, saturated by dipping in a ferroxyl solution heated to 180 to 200°F (82 to 94°C), shall be applied to the flat surface of the specimen or of the article. The solution composition shall be as follows:

Potassium ferricyanide ($K_3Fe(CN)_6$)	1 gm.
Sodium chloride (NaCl)	10 gms.
Agar	10 gms.
Water (distilled or deionized) to make	1 litre

After 10 minutes, the heated filter paper shall be removed. Both the plated surface and the filter paper shall be examined. Where corrosion of the basis metal will occur at pores or other defects due to the plating, dark blue spots will have been developed. Contact may further be assured by the use of a soft bristle brush moistened with the reagent solution. For a permanent record, the filter paper can be dried.

4.5.5 Embrittlement relief. Compliance with 3.2.6 shall be determined with samples of plated parts taken as specified in 4.4.3.5. Parts such as spring pins, lock rings, etc., which are installed in holes or rods, shall be similarly assembled using the applicable parts specifications or drawings tolerances which impose the maximum sustained tensile load on the plated part. The selected samples shall be subjected to a sustained tensile load equal to 115 percent of the maximum design yield load for which the part was designed. Parts which require special fixtures, extreme loads to comply with the above requirements, or where the maximum design yield load is not known, may be represented by separate specimens prepared in accordance with 4.4.4.3. The notched samples shall be subjected to a sustained tensile load equal to 75 percent of the ultimate notch tensile strength of the material. The articles, parts or specimens shall be held under load for at least 200 hours and then examined for cracks or fracture.

5. PREPARATION FOR DELIVERY

5.1 Packaging and packing. Preservation, packaging and packing methods for electrodeposited plated parts or articles employed by a supplier shall be such as to preclude damaging during shipment and handling.

6. NOTES

6.1 Intended use.

6.1.1 Class 1 plating. Class 1 plating is applied as a decorative finish, usually over nickel, or copper and nickel, on basis metals such as iron and steel, copper and copper-base alloys, and zinc and zinc-base diecasting where necessary to protect the basis metal from corrosion and wear and to provide a pleasing appearance. The function of the underlayers of nickel is to provide a pore-free continuous underplate for the chromium outer layer. Generally, the thicker the nickel layer, the better the corrosion resistance. The systems of an outer layer of chromium over the combined plated nickel and copper are generally used in a combined total thickness of 0.0001 to 0.002 inch (2.5 to 51 µm) depending upon service conditions and the basis metal.

6.1.1.1 Chromium platings 0.0005 inch (13 µm) or more in thickness are likely to crack nickel plating on brass basis metal. The minimum thickness of chromium should be obtained under conditions such that the maximum thicknesses are less than 0.00005 inch (1.3 µm).

6.1.2 Class 2 plating. Class 2 plating, also known as "industrial chromium" or "hard chromium", is used for wear resistance, abrasion resistance and such incidental corrosion protection of parts as the specified thickness of the plating may afford. Engineering chromium is usually applied directly to the basis metal and is finished by grinding to the specified dimensions. It lacks the brightness of class 1 plating. Additional corrosion resistance can be obtained by use of an undercoat of electrodeposited nickel in thickness of 0.001 to 0.002 inch (25 to 51 µm) on ferrous parts, the minimum thickness to be determined by service conditions. Heavy deposits of the class 2 plating may be used for buildup of worn or undersized parts, or for salvage purposes, and to provide protection against corrosive chemical environments. Final grinding of the chromium plating can increase the number of cracks in the deposit. For greater corrosion resistance, based upon equal thickness, unground deposits should be selected rather than ground deposits.

6.2 Ordering data. Purchasers should select the preferred options permitted herein and include the following information in procurement documents.

a. Title, number, and date of this specification.

b. Class of plating (see 1.2.1, 3.3.1, 3.3.2, 3.3.2.1, 3.3.2.2, 3.3.2.3, 3.3.2.4 and 3.3.2.5).

c. Deposition and finish, if applicable (see 1.2.2, 3.2.9 and 3.3.1).

d. When plating is to be applied, if other than specified (see 3.2.1, 3.2.4, 3.3.1, 3.3.2, 3.3.2.1, 3.3.2.2, 3.3.2.3, 3.3.2.4 and 3.3.2.5).

e. Cleaning of steel, if other than specified (see 3.2.3).

f. Underplating, if other than specified or required (see 3.2.5).

g. Coverage, if other than specified (see 3.2.7).

h. Surface finish; if particular finish required (see 3.2.9).

i. Thickness of plating, as specified (see 3.3.1, 3.3.2, 3.3.2.1, 3.4.1.1, 3.4.1.2, and 3.4.2.1).

j. Control record requirement (see 4.3.1).

k. Preproduction control examination (see 4.3.2).

l. Sampling plan (see 4.4.2).

m. Number of samples for destructive testing (see 4.4.3).

n. Hardness, porosity and hydrogen embrittlement tests, whether required for quality conformance inspection (see 4.4.3.3, 4.4.3.4 and 4.4.3.5).

6.2.1 The manufacturer of the basis metal parts should provide the plating facility with the following data:

a. Hardness of steel parts (see 3.2.1, 3.2.2, 3.2.6 and 3.3.2).

b. Heat treatment for stress relief, whether has been performed or is required (see 3.2.2).

c. Tensile loads required for embrittlement relief test, if applicable (see 3.2.6 and 4.5.5).

6.2.2 The manufacturer of the basis metal parts should provide the plating facility with notched specimens (see 4.4.4.3) to be plated for conformance with 3.2.6 required for production control (see 4.3.2.1 and 4.3.4) and for lot acceptance (see 4.4.3 and 4.4.3.5).

6.3 Stress relief. There is a hazard that hardened and tempered cold-worked or cold-straightened steel parts may crack during cleaning and plating. Such parts shall have a suitable heat treatment for stress relief prior to cleaning and plating (see 3.2.2).

6.4 Baking time. For high strength materials (Rockwell C40 and above), it may be beneficial to extend the baking time to 23 hours to insure complete hydrogen embrittlement relief (see 3.2.6).

6.5 Class 1 processing. Class 1 chromium plating may be processed for the following forms of deposition:

R- Regular or conventional
MP- Micro-porous
MC- Micro-cracked

Generally, a nominal coating thickness, approximately 0.00001 inch (0.01 mil or 0.25 μm) is used for all forms of the chromium deposition. The thickness of Form R plating should not exceed 0.00002 inch (0.02 mil or 0.51 μm) as the resultant chromium coating tends to crack spontaneously. Form MP deposition should contain a minimum of 64,500 pores per square inch (100 pores per square millimetre), invisible to the unaided eye. Form MC desposition should have more than 750 cracks per inch (80 cracks per millimetre) in any direction over the significant surfaces.

6.5.1 Correlation. The correlation between the chromium plating forms and the grades and forms of nickel deposition as detailed in QQ-N-290 are indicated in table III.

6.5.2 Determination of deposition form. The micro-porous or micro-cracked deposition characteristic can be determined by examination of electrodeposited copper at discontinuities in the unbuffed chromium plated surfaces. The color contrast between the smallest dot or streak of copper and the surrounding chromium can be readily observed.

6.5.2.1 Preparation. All cut edges and those surfaces of selected specimens which are not chromium plated should be masked with a pressure sensitive PVC tape conforming to HH-T-0025, Tape, Pressure-Sensitive Adhesion, Plastic (For Electroplating). The conductor (wire, rack or hook)which will carry the current to the specimen while copper plating should also be masked below the plating bath level, except where electrical contact is made with the specimen. The masked specimen should be cleaned by soaking in a hot alkali cleaner until the chromium plated surface is free from water breaks after thorough rinsing in cold water and dipping in a 5 percent sulfuric acid solution. Gentle brushing the plated surface with a soft brush, while in the cleaner, can be helpful.

6.5.2.2 Copper deposition. When the specimen is immersed in a solution whose composition is as follows, the current should be on:

Copper Sulfate ($CuSO_4 \bullet 5H_2O$)- 28 to 32 oz/gal (210 to 240 gm/l)

Sulfuric Acid (H_2SO_4) - 6 to 8 fl oz/gal (47 to 62 ml/l)

Table III. Correlationship of Class 1 chromium plating deposition and Class 1 nickel plating grades and deposition

Grades of Nickel Deposition (See QQ-N-290)	For Steels, Zinc and Zinc Alloys		For Copper and Copper Alloys	
	Nickel 1/ (See QQ-N-290)	Chromium	Nickel 1/ (See QQ-N-290)	Chromium
A	M and SD	R	-	
B	M	R, MP and MC	M and SB	R
	SD	MP and MC		
C	M	MP and MC	M	R, MP and MC
			SD	R
			SB	MP and MC
D	SB, M and SD 2/	R	M and SD	MP and MC
E	SB, M and SD 2/	MP and MC	SB, M and SD 2/	R
F	SB, M and SD 2/	R, MP and MC 3/	SB, M and SD 2/	MP
G	-	-	SB, M and SD 2/	R, MP and MC 3/

1/ Where a dull or satin-like finish is required unbuffed SD nickel may be substituted for SB nickel or for the bright layer of M nickel.

2/ SD or M nickel deposition may be substituted for SB nickel deposition where the nickel-chromium system is subjected to mild or moderate service conditions.

3/ MC or MP chromium deposition may be substituted for R chromium deposition where the nickel-chromium system is subjected to mild service conditions.

Brightness and additional agents should be used in the plating bath for the purpose of brightening the deposit as detailed above in 6.5.2. Operating conditions should be as follows:

Temperature	- Room (65 to 75°F or 18 to 24°C)
Current density	- 3 amperes per square foot (0.32 amperes per square decimetre)
Time	- 15 minutes
Anode	- Copper (conforming to QQ-A-673)

The specimen should be removed, carefully rinsed in cold water, then hot water and allowed to dry. Where the pores or cracks will be counted, the specimens should not be wiped. Copper nodules, deposited at the sites, are not firmly attached. Any physical contact after plating may remove some of the copper depositions and cause erroneous results. Photomicrographs may be used for determining the deposition forms and they could be prepared in accordance with ASTM E2, Micrographs of Metals and Alloys (Including

Recommended Practice for Photography as Applied to Metallography). The number of pores or the number of cracks may be estimated by counting on a ground-glass screen, on a photomicrograph of a representative field of the specimen, or on the specimen itself. A circle or rectangle of known area (such as 100 square mm to simplify calculations) on a micrograph or on the ground-glass screen of the metallograph can be inscribed. The selected magnficiation, usually about 100X, should be suitable to properly count the pores or cracks for observation of any limitations permitted for deposition.

Custodians:
Army - MR
Navy - AS
Air Force - 11

Preparing activity:
Navy - AS
(Project No. MFFP-0078)

Review activities:
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Navy - OS
Air Force - 84, 70
Defense Supply Agency - IS

User activities
Army - AT, GL
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(See Instructions – Reverse Side)

1. DOCUMENT NUMBER	2. DOCUMENT TITLE

3a. NAME OF SUBMITTING ORGANIZATION	4. TYPE OF ORGANIZATION *(Mark one)*
	☐ VENDOR ☐ USER ☐ MANUFACTURER ☐ OTHER *(Specify)*: ______
b. ADDRESS *(Street, City, State, ZIP Code)*	

5. PROBLEM AREAS

a. Paragraph Number and Wording:

b. Recommended Wording:

c. Reason/Rationale for Recommendation:

6. REMARKS

7a. NAME OF SUBMITTER *(Last, First, MI)* – Optional	b. WORK TELEPHONE NUMBER *(Include Area Code)* – Optional
c. MAILING ADDRESS *(Street, City, State, ZIP Code)* – Optional	8. DATE OF SUBMISSION *(YYMMDD)*

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SUBSTITUTION PLAN

Public Version

Legal name of applicants:	Ideal Standard Produktions-GmbH Ideal Standard - Vidima AD
Submitted by:	Ideal Standard - Vidima AD
Date:	08.12.2020
Substance:	Chromium trioxide, EC No: 215-607-8, CAS No: 1333-82-0
Use title:	Electroplating of different types of substrates using chromium trioxide to achieve functional surfaces with high durability and a bright or matt silvery appearance for sanitary applications
Use number:	1

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DECLARATION

The Applicants *Ideal Standard Produktions-GmbH* and *Ideal Standard – Vidima AD* are aware of the fact that evidence might be requested by ECHA to support information provided in this document.

Also, we request that the information blanked out in the public version of the Substitution Plan is not disclosed. We hereby declare that, to the best of our knowledge as of today (30.11.2020) the information is not publicly available, and in accordance with the due measures of protection that we have implemented, a member of the public should not be able to obtain access to this information without our consent or that of the third party whose commercial interests are at stake.

Signature:

Date, Place: 30.11.2020, Wittlich

Name: Stefan Thul

Titel: Technical Leader (TEF)

Company: Ideal Standard Produktions-GmbH

LIST OF ABBREVATIATIONS

ABS	Acrylonitrile-Butadiene-Styrene
AfA	Application for Authorization
AoA	Analysis of Alternatives
BAM	Federal Institute for Materials Research and Testing
Cr(III)	Trivalent Chromium, Chromium (III)
Cr(VI)	Hexavalent Chromium, Chromium (VI)
CrO3	Chromium Trioxide
CTAC	Chromium Trioxide Authorisation Consortium
ECHA	European Chemicals Agency
FuSchiDec	Working group Funktionale Schichten mit dekorativem Charakter
ISO	International Organization for Standardization
PL	Project Leader
PVD	Physical Vapour Deposition
R&D	Research and Development
REACH	Registration, Evaluation, Authorisation and Restriction of Chemicals, Regulation 1907/2006, as amended
SST	Salt Spray Test

1. INTRODUCTION

In 2018, the applicants, Ideal Standard Produktions-GmbH and Ideal Standard - Vidima AD (further referred to as Ideal Standard), submitted an Application for Authorisation (AfA) for the continued use of chromium trioxide (CrO_3) in electroplating of metal (brass) and plastic (Acrylonitrile-Butadiene-Styrene, ABS) substrates for sanitary applications. Chromium trioxide is currently used at the applicant's production sites in Wittlich (Germany), Sevlievo and Gradnitsa (Bulgaria).

The basic technology for functional chrome plating with decorative character comprises a process chain and can be divided in three sub-processes: the pre-treatment, the main process and the post- treatment (refer to the Analysis of Alternatives (AoA), chapter 3.2). Depending on the substrate treated, in either one or two process steps chromium trioxide is used. For metal substrates, only the main process is dependent on the substance, while for plastic substrates also the pre-treatment requires chromium trioxide for an adequate etching of the surface. Importantly, these two different steps in the electroplating process are strongly interlinked. Only the combination of an adequate pre-treatment together with the following electroplating steps guarantees the necessary coating performance of the final product. Hence, both were discussed in two different uses in the submitted AfA. An authorisation decision by the European Commission is still pending. In a letter dated from 8th June 2020 the European Commission has requested the applicant to submit a substitution plan which is hereby presented. According to the statement of the European Commission, use 2 describing the pre-treatment to electroplating processes has a different scope and associated analysis of alternatives and therefore is not affected by the request of the present letter.

In the sanitary sector, electroplating is used to achieve a high-quality surface with excellent durability in contact with aggressive and demanding environmental conditions and at the same time has a high aesthetic and decorative value. The finishes have a bright or matt silvery appearance. The metallic chrome layer is applied as final coating on top of a multi-layer system and the combination of underplates is responsible for the final appearance (bright or matt) of the top coating as well as for the even surface. The underplates vary depending on the different required functionalities of the final product and the used substrate.

The applicant is working toward a substitution and transition to hexavalent chromium (Cr(VI))-free surface treatment of sanitary applications. However, this is a complex and lengthy process where several factors need to be considered. The applicant's development and implementation process is separated in different phases presented and described in more detail in this substitution plan (chapter 3).

Identification of possible alternatives

The usage of chromium trioxide in electroplating for sanitary applications has multiple advantages, which are mainly based on the unique characteristics of the hexavalent chromium compound. These for example are the valuable properties of the metallic chrome layer for sanitary applications such as among others corrosion resistance, wear resistance, adhesion and chemical resistance (refer to AoA, chapter 3.3). These numerous beneficial properties of metallic chrome coatings created from chromium trioxide are critical for sanitary applications and have made this compound the state-of-the-art substance.

Importantly, all key functionalities mentioned in the AoA and related minimum requirements are highly interconnected with each other. Therefore, it is mandatory that a potential alternative sufficiently fulfils every single minimum requirement to achieve a high-quality surface under the conditions of use and subsequently to prove suitability of the alternative technology.

In the AoA which is part of the AfA submitted in 2018 by the applicant, a comprehensive assessment against the key functionalities was performed. The applicant presented detailed technical and economic information for three most promising alternative technologies for the Cr(VI)-based electroplating (refer to AoA, chapter 6.2). None of them were equipped with the required combination of technical performance at the current stage.

The most promising alternatives to the hexavalent chromium electroplating process found during the assessment were trivalent chromium electroplating (Cr(III)-based electroplating) and two variants of processes based on physical vapour deposition (PVD). However, these two technologies Cr(III)-based electroplating and PVD-based processes differ fundamentally. Cr(III)-based electroplating is a galvanic process similar to Cr(VI)-based electroplating. Importantly, an etching process was still required for this alternative, which is based on Cr(VI) so far. In order to develop a completely Cr(VI)-free method, a suitable etching alternative needs to be developed. Potential alternatives to etching of plastics were discussed in Use 2. The PVD-based processes do not require chemical etching pre-treatment but use a completely different coating technology based on vacuum process (refer to AoA, chapter 6.2.2 and 6.2.3 for process details). The outcome of the alternative assessment presented in the AfA submitted in 2018 is shown in the following Table 1.

Table 1: Most promising alternatives for the Cr(VI)-based electroplating with colour-coded technical assessment criteria with available information.

Alternative method	Technical key functionalities								
	Corrosion resistance	Wear resistance / abrasion resistance	Adhesion	Chemical resistance	Substrate compati-bility	Temperature change / heat resistance	Colour consistency	Surface appea-rance	Process conditions
Trivalent chromium electroplating		varying, mostly failed		varying, mostly failed					
PVD-based processes: PVD metal						depending on deposited metal	depending on deposited metal		
PVD-based processes: Lacquer + PVD + lacquer				depending on deposited metal	depending on substrate			depending on deposited metal	

Red = not sufficient; Yellow = parameters/assessment criteria fulfilment not yet clear; Green = sufficient; Colourless = no data.

As the applicant demonstrated in its AoA in 2018, none of the assessed technologies was able to compete with the performance of electroplating using chromium trioxide for applications in the sanitary sector. Hence, the applicant continued supporting R&D activities related to Cr(III)-based electroplating in close collaboration with the chemical supplier by testing the process and coated products to further improve the coating properties and fulfil the required key functionalities.

Although defined as shortlisted alternatives, both PVD-based processes already possessed several technical and economic limitations 2 years ago especially related to process conditions, corrosion and wear resistance. Further limitations were very high investment and production costs as well as uncertainties regarding availability of PVD machines and applicability to the broad product spectrum in the sanitary sector. Trivalent chromium electroplating already showed satisfying results for some of the key functionalities such as for adhesion and substrate compatibility. Furthermore, it is a similar galvanic process and has the potential of comparable performance. Hence, it was considered the most promising and favoured alternative for sanitary applications. The main focus of R&D efforts by the applicant has been placed on this alternative in order to replace chromium trioxide for functional chrome plating for its applications. PVD-based coatings will most probably only be used for niche products of small series possessing e.g. special colours and therefore being not the main topic of R&D activities according to the development of a suitable alternative to Cr(VI)-based electroplating.

Information on R&D activities since November 2018 and the impact of R&D results on the substitution of chromium trioxide in electroplating processes are given in chapter 2 of this substitution plan. Furthermore, the applicant elaborated a timeline comprising six different phases describing substitution activities. Please note that these activities and the timelines are based on the assumption that an alternative is available and leads to satisfying coating properties sufficiently fulfilling the requirements for sanitary applications.

Importantly, in order to reach coating properties comparable with Cr(VI)-based coatings, more R&D effort both at the side of the applicant and the chemical supplier is necessary for achieving the key functionalities defined by the applicant for its products and demanded by its customer. With this substitution plan the applicant further wants to present its engagement regarding a future substitution towards Cr(VI)-free coatings.

2. FACTORS AFFECTING SUBSTITUTION

As already mentioned above, trivalent chromium electroplating is the most promising alternative for sanitary applications. Hence, the applicant spent a lot of effort in R&D activities in close collaboration with the chemical supplier ([redacted]) towards this alternative. Therefore, when describing factors affecting substitution (chapter 2) and later on the timeline of actions required for substitution (chapter 3), it will be focused on this type of alternative.

Trivalent chromium electroplating is based on the same technology as the currently used process based on hexavalent chromium where similar equipment with wet-in wet bath technology is used (though plating lines and wastewater treatment must be expanded). Therefore, this alternative is technically the closest drop-in alternative. Nevertheless, the transition from hexavalent to trivalent chromium electroplating cannot simply be performed by changing the electrolyte. Before, comprehensive analyses of the influence on quality and performance of the final multi-layer system including the chromium top layer when using different types of substrates must be performed.

The applicant has been very engaged in these testings and already presented several results in the AoA submitted in 2018. Trivalent chromium coatings were applied on plastic and metal substrates and tested against key functionalities for the assessment of alternatives to Cr(VI)-based electroplating described in the AfA.

At that time, test results showed that Cr(III)-based electroplating was not yet a technical feasible alternative for the substitution of chromium trioxide in the sanitary industry. Therefore, the applicant cooperated in further R&D activities with the supplier in order to improve the coating properties in the last 2 years. Although new insights and progress could be gained it was still not possible to sufficiently fulfil the requirements of several key functionalities compared to hexavalent chromium electroplating e.g. related to corrosion and chemical resistance or colour consistency. Furthermore, products [redacted]. One of the largest technical challenges, which still could not be solved in collaboration with the chemical supplier, is that Cr(III)-based coatings suffer from bath impurities. These mainly involve foreign metal ions coming for example from the racks, the brass substrate or the production surroundings. Foreign metal ions might be embedded in the coating and can influence the surface appearance (yellowish/brownish shade of the coating colour resulting from corroded iron ions). This inconsistency in colour makes the assembly of different parts more difficult especially for the applicant's customers. Additionally, the longer the Cr(III)-based electrolyte solution is used, the more accumulation of impurities in the bath occurs, which have an influence on the final colour of the product. Finally, the yellowish colour may also appear for example after long transport times of plated parts, even though the products have left the production facility with an adequate colour.

Longevity, which is considered as well as a very important criterion, cannot be estimated correctly for "real" applications based on laboratory analyses. Hence, field tests are required. Due to the water's fundamental impact on public health, products being in contact with drinking water are subject to national and international regulation. Hence, nickel leaching is an important key functionality especially for the sanitary industry that manufacturers parts in contact with drinking water. Importantly, leaching occurs (if at all) over a longer period of time depending on corrosion effects of the coated surface. As long-term testings will first be started when the alternative coating fulfils the requirements, testing of nickel leaching can only be tested when the final Cr(III)-based coating has been identified. Generally, testing for nickel leaching takes approximately two years including subsequent testings of two parts (one year for each part considering waiting periods at laboratories, the actual testing of ca. 6 months and the finalization of the final reports).

Cr(III)-based electroplating techniques and different kinds of electrolytes have already been commercially available for several years and therefore also in 2018 when the applicant submitted the AfA for CrO_3. However, the Cr(III)-coated parts for sanitary purposes which are available on the market do not comply with the applicant's requirements and customer demands illustrated in the AoA, such as the longevity of parts. Despite the increasing efforts in R&D and performance improvements during the last years, Cr(III)-plated parts are still not qualitatively comparable to Cr(VI)-plated parts for sanitary applications. Critical quality requirements are not fulfilled for example in long-term high-quality applications such as hotels where installations are highly frequented and intensively cleaned regularly so that technical limitations become even more obvious after a short time. This is not acceptable for the applicant's customers. Importantly, it is not expected that customer will change their purchase behaviour in the near future especially when there is a demand for long-term stable and robust surfaces for sanitary products. It is more likely that, when Cr(VI)-coated parts are not available in the EU anymore, they will prefer to import products based on hexavalent chromium from non-EU-countries. Independently, products must comply with e.g. the drinking water directive. Furthermore, the applicant is bound to contracts and legal obligations. On the one hand, Ideal Standard underlays sales contracts stipulating a certain time period of guaranteed delivery. On the other hand, there are spare part obligations due to which it is forced to deliver parts of same quality for at least 5 years. At the current stage, this cannot be ensured with trivalent chromium electroplating.

Exchanging the Cr(VI)-based process with Cr(III) electrolytes comes along with important process changes that will influence the economic feasibility. Although Cr(III)-based electroplating is based on the same technology (i.e. galvanic process), extensive modification work on the current plating line will be required. Hence, additional plating and rinsing baths, additional wastewater treatment measures and additional process equipment for the cooling of Cr(III) baths must be acquired. Additionally, technical re-constructions for the automatic movement of parts along the galvanic baths must be considered (refer to AoA, chapter 6.2.1.3).

Operational costs such as higher chemical costs, lower production outputs, higher scrap rates and analytical efforts will arise when hexavalent chromium electroplating is replaced by trivalent chromium electroplating. Considering the whole process, costs per part are estimated to be [redacted] higher with Cr(III)-based coatings. Since organic complexing agents are used during this alternative technology additional wastewater treatment measures might be required because they are likely to interfere with the current system. It is worth mentioning that there are also some benefits when transition will be carried out such as less air emissions, less toxic mists (which is already at the limit of quantification) and reduced costs for disposal due to less sludge production. However, the significant investments should not be neglected (refer to AoA, chapter 6.2.1.3).

In conclusion, the applicant continued tests and supporting R&D activities in close collaboration with the chemical supplier to improve the coating properties of the most promising alternative Cr(III) electroplating. Considering the above described newer tests, Cr(III)-based coatings can still not be produced in the required quality and reveal limitations related to the process transition and the surface properties showing insufficient coating properties for applications in the sanitary sector. **Please note that in 2020 the Corona pandemic had a significant impact on the applicant's activities and investments** especially related to the research area and the efforts on development activities towards suitable alternatives for hexavalent chromium electroplating. External workers e.g. from the formulator or the plating line supplier were not allowed to enter the site and travelling to formulators was not allowed. To conclude, all activities and tasks described in the R&D plan for 2020 had to be shortly postponed and it cannot be predicted when this pandemic will be overcome. It will certainly throw the applicant’s R&D progress back and also depends on the circumstances present at the chemical supplier. The current situation therefore results in a shift of possible investments and hence to a prolongation of the time needed to fully replace chromium trioxide.

Therefore, more research activities to finally receive an adequate coating alternative to Cr(VI)-based electroplating are needed in the future. Testings with new developments from chemical suppliers and process development must continue. Thereby, development and potential implementation of the alternative will be supported by the applicant, particularly with respect to the most promising sulphate-based Cr(III) electrolytes.

3. LIST OF ACTIONS AND TIMETABLE WITH MILESTONES

The substitution of hexavalent chromium electroplating is a lengthy process and comprises several different activities among others the development including several testing series, technical implementation and market introduction. Based on the current knowledge and its R&D activities, the applicant elaborated a timeline for the substitution of chromium trioxide in functional chrome plating with decorative character for sanitary applications (Figure 1). This timeline comprises six phases which refer to research activities up to the final market introduction of the currently most promising alternative being trivalent chromium electroplating. Importantly, as the timeline represents the best-case scenario, there are clear aspects that show that a review period of at least 12 years is needed until substitution of chromium trioxide in plating of sanitary goods can be achieved. Additionally, especially the first phase describing R&D activities does not only depend on the progress related to the plating of metal and plastic substrates, but also on the progress of R&D activities related to alternatives for the etching pre-treatment of plastic substrates (these two steps are strongly interconnected and should be considered together).

Phase 1: Development / Trials / Risk Analysis (at least 2 years)

Any potential alternative must sufficiently fulfil every key functionality to achieve a high-quality surface under the conditions of use. Therefore, the potential of the most suitable alternative and the accompanied risk regarding technical performance, market implementation and regulatory compliance is being evaluated carefully during this first phase of the timeline (at least 2 years including shifts and delays due to the Corona pandemic).

As the applicant in general is a downstream user of chromium trioxide and relevant alternatives, it strongly depends on the formulator and its development activities with respect to alternative chemicals and therefore being the driving force in this process. Nevertheless, the applicant strongly cooperates with the formulators and supports their activities where possible, e.g. by providing feedback on tests conducted with the alternative in-house.

During an extensive alternative assessment which was demonstrated in the AoA submitted in 2018, the applicant elaborated the general feasibility of three potential alternatives. While the two PVD-based technologies possessed limitations according to the key functionalities, costs and availability, these might most probably only be applicable for niche products. Therefore, further research in order to develop and improve the most suitable alternative for hexavalent chromium electroplating (Phase 1) will mainly focus on trivalent chromium electroplating.

In order to further improve the most suitable alternative (Cr(III)-based electroplating), the most common method is to vary different parameter (e.g. electrolyte composition, process parameter) and investigate the influence on the performance of the resulting coating. Variations in the past and planned for the future include for example the type and composition of the layer system, the composition of different electrolytes (e.g. chloride- and sulphate-based systems) and the process parameter. The latter one comprises for example the variation of exposure duration of parts to be coated in the plating bath, temperature, current density and electrolyte concentration. Different additives and the insertion of foreign metal ions into the final chromium layer must be considered as well. It is important to prove every type of variation by performing comparative tests. For the development of the Cr(III)-based plating alternative of plastics, which is one of the substrate types the applicant uses, some of the experiments are carried out in combination with a Cr(VI)-free pre-treatment alternative. With this, it is more complex to adjust the surface properties and simultaneously not being impaired by the alternative pre-treatment.

Beside cooperation with its formulators, the applicant further is member of several working groups like the FuSchiDec (Funktionale Schichten mit dekorativem Charakter) and CTAC (Chromium Trioxide Authorisation Consortium) groups (both founded in 2012, see AoA chapter 5.1). Within these groups it cooperates with other companies from the sanitary industry. Furthermore, the applicant is member of the European manufacturer’s association CEIR (The European Association for the Valve Industry) and works as well as with external and internal laboratories for analyses of test samples. In addition, the applicant is always interested in new cooperation in order to push the improvement of promising alternative coatings.

Although, risk analyses according to the transition from hexavalent chromium electroplating to an alternative technology are mostly finalized, development and optimization of coating properties needs more time.

It is again worth mentioning, that the Corona pandemic arising in the beginning of 2020 had a significant impact on the applicant's activities and investments especially related to the research area and the efforts on development activities towards suitable alternatives for hexavalent chromium electroplating (see chapter 2).

Phase 2: Process Development In-house (at least 4 Years)

The process has to be developed in-house in close collaboration with the alternative supplier. This step includes initial tests and process adjustments depending on results of the sample parts. Importantly, the applicant is only user of the alternative and strongly relies on input from the supplier (at least 4 years).

More precisely, the process development includes to produce a coating using the alternative technology in a pilot plating line or one of the present plating lines, if possible. As the implementation of a pilot line including rinsing baths, ion exchanger, laboratory analytics etc. accompanies with the need of free space, this might be a problem. Therefore, in order to avoid the construction of a cost-intensive new production hall, it might be possible to build up a smaller version. In general, this is a very time- and cost-consuming phase because on the one hand capacities such as staff, laboratories and test capacities, certifications and raw material must be provided and externally requested (which is challenging in times of the Corona pandemic). On the other hand, the development most likely comprises several rounds in order to finely adjust the process. The possible workflow might be as follows:

1. <u>Set-up of process parameters</u>	Including adjustments on the system and bath compositions
2. <u>Definition of the current status</u>	Including external analyses which entails additional costs and potentially long duration to receive results
3. <u>Preparation of parts to be coated</u>	Including trackable labelling
4. <u>Test series of alternative coatings</u>	Several tests might be required for simulation of e.g. production conditions, carryover effects from bath to bath and different product types
5. <u>Testings of coating properties</u>	Internal and external testings of key functionalities according to the testing strategy of the applicant (refer to AoA, chapter 3.3) first testing adhesion and wear / abrasion resistance and corrosion resistance
6. <u>Evaluation</u>	Assessment of results
7. <u>Repeating of workflow</u>	If necessary, parameters must be adjusted and workflow starts from the beginning

The time-determining step during this workflow and process development comprises external laboratory analyses and to verify the selection of an adequate formulation most suitable for the applicant’s requirements identified in phase 1. According to the latter one, the selection of the right formulation is not a trivial task because their properties differ depending on the respective supplier and therefore different efforts for the final switch-over of the plating systems come along with it.

In case of a transition to a Cr(VI)-free alternative, specialized staff is required. Own staff must be trained potentially generating staffing shortage at other working places, or specialists that are only rarely available on the market must be employed leading to additional costs, e.g. for training purposes. As soon as a pilot line is in place, the current technical staff will be introduced in the tasks on the alternative technology e.g. including analytics and maintenance work.

Phase 3: Long-term Testing – at Single Customer Level; for Certification for Conformity with Drinking Water Directive (2 – 4 Years)

The sanitary sector comprises a very time-consuming development and implementation process both from a technical and regulatory point of view. Long-term tests have to be developed for all parts, e.g. with respect to nickel leaching (drinking water directive) or new materials in contact with drinking water. "Real-life" tests in a small series at single customer level are performed in order to evaluate the performance of products under typical conditions of use and identify significant technical limitations. Depending on obtained results, the process is adapted, and re-testing is performed until sufficient performance to meet the requirements of the sanitary sector is obtained (2 – 4 years).

In general, long-term testings can be performed in two different ways, laboratory-based testings and field tests providing results under "real" conditions. Laboratory-based testings can already be performed during phase 1 when single key functionalities should be analysed over a longer period of time. Therefore, sample parts are prepared and both, internal and external laboratory analyses are carried out. In case of transition to trivalent chromium alternative and when several other competitors also need to switch to this technology, capacities from external laboratories might become less and time for receiving testing results might increase. Field tests are first started when laboratory testings provide satisfying results for the requirements of the different key functionalities. The advantage of this approach is to receive reliable results of the coatings under "real" conditions at an early stage of development and not when the coating was already introduced to the market. This would avoid customer complaints and a loss of image due to deficient parts placed on the market. Additionally, the applicant receives a certainty for decision-making processes prior to significant investments.

Despite the importance of long-term testings, the duration of these tests must be taken into account. While laboratory-based long-term testings only take several weeks to months, field tests generally take several years. Hence, it is of utmost importance that previous R&D

investigations were performed conscientious and precisely and the alternative process is operating very stable especially under series production conditions. Otherwise, the risk of time and economic losses increases significantly. The most critical aspect in this scenario would occur when requirements of key functionalities are not met under “real” conditions and larger adjustments in several runs have to be done in order to improve results.

For analyses of single properties, in case they fulfil the requirements sufficiently, it might be possible to start long-term testings at an earlier stage in order to stay on schedule. This will only be an option, when the applicant is convinced that one or more of the key functionalities has reached its maximum performance and possesses reliable and satisfying results during the R&D phase.

The number of tested products during a field test depends on the extent of the project. The best case for example is reflected by investigating parts in hotels where the number of tested products is large enough to receive reliable and comparable results. In general, larger projects also possess larger risks. This is because the applicant is bound to provide spare parts if required and their number as well as the probability that this happens increases with a larger number of test parts. However, only selected (and well pre-tested) products are used within field tests.

Within the long-term testings, either laboratory-based or field testings, compliance and certification for conformity with drinking water directive is very important. This includes binding specifications rather to material than to surface coatings, but is indispensable before products can be introduced to the market (the applicant, as a producer of sanitary products, is responsible for compliance of produced parts with legal obligations). This can only be verified officially at one of the responsible admission offices. In this context, it is important to mention that the drinking water directive is regularly revised implying uncertainties for the applicant with respect to future requirements.

Phase 4: Technical Modification of Production Site (4 – 6 Years)

Technical modification of the production site can be initiated gradually as soon as the process is under control and the coatings are accepted by customers. Besides the actual reconstruction measures of the production site this step may comprise approval procedures (permission) for the reconstruction of the production building, identification and development of suitable land and authority permission for the process start (4 – 6 years).

However, before any activities related to technical modifications of the production site can take place, a final proof of the current conditions and systems in place as well as the needs for a transition have to be carried out. For this, the applicant receives also information from the chemical supplier (formulator) and producer of the alternative coating system.

With respect to trivalent chromium electroplating, the finally chosen formulation requires different processes and workflows. Therefore, necessary conditions and connection points must be checked. It is very likely, that the new process cannot be implemented in the present plating lines without significant modifications and not all equipment can be reused. Additionally, it must be considered that the alternative Cr(III)-based coating system will most likely be run in parallel to the present one for a certain period of time (see phase 5 and 6) ensuring the required production capacities. Therefore, free space must be generated at the applicant's site and as a worst-case scenario, an additional production hall must be built taking up to 2.5 years. Prior to the construction of a new production hall 6-12 months must be considered for decisions of local authorities after all documents were submitted by the applicant.

Furthermore, for trivalent chromium electroplating the wastewater treatment might have to be extended or completely replaced and external disposal might be necessary, e.g. due to complexing agents used during the process requiring a special treatment. In any case, when running two different galvanic processes in parallel, wastewater treatment will have to be extended.

Beside all technical aspects, delivery time of the required electroplating system and equipment (e.g. steel construction, control unit) is estimated to be at least 2 years which might be increased depending on the demand of the applicant's competitors. When delivery times become too long, this might lead to a delay in this phase and therefore elongate the complete transition process. After the alternative system is delivered, implementation must be performed taking approximately 1 year which itself depends on the outcome of the previous phases and implies again that previous tasks were performed conscientiously and on time.

Phase 5: Market Introduction / Capacity Build-Up (at least 2 Years)

After internal and external quality tests (laboratory and field tests), when key functionalities were met, customers of the applicant checked and approved the alternative coating and modification of the production site took place, market introduction of newly developed and produced parts occurs and the production capacity can be increased. Further upscaling of the process depending on market needs is possible (at least 2 years).

It is worth mentioning that it won't be possible to switch the production process to the alternative technology on an existing product portfolio. As the products' structure must be considered during the plating process, it's design must be adapted to the new implemented plating system. The risk that quality characteristics cannot be met anymore is too large and might result in huge scrap rates and reclamations. Hence, although being time- and cost-consuming, the best possibility is to run the 'old' hexavalent chromium electroplating timewise in parallel with the 'new' alternative technology and make the switch series by series. While increasing the capacity for parts of new series plated by applying the alternative trivalent chromium electroplating, the capacity of Cr(VI)-plated parts from old series will be decreased.

The market introduction and build-up of the alternative plating technology will take at least 2 years. It must be considered that a shorter duration for this phase might lead to a premature switchover and might result in significant deficits including quality and delivery aspects. Additionally, marketing activities, advertisements and printed catalogues must be carried out at an early stage (at the best before market introduction started) in order to adequately campaign for the products plated via the alternative technology.

Phase 6: Phase-Out of Cr(VI) (at least 2 Years)

Phasing-out of Cr(VI) is expected to take at least 2 years. Aspects, such as sales contracts have to be considered. While contracts with customers normally take 2 years, the warranty period Ideal Standard grants normally to its customer during which the products must be free from defects related to material, production and construction is 5 years. However, customers expect much longer periods due to high-quality products and surfaces and therefore generally demand for at least 10 years.

To conclude, the best possibility for phasing-out Cr(VI) is to do this on series by series basis. While decreasing the capacity for 'old' Cr(VI)-based products, the capacity for 'new' alternative-plated products can be increased. In any case, with around [redacted] coated by the applicant, it is obvious that a phase-out of Cr(VI) is a lengthy process keeping in mind that it directly depends on the acceptance of clients.

Conclusion

In conclusion, based on a best-case situation for the substitution timeline considering the durations for the single phases, transition of hexavalent chromium electroplating to the trivalent chromium-based process is estimated to take **at least 12 years** (Figure 1). As unexpected situations and issues can always arise (especially in times of the Corona pandemic), the applicant's activities and therefore the transitions toward an alternative may be impeded. Hence, prolonged timelines for single phases or the whole transition period are likely as well.

The here presented timeline slightly differs from the one, described in the AoA submitted in 2018. In specific, additional time is needed for the first phase (R&D) as there are still technical limitations with respect to the Cr(III)-based alternative (e.g. colour consistency) and the fact that the Corona pandemic forced the applicant to postpone the planned R&D activities for 2020. This has set back it's engagement on the development of the alternative.

Please note that the described phases are not standalone processes but are interconnected with each other and also show a high degree of overlap.

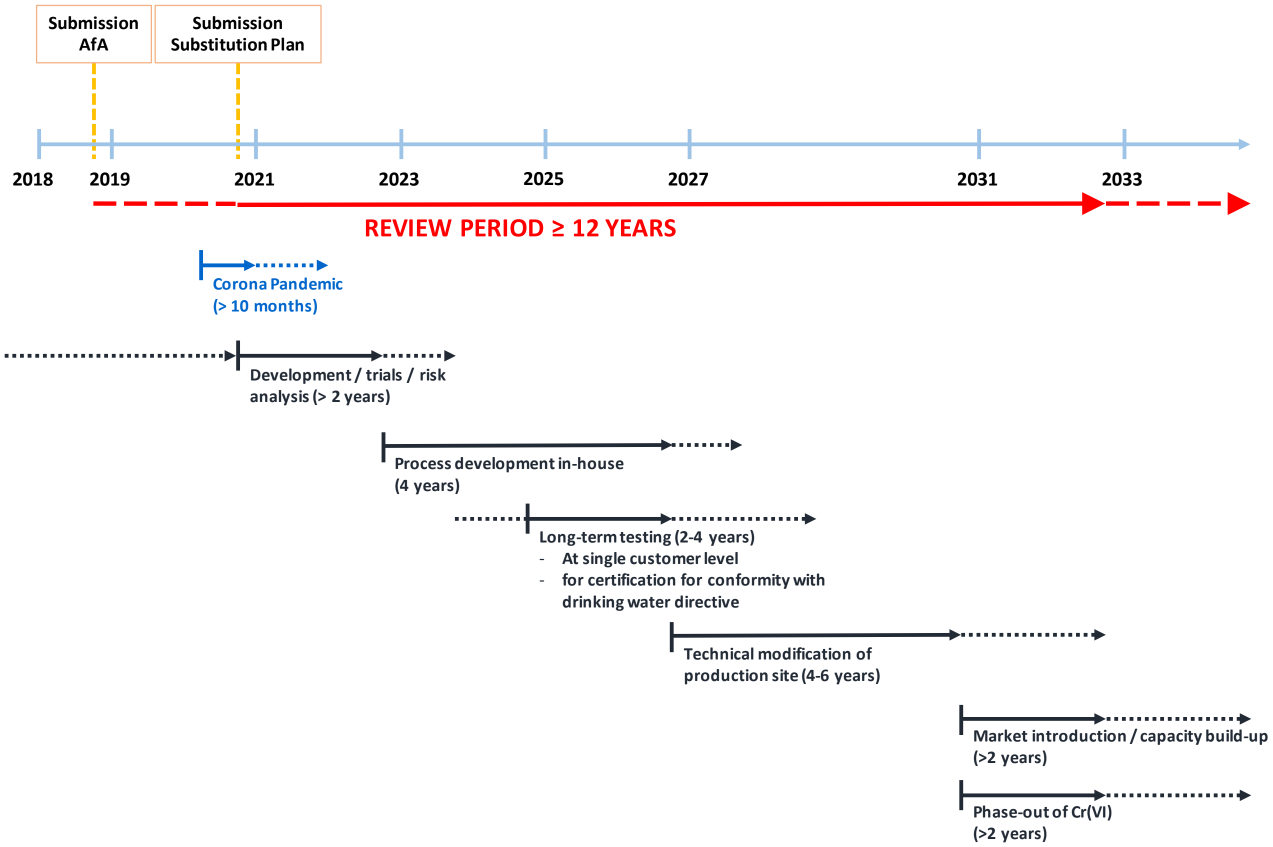

Figure 1: Substitution timeline for functional chrome plating with decorative character for sanitary applications.

4. MONITORING OF THE IMPLEMENTATION OF THE SUBSTITUTION PLAN

Ideal Standard is generally working under defined structures and has a project monitoring system in place being certified with the ISO 9001:2015 quality management system standard, ISO 14001:2015 environmental management system standard and OHSAS 18001:2007 safety management system standard. With this standard, the applicant provides an effective organizational system based on which various types of tasks and projects can be effectively managed. This is also related to complex change projects such as the development and implementation of the best-possible alternative to hexavalent chromium electroplating being and interdisciplinary, extensive and complex project. However, although parts of this such as the application of authorization are executed in projects, Ideal Standard is not exclusively organized in form of projects. They have various forms of management and organization in place. Hence, the preparation of sample parts and their evaluation regarding alternatives correspond to the scope of single departments and therefore must not necessarily underlay a project.

In each project a dedicated team (6-7 or 10-20 team members depending on the project's phase) is working on the achievement of the specific aim, i.e. the substitution of Cr(VI) for electroplating purposes. Related to the development and implementation of an alternative to hexavalent chromium electroplating, the project team can vary depending on the specific phase. Each project team comprises a project leader and team members coming from the specialized departments. While there are more technical experts from e.g. technology functions, quality management, research and testing and especially external chemical suppliers required during the first phase of alternative development and implementation (R&D), phase 5 (market introduction) will require more experts from the sales and marketing department (Table 2). In the course of the whole project, internal team members will come among others from the new production development, product management, marketing and sales department as well as from external and internal laboratories. External team members will comprise chemical suppliers with whom a close collaboration already exists, but also with the manufacturer of the alternative process system as well as the testing authorities (e.g. Federal Institute for Materials Research and Testing, BAM) being responsible for analyses and investigations. As the work packages are handled by the team members, it is worth mentioning that in each phase the responsibility is clearly assigned e.g. team members from the technical functions and production department are responsible for phase 1 and 2 of the substitution timeline. Additionally, there is the project leadership (PL) which is divided into strategic, financial and technical lead. Therefore, representatives from operations, finance and technical functions share this position in the project. The project leader generally pays attention that the project's rules and progress are met. The PL is allowed to decide in strategic and technical changes of the project as well as to release a larger budget for well justified reasons (leadership and budget responsibilities are related to the scale of strategic influence or budget).

The budget is released from the respective departments involved in the project e.g. for activities during the R&D phase, costs will be covered by the departments at the affected production sites (Ideal Standard Produktions-GmbH, Ideal Standard Vidima AD). As the project on finding, developing and implementing an adequate alternative to hexavalent chromium electroplating is of high priority for Ideal Standard, resources for other tasks or projects will be reduced or even cancelled.

In order to stay on track, regular controlling was implemented. This is divided generally into three types. First, there are weekly team meetings including presentations, conference calls or correspondence via E-Mail among the team members (working groups). Topics are the current status of the project and phases including general aspects like safety, technology and economic aspects as well as recent results and potential issues e.g. regarding the set-up or test-methods. Here, discussions are more detailed and focused on technical aspects. Depending on the outcomes and new findings, smaller adaptions on the planned approach might be done during this type of meeting. Second, there are meeting or conference calls (frequency depending on ongoing activities and results) with the management. Here, topics are less technical and more focused on the general progress (activity- and result-oriented) of the project such as the degree of milestone fulfilment and financial aspects including required approvals. Third, there are meetings (frequency depending on ongoing activities and results) with external partners such as the formulators of Cr(VI)-free electrolytes.

Documentation is carried out on a centralized filing where all files such as meeting minutes, progress reports, testing results including evaluation and outcomes are placed.

Table 2: Overview on responsible and participating departments for the development and implementation of the best-possible alternative to CrO_3.

[redacted]		[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]

[redacted]

5. CONCLUSIONS

According to the applicant Cr(III)-based electroplating is the most promising alternative to replace the use of chromium trioxide for the electroplating of parts for sanitary applications, although among others considerable challenges e.g. related to colour consistency still exist. Implementing several alternatives in parallel is not feasible due to economic, availability and capacity reasons. Importantly, the applicant is only user of the alternative and strongly relies on input from the supplier (formulator).

In conclusion, based on a best-case situation for the substitution timeline considering the durations for the single highly interconnected and overlapping phases and uncertainties arising from the current Corona pandemic, transition of hexavalent chromium electroplating to the trivalent chromium-based process in the sanitary sector is estimated to take **at least 12 years**. Thus, it is applied for a review period of 12 years.

Certificate of Conformance

Issue Date: 12/01/22

PO Number: 2000R

Part Number and Revision: 420-000162

Part/Process Description: COPPER-NICKEL-CHROME PLATE AMS2460A, TYPE I (BRIGHT FINISH), CLASS 1 (CORROSION PROTECTIVE FINISH).

Quantity Shipped: 60 ea

The undersigned states that "The articles furnished are in conformance with the purchase order requirements, engineering drawings and specifications and have been verified to meet RoHS (Directive 2011/65/EU) requirements & the amended European Delegated Directive (EU) 2015/863. The components have also been certified to not contain any Substances of Very High Concern (SVHCs) per EU REACH Regulation (EC) No 1907/2006 concerning the Registration, Evaluation, Authorization and Restriction of Chemicals (REACH).

Supplier Name: Sherms Plating

Supplier Address: 2140 Acoma Street, Sacramento, CA 95815

Representative Name (Print): ART HOLMAN

Title: GENERAL MANAGER

Signature:

Date:

Certificate of Conformance

Issue Date: 12/21/22

PO Number: 1180R

Part Number and Revision: SD000405

Part/Process Description: COPPER-NICKEL-CHROME PLATE AMS2460A, TYPE I (BRIGHT FINISH), CLASS 1 (CORROSION PROTECTIVE FINISH).

Quantity Shipped: 61 ea

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Supplier Name: Sherms Plating

Supplier Address: 2140 Acoma Street, Sacramento, CA 95815

Representative Name (Print): ART HOLMAN

Title: GENERAL MANAGER

Signature:

Date:

Certificate of Conformance

Issue Date: 10/27/22

PO Number: 21600

Part Number and Revision: 420-00100 Rev E

Part/Process Description: COPPER-NICKEL-CHROME PLATE AMS2460A, TYPE I (BRIGHT FINISH), CLASS 1 (CORROSION PROTECTIVE FINISH).

Quantity Shipped: 70 ea

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Supplier Name: Sherms Plating

Supplier Address: 2140 Acoma Street, Sacramento, CA 95815

Representative Name (Print): ART HOLMAN

Title: GENERAL MANAGER

Signature:

Date:

Certificate of Conformance

Issue Date: 1-24-2023

PO Number: 8262026

Part Number and Revision: 420-00100 Rev E

Part/Process Description: COPPER-NICKEL-CHROME PLATE AMS2460A, TYPE I (BRIGHT FINISH), CLASS 1 (CORROSION PROTECTIVE FINISH).

Quantity Shipped: 100 ea

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Supplier Name: Sherms Plating

Supplier Address: 2140 Acoma Street, Sacramento, CA 95815

Representative Name (Print): ART HOLMAN

Title: GENERAL MANAGER

Signature:

Date: