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Hard Chrome Plating: Chromate Free Alternative Processes in Aerospace Applications

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This document is released for purpose of providing voluntary supplemental guidance for replacing chromates in hard chrome plating processes within the aerospace industry.

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Table of Contents

Version History.....	2
1 Purpose.....	3
1.1 Scope.....	3
2 Background.....	4
3 Requirements for Alternative Technologies	5
3.1 Performance of Hard Chrome Plating.....	5
3.2 Additional Properties to be Considered for Replacement Technologies.....	5
4 Critical Replacement Technologies	6
5 Existing Alternatives.....	7
5.1 No Coating.....	7
5.2 Electrodeposited Coatings.....	7
5.3 Electroless (Nickel) Coating	7
5.4 Thermal Spray Coatings	7
5.5 Chemical Vapor Deposition (CVD)	9
5.6 Physical Vapor Deposition (PVD)	9
6 Upcoming Technologies.....	10
6.1 Trivalent Chromium based Deposition	10
7 Conclusion	11

1 Purpose

This document provides voluntary supplemental guidance for replacing chromates in hard chrome plating processes within the aerospace industry. This industry specific guidance document was developed by the International Aerospace Environmental Group, Work Group 2 “Replacement Technologies”, Hard Chrome Plating project. Issue 1 from October 2020 has been updated to Issue 2 in 2025.

1.1 Scope

This document provides a collection of available alternatives and upcoming technologies with recommendations for their application (applicability, performance, EHS), which may not be exhaustive. All available technologies described are already in use in the aerospace industry for certain applications.

2 Background

Functional Hard Chrome plating is widely used throughout the Aerospace industry. To produce functional hard chrome plating (HCP), chromic acid is used in the plating process. Under applicable government regulatory programs, the hexavalent chromium compound (i.e., chromium trioxide) used to produce chromic acid is identified as having an adverse effect on human health and the environment. Consequently, the European Union (EU) has banned the import and use of chromium trioxide unless authorizations for specific use applications have been approved. An authorization application for the use of chromium trioxide in hard chrome plating has been made by the Chromium Trioxide Authorization Consortium (CTAC). This authorization was granted for 7 years (expired September 2024). Re-authorization was requested by different consortia, including Aerospace and Defence Chromate Reauthorisation (ADCR). For plating, the re-authorization has been extended to November 2034 in the EU and September 2036 in the UK.

In addition, some of the bath additives, like PFAS containing mist suppressants, are being restricted for use in certain countries or under evaluation.

Hard chrome is electroplated onto steel or other metal alloys and can provide:

- A cost-effective coating that can be easily applied to parts of complex geometry.
- A hard coating which is resistant to wear, sliding and fretting.
- Environmental and corrosion resistance.

At present, there are a number of alternatives to functional hard chrome plating but no direct drop-in replacement. Therefore, any replacement of hard chrome involves application analysis and design modifications.

3 Requirements for Alternative Technologies

3.1 Performance of Hard Chrome Plating

Important characteristics of hard chrome plating are listed below (non-exhaustive):

- High hardness
- Wide thickness range
- Good adhesion to base metal
- Visual aspect
- Corrosion resistance
- Ability to be grounded or polished to a very smooth finish
- Can be applied to non-line-of-sight applications

For more specific applications, additional requirements are applicable. An example (AMS2460) is given below:

- Appearance: Shall be smooth and uniform in appearance
- Thickness: 0.00001 to 0.015 inches (application dependent)
- Hardness: 600 HVN (Vickers) minimum for plating finished to a semi-bright or matte luster and 850 HVN (Vickers) minimum for plating finished to a bright pebbly luster
- Adhesion: Meet requirements per ASTM B 571 (Knife-Chisel or bend test with no mandrel), no visible separation at 4x magnification.
- Hydrogen Embrittlement: Shall not cause hydrogen embrittlement for steel parts 36 HRC and over (testing per ASTM F 519)
- Porosity: Plating shall be porosity free to prevent corrosion

3.2 Additional Properties to be Considered for Replacement Technologies

During the development of replacement technologies for hard chrome plating, it was evident that application specific requirements are need to be tested. Possible replacement technologies might have varied performances, therefore, a single technology may not be feasible for a drop-in replacement. The property considerations for replacements technologies are:

- Wear Resistance
- Friction and Lubricity Properties
- Fretting Behaviour
- Load Resistance
- Corrosion Resistance
- Fatigue Resistance

Additionally, application specific criteria must be satisfied, and the coated components must be tested and validated. For example, tests like track roller, pin-in-bushing, wear and sealing tests, etc., will be necessary for process qualification.

4 Critical Replacement Technologies

Replacement technologies which rely on nickel and/or cobalt metals and salts are seen as critical. Nickel metal is a known skin sensitizer and classified as carcinogenic Cat.2. In the EU, further restrictions to lower exposure levels are likely. Nickel salts (e.g., nickel sulphate) used for electrolytic coating processes are classified as carcinogenic and reprotoxic Cat.1. Cobalt and Cobalt salts are classified in the same way as nickel salts. Cobalt carbonate, cobalt dichloride (anhydrous), cobalt diacetate, cobalt dinitrate and cobalt sulphate are part of the EU REACH candidate list.

As such, these technologies would not provide meaningful reprieve or long-term benefit in terms of environmental health and safety. However, they could be applied as a short-term solution due to the current regulatory pressure to replace hard chrome immediately.

5 Existing Alternatives

For ease of design and selection, the hardness and some additional properties such as corrosion resistance of the alternative coatings are given in the following sections. These values are provided for illustration purposes only. Exact values will need to be verified and confirmed for a given combination of part and coating technology.

5.1 No Coating

For new design of parts, through proper material selection, a material or a pair of materials can be chosen to eliminate the need for coatings in a specific application. It has been shown that for certain applications (e.g., for a latch), a combination of stainless steel/stainless steel and stainless steel/aluminium with a conjunction of dry film lubricants is sufficient.

5.2 Electrodeposited Coatings

In electrodeposition (or electroplating), electrical current is used to reduce metal cations in solution so that they form a coating on an electrode, which is the part to be coated. Due to the limitations of homogeneous electrical field in the setup, uniform coating for parts of complex geometry is not feasible. The surface to be coated needs to be conductive for the electrodeposition process.

Coating types:

- Cobalt: Hardness 400 HV maximum
- Cobalt Phosphorus (e.g., AMS2428): Hardness: ≥ 510 HV, corrosion resistance: >200 h SST
- Cobalt Phosphorus with particulate: Hardness > 550 HV/ >850 HV after heat treatment
- Nickel: Hardness >300 HV
- Nickel Tungsten (NIW): Hardness 600-690 HV/ 1060-1150 HV after heat treatment
- Ni-Co-P, Ni-Co-P-SiC, Co-P

5.3 Electroless (Nickel) Coating

Electroless plating is a non-galvanic coating deposition method. In this process several, chemical reactions occur simultaneously without external electrical power in an aqueous solution. The reduction of metal ions (e.g., Ni²⁺) leads to the deposition of material onto the part. With proper pretreatment, electroless coating can be applied to non-conductive surfaces. This process is particularly suitable for parts of complex geometry due to throwing power and no electrical field effect. Coating types:

- Electroless Nickel (Phosphorus) Coating (e.g., AMS 2404 (AMS-C-26074)): Hardness 450 - 550HV, up to 1000 HV with heat treatment. With high phosphorous content (≥ 10 wt%), the coating provides good corrosion and chemical resistance in neutral and acidic media.
- Electroless Nickel Phosphorus with PTFE (e.g., AMS 2454): Hardness > 300 HK25, low friction
- Electroless Nickel Boron (e.g., AMS2399, AMS2433 Type 1 or 2): Hardness >650 HV as plated; >1000 HV after post treatment

5.4 Thermal Spray Coatings

Thermal spray metallic coatings are produced by projecting metal powder heated to its semi-molten state, onto the surface to be coated using a stream of gas or plasma. These coatings consist of several stacks of metal splats, resulting from spraying multiple passes. Each pass lays a coating layer of $\sim 20\mu\text{m}$

by piling up splats on the substrate surface. Some level of porosity can exist between these splats. The morphology and properties of the coating are directly linked to the process type.

In addition to metal, deposition of ceramic materials or cermets is also possible using thermal spray systems. Examples of ceramic coating that may be applied by thermal spray system include aluminium oxide, aluminosilicate and zirconia-based ceramics. A "cermet" is a blend of metal-oxide ceramic (cer) and metal (met) materials binders (e.g., Aluminium Oxide – Nickel Aluminium).

High velocity oxygen fuel (HVOF) spraying uses a mixture of gaseous or liquid fuel (e.g. hydrogen, methane, propane, kerosene) and oxygen, which are fed into a combustion chamber, where they are ignited and combusted continuously. The resulting plasma (jet) reaches a velocity above 1000 m/s and metallic powder is injected into the plasma. The stream of hot gas, including the powder, is propelled towards the surface to be coated. The ceramic and/or metal powders partially melt in the plasma stream and are deposited upon the substrate. The resulting coating has low porosity and high bond strength compared to traditional techniques such as flame spray.

There are some limitations to the thermal spray process. The substrate needs to withstand the relatively high temperatures during thermal spraying. Being a line-of-sight process, thermal spray cannot coat internal features of parts (such as tubes) with small internal diameters (< 75 mm) and high aspect ratio holes. This method is not suitable for parts of complex geometry and needs post machining (e.g., grinding) for lower Ra and corrosion resistant coating (e.g., chromate conversion coating, corrosion preventative oil) for corrosion protection.

Lower temperatures are only possible with specific thermal spray processes (such as cold or kinetic spraying) and coating materials.

Coating types:

- CuAlFe (Copper Aluminium Iron): Hardness >150 HV
- Molybdenum: Hardness >400 HV, low corrosion protection, corrosion product (MoO₃) classified as carcinogenic 2
- WC (Tungsten Carbide): Hardness 800 – 1200 HV; Corrosion Protection < 750h SST (ISO9227)
- CoCrMo (Cobalt Chrome Molybdenum): Hardness: 400 HV, no direct contact with aluminium alloys or non-corrosion resistant steel recommended to avoid galvanic corrosion
- CuNiIn (Copper Nickel Indium): Hardness 120 HV, no direct contact with aluminium alloys or non-corrosion resistant steel recommended to avoid galvanic corrosion
- WC-Co-Cr (Tungsten Carbide Cobalt Chromium) and WC-Co (Tungsten Carbide Cobalt) (e.g. AMS7882, AMS7881, and AMS2448): Hardness 850 HV, no direct contact with aluminium alloys or non-corrosion resistant steel recommended to avoid galvanic corrosion.

5.5 Chemical Vapor Deposition (CVD)

Chemical vapor deposition (CVD) is a group of processes that involve depositing a solid film by chemical reactions in a controlled atmosphere chamber. The temperature of the substrate may reach temperatures above 500 °C during the processing.

Coating types:

- Diamond-Like Carbon Coating: Hardness 500 – 3500 HV, does not provide corrosion protection
- WC (Tungsten Carbide): Hardness 800 – 1200 HV, Corrosion Protection < 750h SST (ISO9227)

5.6 Physical Vapor Deposition (PVD)

Physical Vapor Deposition (PVD) can be defined as a family of processes in which the deposition species (i.e., ions and molecules) is created in a low vacuum by vaporization, then transported and deposited on part surface to grow a thin film coating. The PVD processes of most interest in wear resistant coatings utilize a source which produces metal ions that are attracted and accelerated to the substrate by applying a bias voltage.

Three types of ion source are commercially used:

- Evaporative ion deposition utilizes an electron beam to evaporate ions from a crucible.
- Sputtering ion deposition bombards a solid surface with a flux of energetic particles to eject atomic species (e.g., ions), which is used as a source for deposition.
- Cathodic arc ion deposition utilizes ions which have been evaporated via a cathodic arc.

Sputtering and arc evaporation sources are the most flexible with respect to ion species. Both can deposit non-metals as well as metals and metal alloys. Electron beam sources are limited to pure metals. To produce optimum coating adhesion, deposits are generally applied at part temperatures more than 300 °C.

Parts to be coated need to withstand vacuum. Surfaces to be coated may be limited due to part geometry. Line-of-sight coating method, for example, coating of internal surfaces, like tubes, is not feasible. The quantity of parts that can be effectively coated at one time will be limited based on chamber size and area to be coated.

Coating types:

- CrN (Chromium Nitride): Hardness >1800 HV, offers limited corrosion protection
- TiN (Titanium Nitride) (e.g. AMS2444): Hardness >2000 HV, does not provide corrosion protection
- WC C: H (Tungsten Carbide Carbon): Hardness 1000-1500 HV, offers low coefficient of friction but does not provide corrosion protection
- DLC (Diamond-Like Carbon) Coating: Hardness 500 – 3500 HV, does not provide corrosion protection

6 Upcoming Technologies

Currently efforts focus on improving the already existing and applied technologies (e.g., vapor deposition and thermal spray), targeting the elimination of their specific drawbacks. This is a logical step considering the conclusion from the analysis of existing technologies – there is no one to one solution for hard chrome plating. Companies are working to enable wider application of their technologies (e.g., overcome dimensional, geometric and temperature limitations, improve corrosion resistance). Unfortunately, some of these improved technologies still rely on nickel and cobalt which could be a problem with upcoming regulations on those metals and their salts.

6.1 Trivalent Chromium based Deposition

A potential future one-to-one replacement could be the electrolytic deposition of Hard Chrome from Cr (III) solution. It is possible to create hard and dense chromium layers with sufficient adhesion which could be an alternative to deposits from chromium (VI). However, the macro cracks in deposits made from Cr (III) are a major concern in terms of sealing and machinability. Current solutions are not yet mature and most of them still rely on a Nickel under layer for corrosion and sealant properties. Leakage through the macro cracks is possible, which could lead to corrosion and loss of fluids in hydraulic and pneumatic sealing applications. These macro cracks need to be eliminated or greatly reduced.

From decorative plating it is known that the cost of the chemicals is greater, but this is usually offset by greater production rates and lower overhead costs. In general, the process must be controlled more closely than in hexavalent chromium plating, especially with respect to metallic impurities. This means process parameters that are hard to control, such as barrel plating, are much more difficult using a trivalent chromium bath.

7 Conclusion

Considering all technologies reviewed in this report, the most important conclusion is that there is no one-to-one replacement for current hard chrome coatings. For each application, a suitable replacement must be evaluated based on the process and coating properties.

For the choice of alternative coating, one must consider the performance of the coating and the different application technologies. The alternate processes have limitations such as line of sight process and temperature effects.

Not all replacement technologies offer a substantial improvement in terms of health and safety concerns. Some technologies contain nickel or cobalt or in some cases utilize their salts. These substances are suspected to be carcinogenic.

For some technologies, there is no commercial specification available. This is also complicating the wider introduction of these alternatives due to lack of performance and quality standards.

A future one-to-one replacement for the current hard chrome plating processes could be hard chrome plating using trivalent chromium based solutions; however, at this time the maturity level of this technology is still considered to be low.