The Evaluation of Tungsten Carbide Thermal Spray Coatings as Replacements for Electrodeposited Chrome Plating on Aircraft Landing Gear

By B.E. Bodger, R.T.R. McGrann & D.A. Somerville

Tungsten carbide (WC) thermal spray coatings applied by the high velocity oxy-fuel (HVOF) process are considered the leading candidates for replacement of hard chrome plating. This article describes the decision-making process followed to establish the acceptability of WC thermal spray coatings for aircraft landing gear applications. Descriptions of both the laboratory testing phase and the in-service evaluation phase are given.

Chrome plating is used extensively for control of wear and corrosion. There are three problems associated with chrome plating, however, that are causing industries and governments internationally to search for alternative processes. One problem concerns the health and environmental hazards that arise from the chrome plating process and disposal of chrome plating materials.[1, 2, 3] A second problem is the increasing cost of chrome plating as a result of:

- More stringent government controls on the process and material disposal,
- Costs associated with shop turnaround time, and
- Allowances for reductions in fatigue life of coated parts.

The third problem is that chrome plating is not an entirely satisfactory solution for control of wear and corrosion in some environments for which the process is presently in use.

A leading candidate for the replacement of chrome plating is a tungsten carbide (WC) coating applied by a thermal spray coating process. A tungsten carbide coating applied by the high velocity oxy-fuel (HVOF) process has a high probability of success for replacing chrome plating.

A potential application on aircraft is for landing gear parts (Fig. 1). Aircraft manufacturers and airlines that are currently chrome plating parts are concerned about the wear and corrosion resistance provided by any coating system offered as a replacement for chrome. While tungsten carbide is widely recognized as having superior wear resistance characteristics,[4] it has yet to be proven that these coatings are equal or superior to chrome plating in aircraft landing gear.

Additionally, a coating system giving improved wear properties may drastically reduce the fatigue life of a component because of cracking that starts in the coating and penetrates into the substrate material. The result may be cracks propagating through the substrate, resulting in loss of the component. Chrome plating, as with any surface treatment, can create a fatigue deficit, *i.e.*, chrome plated parts have fatigue lives that are shorter than those of uncoated parts.[5] For this reason, if a part that carries dynamic loads is to be chrome plated, it is made of heavier construction to reduce in-service stresses, and thereby restore the expected fatigue life to values that would be near those for the uncoated part. Designing for a fatigue deficit costs money because of the heavier construction required, and because heavier aircraft parts reduce payload and increase fuel consumption.

Aircraft landing gear manufacturers and air transportation companies want an alternative to chrome plating that:

- Is nonhazardous to health and the environment,
- Costs no more to apply than chrome plating,
- Has acceptable corrosion and wear resistance properties, and
- Reduces the fatigue deficit problem.

Aircraft landing gear manufacturers and air transportation companies are reluctant to switch from chrome plating until an alternative process has been proven to produce components that are at least equal to those that are chrome plated. In the following sections, a description of the testing program that was followed by

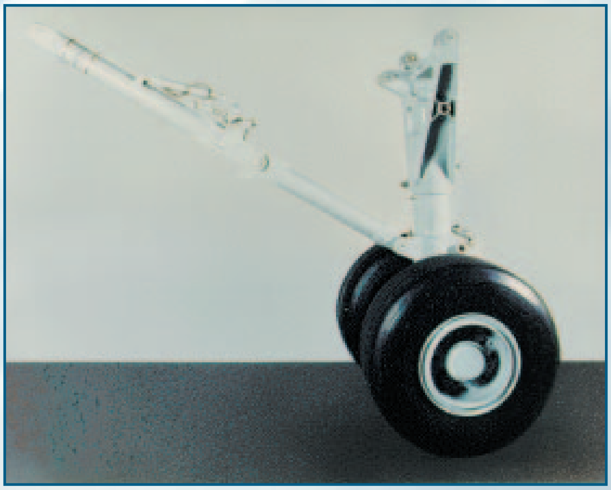

Fig. 1—Assembled landing gear.

This is an edited version of the Garland Award paper delivered at the 33rd Aerospace/Airline Plating & Metal Finishing Forum that was held in San Francisco, CA in March 1997.

Fig. 2—B737 nose landing gear—inner cylinder.

Lufthansa Airlines through Boeing and Airbus to determine the acceptability of WC as a chrome plating replacement will be presented.

Objective

The objective of the study was to determine the suitability of WC thermal spray coatings as replacements for chrome plating on specific components. If this objective could be accomplished, the investigation of the replacement of chrome plating on other parts by WC thermal spray coatings would be pursued.

Lufthansa initiated these studies two years ago, at which time Boeing focused on application to the B737 landing gear. Airbus, through Messier-Dowty, began its studies the following year on the A320 landing gear.

Approach

The test program to determine the suitability of WC thermal spray coating as a replacement for chrome plating was divided into two phases for the landing gear for both the B737 and the A320.

Phase One was a broad laboratory test program. It was followed by Phase Two, which was in-flight evaluation of the coating on selected components. Only after successful qualification in the Phase One laboratory tests was Phase Two allowed to proceed. Phase Two testing would initially be focused on nose landing gear inner cylinders, such as shown in Fig. 2.

A cooperative testing program involving subcontractors, landing gear manufacturers, aircraft manufacturers, and airlines was begun. Southwest Aeroservice, Inc., Praxair, and Messier-Dowty, along with aircraft manufacturers Boeing and Airbus Industries, at the request of Lufthansa, participated in the testing program.

Test Matrix for Evaluation of WC Thermal Spray Coatings As Replacements for Chrome Plating

Testing	Company	Method
1. Corrosion	Lufthansa Technik	ASTM B117-90, Salt Spray
2. Machinability & Detectability of Abuse	Messier-Dowty, Praxair	Fluorescent Penetrant, Magnetic Particle, Stresscan
3. Fatigue	Messier-Dowty, Southwest Aeroservice	Axial fatigue, R = 0.1, K_t = 1.035
4. Friction	Messier-Dowty, Southwest Aeroservice	DOLEX friction test
5. Sealing & Seal Durability	Messier-Dowty, Southwest Aeroservice	

Phase One: Laboratory Testing

An extensive thermal spray coating testing program involving different substrate materials (steel, aluminum and titanium) and several application processes had been under way at Boeing for several years. This laboratory testing experience, conducted with Lufthansa, included fatigue, coating adhesion, and several wear tests (sliding wear, erosion wear, dry abrasion and impact wear). The satisfactory performance of WC thermal spray coatings in these earlier tests allowed Boeing to begin Phase Two early in 1996. The part chosen for initial testing by Boeing was the B737-300 nose landing gear.

The Phase One laboratory program undertaken by Messier-Dowty included comparisons of WC coating and chrome plating on ultra-high-strength, low-alloy steel in five test areas. First, a comparison was made of the "survival" of the coatings during corrosion testing. The second set of tests involved comparing WC and chrome plated parts for machinability and detectability of grinding abuse. The third area of testing was fatigue testing. Friction and wear tests were the fourth area of testing. Finally, an examination of the performance of both WC and chrome sliders placed against seals was made. The Phase One (Laboratory) test matrix of Messier-Dowty is given in the table.

The corrosion tests were conducted by Lufthansa Technik.[6] The tests were salt spray corrosion tests, performed according to ASTM B117-90, designed to run for 750 hr. The dimensions and material of the base metal of the chrome plated specimens were 150 mm x 100 mm x 6 mm steel (AISI 1010). Two plating thicknesses were used, 100 µm (4 mils) and 200 µm (8 mils) after surface grinding. The HVOF specimens were the same material, length and width, but were 15 mm thick. The coatings were ground to the test thicknesses (100 µm and 200 µm) after spraying.

Fatigue tests were conducted by Messier-Dowty. For these tests, coupons were prepared from a high-strength, low-alloy steel (E35NCD16) base material. Three conditions were tested:

1. Uncoated
2. Shot-peened and chrome-plated
3. Shot-peened and HVOF WC-Co coated.

The machinability and detection of grinding abuse testing involved the use of several nondestructive testing procedures to compare the ease of detection of abuse during machining and grinding of chrome plated and WC coated specimens. In the friction tests, steel pins were coated with WC-Co and tested against copper-zinc (CuZn19A16) bushings. The seal and seal durability tests utilized full-size WC-Co coated sliders against rings and seals for 10,000 cycles.

Phase One Results

Southwest Aeroservice, Inc., among others, participated in this program by preparing specimens for these tests. Included among the specimens were those for corrosion and fatigue tests. The results of these two test areas will be examined in more detail.

In the corrosion tests, the HVOF coatings outperformed chrome

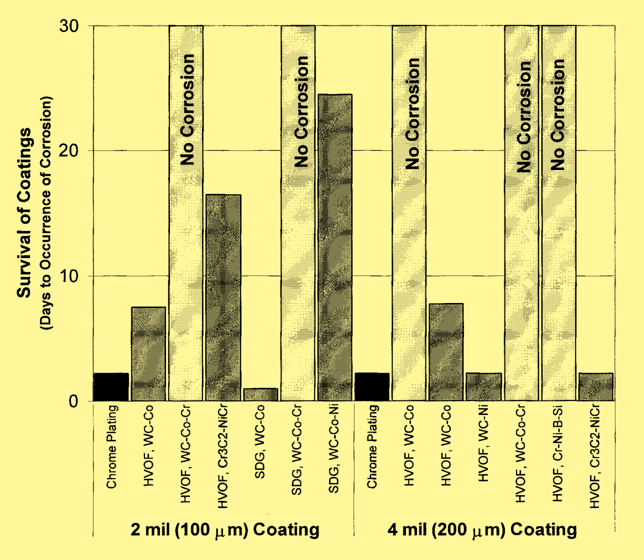

Fig. 3—Summary of Phase I Corrosion Test Results (Photo courtesy of Lufthansa Technik[6]).

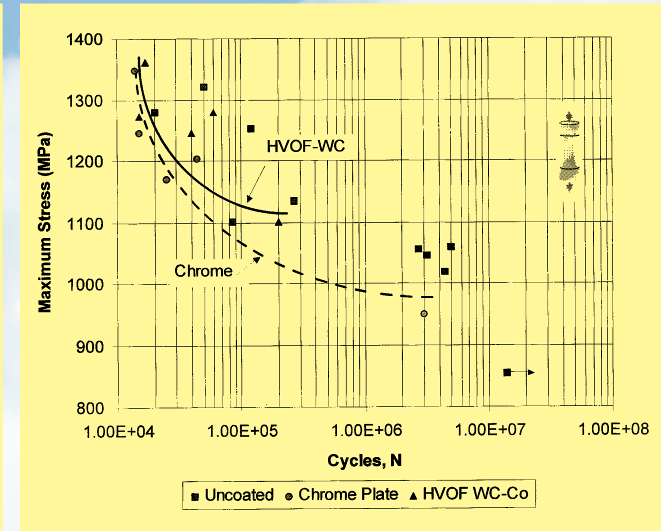

Fig. 5—Cyclic Fatigue Test Results—4340 Steel, Smooth Gage Specimens (adapted from Ref. 8).

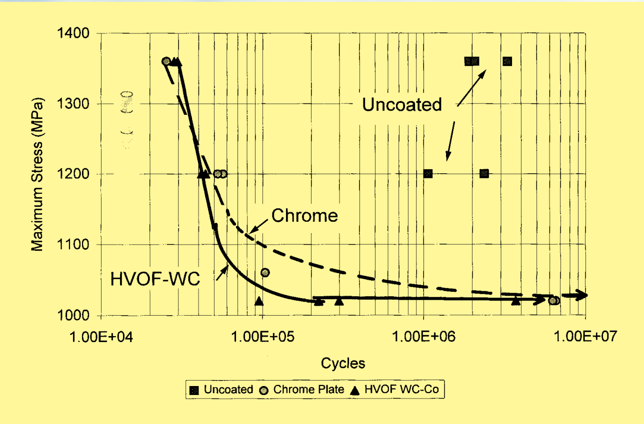

Fig. 4—Axial Fatigue Test Results: R = 0.1, K_t = 1.035 (Courtesy of Messier-Dowty[7]).

plating. In the fatigue tests, HVOF WC coatings and chrome plating were comparable.

The results of the corrosion testing are summarized in Fig. 3. The results show the "average" days to occurrence of corrosion for four duplicate specimens of each category. Of the 2-mil (100 µm) thick coatings, both of the WC-Co-Cr coatings completed the tests with no corrosion. For the thicker coating, 4 mils (200 µm), three HVOF coatings completed the test with no corrosion: WC-Co, WC-Co-Cr, and Cr-Ni-B-Si coatings. The survival of these coatings was significantly better than the survival of the chrome plated specimens.

Figure 4 shows the results of the fatigue testing for bare metal, chrome plated and HVOF-WC coated specimens. This figure is very interesting in that it shows very little variation between the chrome plated and the WC sprayed fatigue performance for the conditions tested.

There is very close agreement at the higher stress levels (1360 and 1200 MPa) used in the testing regime. At the lower stress levels (around 1020 MPa) the chrome plated specimens are slightly better.[7]

More recent test results comparing chrome plating and WC-Co indicate that HVOF WC coatings outperform chrome plating at these stress levels.[8] The results of this testing are shown in Fig. 5 for low-cycle fatigue testing of smooth, cylindrical-gage section specimens. The testing was conducted on 4340 base material specimens, chrome plated specimens and HVOF-WC sprayed specimens.

The final results of the Messier-Dowty Phase One testing were very positive. As summarized in the Messier-Dowty report:

The HVOF coatings examined showed some interesting advantages with respect to chrome plate, in particular improved corrosion resistance and reduced susceptibility to grinding abuse.

Fatigue and wear properties were sufficiently similar to allow in-flight evaluation to proceed.[7]

The corrosion tests showed that several HVOF coatings performed better than chrome plating. The results of the fatigue and friction tests showed that WC-Co coatings were at least as good as chrome plating.

Phase Two: In-Flight Testing & Results

The second phase of the decision-making process at Boeing involved in-flight use of a WC-Co thermal spray-coated Boeing 737-300 nose landing gear (NLG) inner cylinder (IC). This part has been in-service since January 3, 1996. A Lufthansa status report was generated during a scheduled in-service inspection in August 1996.[9] The WC-Co coated NLG component had experienced 1184 cycles during 1124 flight hr. The entire inner cylinder was inspected for cracks using fluorescent penetrant. No irregularities were found. Roughness measurements of the sliding surface revealed no difference in surface roughness compared to that on the date of installation.

A second in-service inspection in January 1997—after a total of 2236 cycles and 2118 flight hr—found no irregularities during penetrant inspection. A slight increase in surface roughness was found, however. Also, a seal had been replaced after 1910 cycles (and 1875 hr), which was almost twice the number

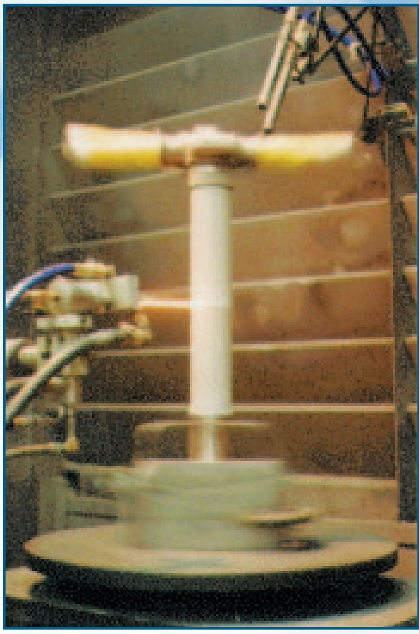

Fig. 6—HVOF spraying of inner cylinder.

of cycles (1000) on chrome plated inner cylinders. As the report indicated, "the performance of the seal facing an HVOF-coated IC is at least as good as that of a chrome plated IC."[10] A scheduled overhaul will be conducted in the fall of 1997.

Phase Two evaluation by Messier-Dowty will be conducted on an A320 nose landing gear sliding member. This part was prepared at Southwest Aeroservice, Inc. for testing beginning in 1997.

Additional plans for in-flight testing beginning in June 1997 include coating three more B737 NLG inner cylinders with HVOF WC-Co-Cr. Also, a B747-200 main landing gear is scheduled to be coated with HVOF WC-Co-Cr in July 1997.

Summary & Conclusions

The decision-making process that was followed in this case study shows that a cooperative program involving aircraft manufacturers, component manufacturers and subcontractors can lead to successful results. The testing needed to determine the suitability of a WC thermal spray coating as a replacement for chrome plating involved the resources of manufacturers and suppliers. The testing program itself, involving both laboratory testing and in-flight evaluation, gives an idea of the work needed to qualify WC thermal spray coatings as replacements for chrome plating.

The performance of the WC coatings in these tests was at least as good and often better than chrome plating. In Phase One testing, the improved performance in corrosion and machinability, as well as the equivalent performance in fatigue and wear of the thermal spray coatings, show that WC coatings are suitable as replacements for chrome plating in these applications. **P&SF**

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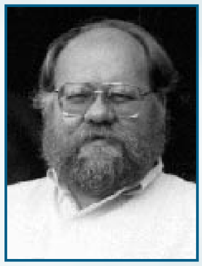

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