Many landing gear, flap supporting, and flap actuating components on Boeing airplanes are made of high-strength alloy steels. Operational advantages are realized when these high-strength, high-heat-treated materials are used in limited-space envelopes. To reap the benefits of high-strength alloy steel components and avoid potential safety issues resulting from damage, airline maintenance and overhaul personnel need to follow proper maintenance procedures and rework practices, checklists, and guidelines during component maintenance and overhaul.
ALLOY STEEL
Many landing gear, flap track, flap carriage, and other flap actuating components on Boeing airplanes are made of high-strength alloy steels, such as 300M, Hy-Tuf, 4340M, and 4330M. These components provide structural benefits (e.g., reliable, durable design) and strength characteristics that permit an efficient use of available airframe space. Other steels in use, including 9Ni-4Co-0.3C, AerMet 100, and precipitation-hardened stainless steels, have similar maintenance and overhaul requirements. (Note: High-strength alloy steels referenced in this article generally have been heat-treated above 180 ksi [180,000 psi]; most have been heat-treated above 220 ksi.)

Airline personnel should follow proper maintenance procedures and Boeing-provided rework practices, checklists, and planning guidelines during maintenance and overhaul of these components. This will help operators achieve the benefits associated with high-strength alloy steels and avoid potential safety issues resulting from damage caused by stress concentrations, detrimental surface conditions, corrosion, improper processing, or other factors.

This article discusses some factors that cause damage in service or during overhaul. Most can be attributed to a lack of familiarity with high-strength alloy steels. Operators usually recognize the benefits of using these steels; however, certain characteristics of the steels are not always given proper consideration during component maintenance or overhaul. These characteristics, including sensitivity to corrosion pitting, susceptibility to microstructural damage resulting from embrittlement, and notch sensitivity, can lead to rapid crack growth in some load environments.

This article describes

1. Benefits of high-strength alloy steel.
2. Importance of proper inspection and rework.
3. Guidelines for reworking high-strength alloy steel components.
1 BENEFITS OF HIGH-STRENGTH ALLOY STEEL

Components made of high-strength alloy steel generally weigh less and require less space to house than components made of lower strength alloys. Using high-strength alloy steel for component design provides an opportunity to do the same job with less material. When properly maintained and overhauled, high-strength alloy steel components demonstrate high levels of service reliability.

The decision to use high-strength alloy steels is based on weight and economic factors. Airframe space for gear components may be reduced because of smaller diameter shock strut components, smaller pins (reduced space for joints), smaller diameter trucks and axles, and, in some instances, smaller drag brace, side brace, and attach fittings. By reducing the space required for these components, the wheel well size can be minimized and aerodynamic surfaces can be optimized, which allow an increase in fuel tank size (optimal wing spar location) or additional space for other uses.

The use of high-strength alloy steel parts is economical because it reduces weight, thereby allowing for more efficient aerodynamic surfaces and providing the potential for increased payload and fuel.

For example, the trailing edge of the wing is relatively shallow. Using high-strength alloy steel flap tracks, flap carriages, and flap actuating components reduces the profile and decreases spatial envelope requirements while meeting or improving aerodynamic requirements. This also optimizes wing shape and reduces the potential need for bulging aerodynamic surfaces, which in turn reduces drag and increases airplane performance.

2 IMPORTANCE OF PROPER INSPECTION AND REWORK

Following proper rework practices and using Boeing-provided documents during maintenance and overhaul are necessary to achieve the benefits associated with high-strength alloy steel components and help ensure safe airplane operation.

Airline personnel who participate in component rework, maintenance, and overhaul tasks should be familiar with the properties of high-strength steels and understand the negative effects that can result from:

- Sensitivity to stress concentrations (notch sensitivity).
- Microstructural damage from embrittlement or overheating.
- Detrimental surface conditions.
- Corrosion.
- Improper processing.

Improper rework practices can result in unscheduled maintenance or surface damage that causes crack initiation. Maintenance efforts focus on corrosion prevention and removal in addition to normal checks for wear and free play.

High-strength alloy steels can experience rapid crack propagation from stress corrosion under certain loading conditions. Therefore, surface damage detection is important during overhaul and on components in service. Removing visible surface corrosion before pitting begins (such as during a C-check) helps prevent conditions that can lead to crack initiation. The best safeguard against corrosion is to ensure that finishes conform to the design and that design improvements are incorporated as minor changes whenever possible.

Components manufactured from steel alloys heat-treated above 180 ksi (180,000 psi) should be reworked in accordance with guidelines in Component Maintenance Manuals (CMM) 32-00-05, 32-00-06, and 32-00-07. Although these guidelines apply directly to landing gear components, they can be used to plan the overhaul rework of all high-strength steel components. Standard Overhaul Practices Manual (SOPM) 20-10-01 generally is specified in each CMM section for the rework of wing components (e.g., flap tracks, flap carriages). For repair of high-strength, 300M steel parts on DC-10 and MD-11 airplanes, use CMM 20-11-02; for DC-9, MD-80, MD-90, and 717 airplanes, use CMMs 20-10-18 and 20-10-06.

In addition, airline personnel need to understand the importance of maintaining component finishes while in service (in situ, or on the airplane). This includes repairing damaged finishes to prevent corrosion and ensuring that solvents and materials that come in contact with the finishes do not result in premature degradation and unscheduled component removal.

Boeing documentation describes the methods for detecting base metal damage while in service and during overhaul. Common techniques include detailed visual inspections and other nondestructive inspection methods, such as magnetic particle inspection (MPI) and fluorescent penetrant inspection (FPI). (See SOPMs 20-20-01 and 20-20-02.) Ultrasonic or eddy current inspections also may be useful for in situ inspections.

Boeing also is developing supplemental, specialized techniques, such as the Barkhausen inspection, to detect base metal heat damage under chrome plating or other protective finishes. This technique can be used successfully to screen components with suspect damage. For example, if an axle fractures as a result of chrome-grinding heat damage during manufacture or overhaul, the Barkhausen inspection allows other suspect components to be screened without first performing a chrome strip and temper etch (e.g., nital etch) inspection on all suspect axles.
GUIDELINES FOR REWORKING HIGH-STRENGTH ALLOY STEEL COMPONENTS

This section provides guidelines for reworking high-strength alloy steel components and describes some of the implications of improper rework procedures.

- Stress concentrations.
- Overheating components.
- Hydrogen embrittlement.
- Cadmium embrittlement.
- Improper finishing.

STRESS CONCENTRATIONS

During component design, eliminating or minimizing areas of stress concentrations is a key objective. Special attention is given to protective finish runouts adjacent to stress concentration details. In addition, all stress concentration details are subject to extensive testing and/or analysis to ensure that no detrimental effects are introduced into a part. Any rework or repair must not increase stress concentrations that degrade component durability.

High-strength alloy steel components (along with those made from other materials) are shot-peened to create a shallow layer of compressive residual stress at the surface. This layer helps to

- Minimize the effects of stress concentrations in transition areas.
- Impede crack initiation and initial crack growth caused by fatigue or stress corrosion.
- Create a surface that will have minimal adverse effects from the residual stresses of plating.

When a surface is machined or ground to remove damage, the reworked area should be shot-peened with proper overlap onto the existing shot-peened surface. During overhaul, personnel must observe the plating runouts specified in the CMM sections and SOPMs 20-10-01 and 20-42-03.

For example, when a coating such as chrome or nickel plating is applied to surfaces to prevent wear or corrosion, the coating must exhibit proper runouts that terminate before the tangent of fillet radii, edges, or other shape changes. Boeing SOPM guidelines should be followed for the rework of any component and for all types of plating or coating. Rework or overhaul of components should not introduce stress concentrations, or otherwise increase stresses, which can reduce the service life of a component below that of the original design configuration.

Stress concentrations can lead to initiation of cracking by fatigue, stress corrosion, or hydrogen-assisted stress corrosion. These cracks may result in a fracture or scrap of a component when found while in service or during overhaul. The following are examples of stress concentrations that can lead to cracking.

Transitions or radii that are sharper than original design. When removing damaged material from part surfaces during rework, the new transitions or radii should not cause an unacceptable increase in stress concentration at the location or degrade the original design features. When locally machining out corrosion or damage during overhaul, a gradual transition into the reworked depression is necessary.

The intent is to remove the least amount of material possible while ensuring that all discrepant material is removed and the original design strength and durability are maintained. There are few options to restore these machined depressions to meet interface requirements. One type of rework or overhaul, sulfamate-nickel plating, is common on shock strut cylinder diameters and is used to repair lug faces to design dimensions as follows:

- Local blends on inner cylinder outer diameter surfaces and outer cylinder inner diameter surfaces often are filled with sulfamate-nickel plating to restore them to dimensions that are suitable for subsequent chrome plate application.
- Spot facing on lugs is controlled to have a generous radius at the transition to the adjacent surface and usually is kept at the minimum depth necessary to clean up the damaged surface. Spot face depressions typically are not filled with plating to restore the dimension but instead are finished in the same manner as the original design. Spot face transition radii need to be such that they can be shot-peened to the requirements of the adjacent surfaces.

When the entire face of a lug must be machined to remove damage, the new lug transition radii should be shaped and positioned in accordance with CMM requirements. Surface transitions into the lug hole and at the lug edges must have design transitions that will allow restoration of shot-peening on all reworked areas and permit complete seating of bushings without contacting hole edges.

Abrupt changes in sections, holes, and sharp-cornered keyways should be avoided. Proper design will reflect generous fillets, gradual changes of shape, and the use of relief grooves in areas of high stress. Finer surface finishes also may be needed to eliminate unnecessary stress concentrations, especially in areas of machined radii or undercuts. Overhaul should reflect the same careful, detailed review that occurred during the original design.

Plating conditions and runout controls that are not in accordance with design standards. During overhaul, many landing gear components are completely stripped to replace nickel and chrome plating. In most instances, these repairs involve rework of the base metal. The new plating deposits frequently are thicker than the original design configuration.

In all cases, it is important to adhere to the SOPM recommendations. This will ensure that the restored plating is of high quality and that it does not terminate with an abrupt edge. Through-thickness cracks in chrome plate (generally present where there is evidence of chicken-wire cracking) can lead to corrosion at the base metal interface.
and deterioration of the plating adhesion. Through-thickness cracking also can lead to fatigue or stress corrosion cracking of the base metal beneath the plating.

Visual evidence of chicken-wire cracking after chrome grinding indicates poor chrome quality and also may indicate the possibility of base metal heat damage. Chicken-wire cracking noted in SOPM 20-10-04 indicates that the chrome should be stripped and replated.

If the plating runouts are blended or machined to remove the abrupt plating edge, the techniques must be well controlled to avoid damaging the adjacent base metal. Improper blending can remove the required shot-peened layer or create undercuts or grooves at the edge of the plating that can cause cracking in service.

Several in-service fractures have been attributed to improper plating technique, poor-quality plating, improper runout conditions, and base metal damage caused by poor blending or machining control.

Proper use of special plating techniques, such as conforming anodes and robbers, can control plating thicknesses and runouts. This can reduce the possibility of chrome chicken-wire cracking and poor runout details.

Plating into a transition (radius transition or undercut) will create a stress concentration that can cause crack initiation. For example, figure 1 shows an outer cylinder clevis plated into the lug transition. In service, fatigue cracking initiated at the plating runout led to lug fracture.

**Corrosion and pitting.** Corrosion pits are stress concentrations. As the pit forms, it damages the shot-peened layer locally at the surface. The pit then grows through the compressive layer, and the change in residual stress state and the pit geometry initiate stress corrosion cracking. This type of cracking most often occurs on surfaces that are both prone to corrosion and exposed to sustained tensile stresses while in service, such as the lower surface of landing gear trucks, axles, and the surfaces of forward and aft trunnions.

Corrosion pitting also can lead to fatigue crack initiation depending on the component, the location of pitting, and cyclic loading conditions. In these cases, the cracks can propagate to the critical length and result in ductile fracture of the component. The degree of cracking tolerated before fracture varies by component, crack location, and component loading conditions.

To prevent excessive corrosion, thorough visual inspections should be performed on a regular basis to evaluate the condition of the protective finishes. Damage should be repaired soon after it is found. Touching up damage to accessible enamel and primer in a timely manner can prevent the formation of corrosion pits and reduce the need for excessive rework during overhaul. Rework that requires low-hydrogen-embrittlement (LHE) cadmium stylus plating should be performed when the component is not loaded.

When the component is removed for overhaul, all evidence of corrosion must be removed and finishes restored to design requirements or better. The sequence of rework operations is provided in CMMs 32-00-05, 32-00-06, and 32-00-07.

Landing gear truck fractures have occurred in service because of corrosion on the inner diameter of the main gear truck beam (figs. 2 and 3). These fractures may be caused by a combination of degraded protective finishes on the truck inner diameter, poor drainage, and contact with the corrosive chemicals in washing solutions or deicing compounds. Truck fractures most often occur at maximum ground loads such as after fueling or during preflight taxi.

Figures 4 and 5 show a drag brace from which corrosion was not removed completely during overhaul. The part was subsequently shot-peened, and new protective finishes were applied over the residual active corrosion. This resulted in crack initiation and propagation while in service and the eventual fracture of the component.

**Mechanical damage.** Stress concentrations can be created by mechanical damage that compromises the protective finishes and alters the compressive shot-peen layer. This
damage often is caused by improper maintenance practices such as jacking adjacent to a jack pad or an inadvertent impact with tools or ground-support equipment (e.g., tow vehicles). Although high-strength alloy steels are hard and resist dents, scratches, and nicks, stress concentrations caused by mechanical damage can dramatically reduce the service life of a component.

High-strength alloy steel components also can be damaged by mishandling during shop rework (e.g., dropping, impact), and in some circumstances, by foreign object debris. Possible mechanical damage to a high-strength alloy steel component should be evaluated by the operator and repaired as needed.

If the damage is local and widespread deformations are not evident, repair may be similar to that required for corrosion and pitting. All deformed material must be removed before refinishing; deformed high-strength steel alloy components must not be straightened. Contact Boeing for assistance, if needed.
OVERHEATING COMPONENTS

Overheating of components can change the original steel temper and mechanical properties of the affected area. Overheating damage can be caused by:

- Frictional heating while in service.
- Abusive machining and grinding operations during manufacture or overhaul.
- Exposure to high temperatures during overhaul bake cycles.
- Unusual conditions such as refused takeoffs and local fires.

The degree to which the mechanical properties are changed depends on the temperature and duration of exposure.

Overheating can result in overtempered martensite (OTM) or untempered martensite (UTM) formations in the base metal. Both conditions can be detected by a temper etch (i.e., nital etch) inspection of the base metal. UTM indications show white during temper etch inspections and often are found within patches of OTM, which show dark gray to black during temper etch inspection. SOPM 20-10-02 provides details about the inspection process and interpretation of the results.

Heat damage generally is removed by carefully machining the base metal. Afterward, another temper etch inspection is done to ensure that the machining did not create more heat damage.

UTM formations may be accompanied by heat-induced cracking within these overheated areas that, if left in place, can propagate while in service. Figures 6 and 7 show service-induced heat damage on the inside diameter of a main gear outer cylinder. This component developed extensive frictional heat damage in the upper bearing contact area as a result of improper clamp-up. The heat damage led to cracking through the cylinder wall. Salvage was not possible.

Less severe friction-induced heat damage can be found on inner cylinders during component overhaul. This damage, which occurs on a more frequent basis, is caused by vertical motion against the lower bearing surfaces. This damage generally is shallow and can be removed by machining. After overhaul operations are completed, the component is returned to service in accordance with CMM requirements.

When grinding chrome to finish dimensions, overheating the base metal can create UTM and OTM formations under the chrome. Figures 8 and 9 show a severe grinding burn on a main landing gear axle that resulted in a fracture. Similar grinding burns also have led to the fracture of flap carriage spindle journals (figs. 10 and 11).

Any visible evidence of chrome plate distress can indicate the likelihood of base metal heat damage. Figures 12 and 13 show a grinding burn that led to the fracture of a pivot pin. SOPM 20-10-04 and CMMs 32-00-05, 32-00-06, and 32-00-07 provide guidelines that indicate when chrome must be removed during overhaul.

Some heat damage is so severe that the heat-treat condition of material is altered in adjacent areas. This widespread reduction in metal hardness (Rockwell-C hardness readings) may indicate that the component cannot be salvaged. Axle heat damage caused by a wheel bearing fracture may lead to such a condition.

Shop procedures such as magnetic particle inspection and LHE cadmium stylus plating can cause arc burns if appropriate precautions are not maintained during processing. Figures 14 and 15 show a fracture resulting from an arc burn that developed during LHE stylus cadmium plating. (Note: In this article, cadmium plating means cadmium-titanium or LHE cadmium plating.)

Overheating will not alter the heat-treat conditions of the base metal if the temperatures are below the original tempering temperature. However, the component still may require special
consideration (or rework) because

- Shot-peening may be compromised (heated above 400°F).
- Cadmium embrittlement may occur (heated above 450°F with cadmium plating present).
- Chromate conversion coating may be degraded (heated above 400°F).
- Organic coatings or sealants may crack or become brittle or discolored (wide range of temperatures).

These situations often occur when components are

- Inadvertently overheated in an oven.
- Exposed to elevated temperatures with some finishes intact or bushings installed.
- Exposed to fire.

Residual cadmium often is left on a part during overhaul processing to protect it from corrosion. The part is then stripped of all cadmium and re-plated near the end of overhaul. Parts with residual cadmium should not be heated over 400°F during overhaul.

Bushings should not remain installed during overhaul unless retained by specific CMM requirements. Bushings must be removed to permit a thorough inspection of the base metal and to avoid bushing-to-bore interface degradation during bake cycles. Design finishes are restored and new bushings with design interferences and dimensions are installed because bushing wear limits do not apply during overhaul.

Wheel bearing fractures or high-energy refused takeoffs often result in high local heat on an axle. Discoloration of the enamel, primer, or chrome or evidence of cadmium damage on the inner diameter of the axle may require the heat-damaged component be removed from service.

Overheating affects components to various degrees; in some instances, only finish durability is degraded. This may result in a shorter than planned time between component overhauls. Contact Boeing for assistance with questions about repairing or salvaging high-strength alloy steel components that appear to have been damaged by overheating.

**HYDROGEN EMBRITTLEMENT**

Hydrogen embrittlement occurs when a high-strength alloy steel component absorbs hydrogen, which is not removed in a timely manner in accordance with the SOPM (e.g., embrittlement relief baking).

When hydrogen remains in a component for an extended time, the microstructural damage that develops significantly degrades the mechanical properties of the steel. The infused hydrogen migrates to areas of high stress (e.g., material internal stresses) and creates local microstructural damage. When the component is installed on an airplane, this internal damage can lead to crack initiation and propagation, resulting in component fracture.

The elevated temperatures reached during hydrogen embrittlement relief baking, which is performed directly after stripping or plating operations during overhaul, effectively remove hydrogen generated during these operations. Processes that must be followed with relief baking include chrome, sulfamate-nickel, and LHE cadmium plating; stripping operations; and many nital etch inspections. After hydrogen-generating operations, relief bake delay time limits must be observed to ensure complete hydrogen removal. In general, the best practice is to initiate baking as soon as possible following a plating operation.

The delay time between plating completion and baking start typically is observed. However, when thick plating deposits or multiple plating operations are performed on a single component, the total time between initial plating start and baking start is a key factor when determining the maximum delay time allowed. For example, embrittlement relief baking must begin 10 hr after sulfamate-nickel plating is completed or within 24 hr after plating.
begins, whichever results in the shortest overall bake delay.

Figure 16 shows a flap track that cracked because of hydrogen embrittlement 149 flight cycles after overhaul. Figure 17 is a scanning electron

microscope view of a typical hydrogen embrittlement crack where separation occurs along grain boundaries. Typically, hydrogen embrittlement cracks propagate rapidly once loads are applied to the part. In some cases, internal residual stresses are sufficiently high to cause cracking even before the part is installed.

**CADMIUM EMBRITTLEMENT**

Overheating LHE cadmium or cadmium-titanium plated components causes embrittlement of high-strength alloy steel by cadmium, resulting in cadmium diffusion into the steel grain boundaries. Solid-metal embrittlement by cadmium can occur at temperatures below the cadmium melting point. These effects on the base metal can begin to occur at 450°F, whereas the cadmium melting point is generally 610°F. The microstructural anomalies resulting from cadmium embrittlement can lead to component fractures in service.

Determining whether cadmium has migrated into the grain boundaries of cadmium-plated, high-strength alloy steel components requires destructive testing of the components. If these components have been overheated, salvage may not be possible. However, if high-temperature exposure was short and discoloration of the enamel or primer was minimal, the component may be a candidate for salvage. Slight or no discoloration of the enamel or primer may indicate the cadmium plating was not heated to the extent that cadmium embrittlement would be suspected. Boeing can assist in this determination.
Improper finishing

Improper application of protective finishes during manufacture or overhaul can lead to finish degradation, corrosion, and corrosion pitting, which can result in component fracture while in service (figs. 2 and 3, pp. 27–28). Some cleaners and chemicals may accelerate finish degradation and lead to corrosion. Operators should ensure that cleaners and chemicals are tested before use in accordance with Boeing document D6-17487, *Evaluation of Airplane Maintenance Materials*. Testing to these requirements will determine whether a cleaner or chemical is detrimental to protective finishes or base metal. However, long-term exposure to the solution or material still may adversely affect finishes.

As a rule, if material removal exceeds 0.0015 in (or 10 percent of the Almen strip intensity), the surface should then be shot-peened to CMM requirements. Exceeding shot-peen requirements is better than leaving areas without shot-peening. All portions of a component that are to be shot-peened should first be completely stripped; no cadmium residue should remain on the surface.

Personnel must ensure that materials used for activities such as cleaning and deicing conform to Boeing document D6-17487 requirements and will accomplish the intended task (verified by the material provider or operator). Refer to the Aircraft Maintenance Manual for materials specified for aircraft cleaning and deicing. The CMM specifies the materials for use in repair. High-strength alloy steel components should be stripped completely during overhaul (including removal of bushings and bearings in all structural components). This allows a thorough inspection of the base metal (a primary component overhaul requirement) and ensures that all finishes, including the LHE cadmium plating and conversion coating, are restored to the original design requirements. This is addressed in an all-model Boeing service letter dated April 23, 2002, *Overhaul of High Strength Steel Components–Cadmium Strip Required* (e.g., 757-SL-20-036-A, 767-SL-20-038-A, 747-SL-20-062-A).

Restoration of the shot-peened layer during overhaul is important to ensure that the shot-peen compressive residual stresses are maintained or restored. Removing or damaging the shot-peened layer can reduce the protection that this compressive layer provides against fatigue and stress corrosion crack initiation. Discontinuous shot-peening can lead to crack initiation at the tensile surface stresses adjacent to edges of abrupt compressive layer runouts (no fade-out). All reworked surfaces must be shot-peened after removing material damaged by corrosion, heat, and deformation.
High-strength alloy steels are used widely in landing gear, flap track, flap support carriage, and flap actuating components on Boeing airplanes. These high-strength materials provide significant structural benefits and can result in a weight savings. These parts often are selected for placement in limited-space envelopes (e.g., wheel wells and wing trailing-edge support structures) because of their reduced profile or smaller diameters.

With these benefits comes a need for airline personnel to exercise precise care when reworking high-strength alloy steel components during scheduled maintenance and overhaul. They need to understand the importance of maintaining component finishes while in service, follow proper rework practices, and use Boeing-provided maintenance procedures, planning guidelines, and checklists during scheduled maintenance and overhaul processes.

Improper rework and overhaul practices may result in loss of finish, corrosion, and damage to or alteration of the base metal, which may require unscheduled maintenance between overhauls. The resulting damage also could precipitate crack initiation and removal of the part from service. Removing corrosion and restoring worn interfaces on a periodic basis are the main emphases of high-strength alloy steel component overhaul rework.

Key benefits of proper rework and maintenance practices include the possibility of extending the gear or component overhaul intervals (time between overhaul). Operators also will benefit from the enhanced reliability and durability of high-strength alloy steel components on their airplanes.

Operators should ensure that proper SOPM and CMM documentation is used during overhaul and rework of high-strength alloy steel components. The planning flowcharts in CMMs 32-00-05, 32-00-06, and 32-00-07 are value-added guidelines for planning the rework of any high-strength alloy steel component on a Boeing airplane.

Editor's note: The SOPMs and CMMs identified in this article can be ordered through the Data and Services Catalog.
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INCREASED USE OF TITANIUM ALLOYS AND TUNGSTEN-CARBIDE COATINGS

Boeing and the industry are working together to develop thermal spray coatings to replace chrome plating. These coatings, which currently are used in some production and repair applications, can be applied using the high-velocity oxygen fuel (HVOF) process. The two coatings primarily in use are tungsten-carbide-cobalt and tungsten-carbide-cobalt-chrome.

These tungsten-carbide coatings can be applied to steel and titanium alloys. Steels can be either chrome plated or coated with tungsten-carbide. Titanium alloys cannot be chrome plated but can be coated with tungsten-carbide through the HVOF process. With this coating, the lighter weight titanium can be used in more landing gear and flight control applications where high-strength alloy steels would have been used in the past, resulting in a weight savings.

Titanium alloys are being used more often in the design of new landing gear and flight control support structure. These materials, which are becoming more readily available, exhibit higher strength-to-weight ratios than do steel alloys. Titanium alloy components require less finishing, are more easily maintained, are less prone to corrode in service, and require less overhaul processing than most high-strength alloy steels. The durable, HVOF-applied tungsten-carbide coatings broaden possible titanium alloy applications. HVOF-applied tungsten-carbide coatings also provide multiple process benefits when compared with chrome plating:

- Embrittlement baking is not needed after application because hydrogen does not infuse into the base metal.
- When grinding the coating to the desired finish, overheating the base metal is less likely.
- Applying coatings using the proper HVOF procedures and equipment can save shop processing and flow time.

These benefits are driving more tungsten-carbide applications to be identified for both steel and titanium alloy components in production and as a substitute for chrome plating during component overhaul. Some repair agencies and airlines are purchasing equipment and preparing facilities for HVOF coating application during overhaul as an alternative to chrome plating.

MAINTAIN FINISH DURABILITY THROUGH PROPER WASHING, CLEANING, AND FREQUENT RELUBRICATION

Properly restoring the finish of high-strength alloy steel components to original design conditions during overhaul minimizes the effects of washing and cleaning solutions, solvents, and compounds on the structure. Design-quality finishes are less likely to degrade in service. In addition, frequent relubrication of these components soon after washing protects finishes at lubricated interfaces. Relubrication intervals are specified in the Aircraft Maintenance Manual (AMM) but generally are adjusted based on operator experience.

Boeing continues to receive reports of premature corrosion from operators that use pressure-washing techniques on their airplanes. The following guidelines will help operators maintain the finishes of their high-strength alloy steel components through heightened awareness and knowledge about key aspects of airplane washing processes.

Washing and Cleaning Techniques

- Operators should avoid using high-pressure washing.
- When cleaning landing gear and other mechanical, electrical, or hydraulic components, operators must follow the requirements in the AMM procedure Remove Material Around Sensitive Components (e.g., 747-400 AMM 12-25-01, p. 301, 2.A.[2]).
- After washing landing gear and control surfaces, operators should complete rinsing within the specified time period. Rinsing must not be delayed.
- Operators should cover joints without relubrication fittings to avoid contamination from water and cleaning solutions.

- If washing is done at the beginning of a scheduled maintenance period, operators should not wait until the end of the period to perform lubrication—the elapsed time may not be acceptable.
- When flushing or rinsing landing gear assemblies, operators should reduce spray pressure, ensure that the nozzle is at least 12 in from the joints, and replace the corrosion preventative compound after washing. (See the multimodel maintenance tip, “Airplane High Pressure Washing,” May 18, 1999.)

Impact of Aggressive Washing on Finishes and Lubrication

- Short-term exposure to materials that normally contact properly restored finishes, such as solvents, should not cause premature degradation or loss of finish requiring repair or unscheduled removal between overhaul. However, premature corrosion and deterioration can occur in service when water or foreign material enters joints as a result of spraying cleaning solutions directly into joints. This aggressive washing technique displaces grease and negatively affects lubricated joints even though immediate relubrication will purge most contaminants from the lubricated cavities.
- Most corrosion-related cracking and fractures in service are aggravated by aggressive washing techniques and corrosive solutions. To help ensure that finishes do not degrade prematurely between overhaul, operators should lubricate all greased bearings and cavities no later than 12 hr after airplane washing. Relubrication and replacement of corrosion preventative compounds within this time period minimizes finish exposure to corrosive cleaning agents following airplane washing.