LINKING GLOBAL TECHNOLOGIES WITH MARKETS

Use of Thermal Spray as an Aerospace Chrome Plating Alternative

Courtesy U.S. Navy. Photo by Ensign John Gay

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EXECUTIVE SUMMARY

Thermal spray coatings have been used for many years in aircraft turbine engines as wear and erosion resistant coatings, thermal barriers, and clearance control coatings. As increasing environmental and safety issues have driven a search for chrome plating alternatives, engineers have found that thermal spray coating, long used for gas turbine engines, can be a very cost-effective alternative to hard chrome plating. Although the initial driver for the substitution of thermal spray coatings for chrome was environmental, the alternatives are now being widely adopted because of their better performance, higher reliability, and lower life-cycle cost.

This document summarizes the current state-of-the-art, property and performance data, and usage of thermal spray coatings as replacements for hard chrome plating on aerospace components. The information covers the use of hard chrome for both original equipment and for overhaul and repair. Its purpose is to provide in one place a summary of information on thermal spray coatings that will be useful for engineers engaged in the design and maintenance of aircraft components.

This document is designed as an electronic book, with links to guide the user directly to information of interest. The document itself contains data summaries and examples, with a large number of underlying full-text references (available at the click of a mouse) to provide as much detail as possible. The information is current as of August 2000, but the document is intended to be readily revised and updated as more information is generated. After a brief introduction, the document is broken into four parts:

Part 1. Aerospace Usage of Chrome – An overview of the types of components and applications in which hard chrome is currently used in the aircraft industry, and the requirements for chrome replacement.

Part 2 Overview of Thermal Spray – Types and principles of thermal spray, especially High Velocity Oxy-Fuel (HVOF) and Plasma Spray – the two primary chrome replacement technologies. This Part includes thermal spray equipment and powders, thermal spray producibility and quality control, stripping, and finishing.

Part 3. Thermal Spray Data – Summary of current data on structure, properties, and performance of thermal spray coatings – hardness, adhesion, embrittlement, corrosion, fatigue, wear, hydraulic rig testing, landing gear rig testing, and flight testing. The text contains data summaries and graphs, with the underlying data accessible via full-text documents.

Part 4. Specifications and Qualified Components – Summary of thermal spray specifications, and of thermal spray-qualified applications and components.

In summary, the data shows that in all critical respects HVOF coatings perform as well as (and in most cases better than) hard chrome. This is certainly true in critical areas, including hardness, wear, fatigue, corrosion, hydraulic testing, and extended flight testing. HVOF can be applied to almost any material without causing hydrogen embrittlement, and in many cases the fatigue debit can be completely eliminated. **As a result HVOF coatings (primarily tungsten carbide cermets) are now specified on more than a hundred components on Boeing aircraft, and are used extensively for overhaul and repair of landing gear cylinders and axles, and flap and slat tracks.** The new Boeing 767-400 is specified for HVOF-coated or chrome plated landing gear, whichever customers request. Parker-Hannifin is eliminating chrome plate, and using thermal spray coatings on all new aerospace hydraulic actuator designs. Airlines such as Delta, Lufthansa, and United are all qualifying HVOF for landing gear overhaul. There are several standard and widely used aerospace specifications for thermal spray processes and for the powder materials they employ. However, thermal spray is not a simple drop-in replacement for chrome plate. As a dry spraying process rather than an electroplate it fits differently into the OEM production and overhaul sequence. Although it can be done in-house, and is in fact available at most repair shops and DoD depots, OEMs frequently contract it out. Furthermore, HVOF coatings, the most common chrome alternative, cannot be used on internal diameters, although plasma spray can be used on diameters down to about 2”. Thermal spray cannot be used to replace thin dense or flash chrome, since it cannot be made thin enough.

The process lends itself to a large number of different coating materials and a wide range of deposition conditions. This makes it highly flexible but more complex to use. Therefore the specifications for a thermal spray coating must be properly defined, and the process optimized to fit both the material being processed and the coating material being applied. For example:

- Since it utilizes a torch or plasma gun, it is possible to overheat heat-sensitive components, making proper temperature measurement and control an essential part of the process specification.
- The coating material must fit the substrate material. The most common coating material is tungsten carbide, but thermal sprayed hard alloys, such as Tribaloy, give better fatigue performance on aluminum alloys.
- The thermal spray coating must be optimized properly for the application. Some thermal spray coatings have performed poorly because they used the wrong coating material or used a deposition process that was optimized for the wrong application. For example, thermal spray coatings optimized for wear resistance may have as large a fatigue debit as chrome (or even larger). Re-optimizing the coating for fatigue has reduced, or even eliminated, the fatigue debit while still retaining superior resistance to wear.

- The finishing specifications for thermal spray coatings are not necessarily the same as for chrome. Thermal spray coatings must in general be finish-ground or superfinished to a much finer surface than is typical for chrome plate. For example, a 16 μinch finish is typically specified for chrome plated hydraulics. Using HVOF coatings with this finish leads to very rapid seal failure. With a 4 μinch or better finish, however, both seal life and rod life are greatly extended.

In summary, the thermal spray process is highly recommended and growing as a replacement for hard chrome plate, but it must be used properly, with accurate specifications, a qualified sprayer, and proper account taken for the materials and applications in which it is used.

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This compilation would not have been possible without the assistance of a great many people in the aerospace industry. We would therefore like to acknowledge the many people and organizations that have contributed to this document. Funding for the work was provided by the Joint Strike Fighter Program Office, NADEP Jacksonville, poc Jean Hawkins. HCAT information has been provided by the members of the HCAT team, courtesy of Bruce Sartwell, NRL, the team leader. Many documents and other information have been provided by companies such as Boeing, Messier-Dowty, Praxair, Sulzer Metco, Southwest Aeroservice, Metcut Research, and the National Research Council of Canada, among others. Many of the documents have been provided by courtesy of ASM International, Materials Park, OH 44073-0002, other documents by courtesy of Gorham Advanced Materials, Gorham, Maine, and by numerous individual authors as indicated in the text.

HOW TO USE THIS REPORT

This document is designed to be used electronically, so that it can be a living document that can be updated with the latest information as it becomes available. It is extensively hyperlinked to permit the reader to jump immediately to items of interest in the text.

Many items in the text – figures, tables, references, section headings, etc. – are hyperlinked, and can be identified by their blue text. Clicking on the text takes you to the item.

The report is designed to contain the most important information within the text. Details and backup information are provided in the form of attached documents, which can be recognized by the yellow boxes, like the one below. **Clicking** on the icon within the box brings up the document, making all the details readily available.

Later cross-references to these documents are shown in blue, and the Document can be opened by clicking on the blue text.

"HVOF Applications Listing SWA.PDF"

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AFRL	Air Force Materials Lab (Dayton, OH)
ALC	Air Logistics Center (Air Force maintenance depot)
AMS	Aircraft Materials Specification (a specification of the Society of Automotive Engineers)
APS, VPS	Air Plasma Spray, Vacuum Plasma Spray
BFG	B.F. Goodrich
C-HCAT	Canadian Hard Chrome Alternatives Team
Cr^{6+}	Hexavalent chrome
DARPA	Defense Advanced Research Projects Agency
D-Gun	Detonation gun (also Super D-Gun) – high velocity thermal spray method based on fuel detonation (proprietary to Praxair)
DND	Department of National Defence (Canada)
DoD	Department of Defense (US)
DOE	Design of Experiment (statistically designed matrix of experiments used for process optimization)
EPA	Environmental Protection Agency
ESTCP	Environmental Security Technology Certification Program (funding HCAT)
GEAE	General Electric Aircraft Engines
GTE	Gas turbine engine
HCAT	Hard Chrome Alternatives Team
HVOF	High Velocity Oxy-Fuel thermal spray
ID	Inside diameter
JG-PP	Joint Group – Pollution Prevention (DoD environmental group assisting with qualifying clean processes)
JSF	Joint Strike Fighter
JSF IPT	Joint Strike Fighter Integrated Product Team
JTP	Joint Test Protocol
NADEP	Naval Aviation Depot (Navy Maintenance depot)
NAWC	Naval Air Warfare Center
NDCEE	National Defense Center for Environmental Excellence
NRC	National Research Council of Canada

NTS	National Technical Systems, Inc.
O&R	Overhaul and Repair
OD, ID	Outside diameter, inside diameter
OEM	Original Equipment Manufacturer
OSHA	Occupational Health and Safety Administration
PC	Personal computer
PEWG	Propulsion Environmental Working Group (turbine engine environmental issues)
PVD	Physical Vapor Deposition (vacuum coating deposition process)
P & W	Pratt and Whitney
QPL	Qualified Provider List
R&O	Repair and Overhaul
SERDP	Strategic Environmental Research and Development Program (funding ID chrome replacements)
TPC	Technology Partnerships Canada (funding C-HCAT)
WC	Tungsten Carbide
WC-Co, WC-CoCr	Cobalt cemented WC (usually WC-17Co or WC-12Co) and cobalt-chrome alloy cemented WC (usually WC-10Co4Cr). (Percentages by weight.)