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Advanced Coating Systems for Air Force Aircraft

The search for coating systems that can reduce the use of hazardous components while providing acceptable corrosion protection for aluminum substrates has made significant progress over the past several years. While a non-hazardous corrosion inhibitor system that has all of the performance characteristics of hexavalent chromium has not been identified, coating systems that eliminate chromate in one or more of the components have shown acceptable performance and are in the process of field demonstration and implementation into production. Two demonstration programs target coatings applied to the outer mold line of aircraft.

The Boeing-led JG-PP program performed laboratory evaluation and flight-testing of non-chromated primers that are applied over a chromate conversion coating. The 4-year flight test program utilizing US Air Force and Navy fighter aircraft officially concluded this year although the coatings will remain on the flight vehicles for a final inspection at the next depot maintenance cycle. Preliminary conclusions are that non-chromate primer applied over a chromate conversion coating may be adequate for many weapon systems. Further details on the JG-PP program can be found at http://www.jgpp.com/.

The Air Force Aging Aircraft Office is sponsoring an Advanced Technology Demonstration (ATD) program to demonstrate a coating system that replaces the chromate conversion coating with a non-chromated adhesion promoter. The chromated primer is retained for long-term corrosion protection. Figure 1 shows the painting process operations, the materials presently used, and the proposed coating component.

The key component change is replacing the chromate conversion coating with Boegel EP-II/AC-131. The Boegel coating technology was developed at Boeing as a non-hazardous adhesion promoter for painting and bonding applications. It is now available commercially from Advanced Chemistry & Technology as AC-131 for the painting formulation and AC-130 for adhesive bonding. The Boegel coating solution is a dilute aqueous mixture of zirconium alkoxide and a silane coupling agent. The solution is applied to the part by spraying or brushing and is allowed to dry in place without a rinse step. The resulting coating is a thin (50 to 200 nm) gradient coating that bonds to the metal surface oxides and has functional groups at the surface to bond into epoxy primers. The coating adheres to aluminum, titanium, and corrosion resistant steel making it a good choice for mixed metal surfaces.

Operation	Present	ATD Demonstration
Clean and deoxidize	Alkaline cleaner Acidic brightener	Solution (acid deoxidizer, MIL-C-38334, Chemidize 727) Solid State (NaHCO3, Spongejet)
Conversion Coating	Alodine 1200	Boegel EP-II/AC-131
Primer	MIL-PRF-23377 or MIL-PRF-85582	MIL-PRF-23377 or MIL-PRF-85582
Topcoat	MIL-PRF-85285	Deft 99-GY-001 (APC)

Figure 1 – Current and proposed Coating System Components

Several studies have shown that coating systems using Boegel/AC-131 conversion coatings have equivalent corrosion performance to those with a chromate

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conversion coating provided a chromated primer is used. Typical results are shown in Figure 2. These panels with the control or ATD candidate coating systems show only minor darkening of the scribes and no white corrosion products after over 5600 hours of exposure to ASTM B117 salt spray. Both panels have a MIL-PRF-85582 primer and Deft Advanced Performance Coating topcoat. Similar results are obtained for panels with primer only and for coatings exposed to cyclic corrosion testing (ASTM G85, A5).

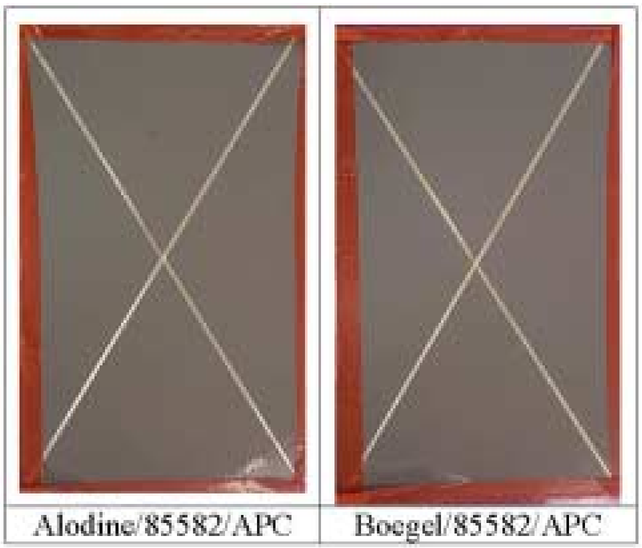

Figure 2 – Control (left) and Candidate (right) coating systems after 5400 hours Salt Fog Exposure

Replacing chromate conversion coating with Boegel/AC-131 has several advantages from a performance and processing viewpoint. The capability of Boegel/AC-131 to adhere to different metal surfaces has been mentioned above. A significant advantage is the expanded options for the deoxidizing or "brightening" process. Chromate conversion coating requires a reactive metal surface that is currently achieved using a "brightener" containing strong aggressive acids. Incomplete removal of the brightener solution can lead to significant corrosion. Incomplete removal of surface oxides will inhibit chromate conversion coating formation resulting in poor paint adhesion. Boegel/AC-131 will bond to adhered oxides as well as to the metal substrate. Consequently, a cleaning process that removes organic soils and loose oxides should be sufficient to produce acceptable adhesion of the coating system. Mild chemical brighteners or mechanical processes can be used to minimize damage to the airframe yet still give good performance with Boegel conversion coatings.

Another advantage of using Boegel/AC-131 is a possible reduction in processing steps and drying times. The rinse step required after chromate conversion coating is eliminated. Dry time between conversion coating and priming is reduced, especially when waterborne primers are used. Other optimizations may be possible such as using Boegel/AC-131 as the rinse step after deoxidizing.

The Aging Aircraft ATD program will develop processing methods, address interactions between the processing operations and materials, and conduct a flight test validation of the demonstration coating system. Target vehicles for process development and flight test validation are anticipated to be C-17 transports and F-15 fighter aircraft. The program work plan will investigate cleaning and deoxidizing procedures as discussed above, develop paint hanger scale coating procedures, validate coating system corrosion and durability performance, develop appropriate stripping and repainting procedures, and conduct an application and flight test of the coating system. The end deliverable will be a process description for painting aircraft appropriate for addition to Air Force Technical Order 1-1-8.

In addition to the ATD program, Boegel/AC-131 has other implemented or emerging applications. The F-22 program has been using Boegel/AC-131 as a replacement for phosphate-fluoride for painting titanium structure for several years. The process is being used at several suppliers and its use has significantly reduced or eliminated paint adhesion failures. Corporate specifications for Boegel coating of titanium for painting and bonding are being prepared for coordination in 1Q02.

Boeing Commercial Airplanes has approved Boegel/AC-131 on interior low corrosion risk non-structural aluminum parts as an alternative to anodizing. Target hardware includes cockpit console components and clips and brackets. A process specification is in work with coordination scheduled for 2Q02.

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Selected Regulatory Updates

Remaining legal challenges to EPA's 1997 more stringent NAAQS (National Ambient Air Quality Standards) for fine particles (soot) and ground level ozone (smog) have recently been overcome. EPA, in partnership with state and local governments, intends to move forward with programs to further reduce emissions from mobile and stationary sources, so that all areas of the country achieve these higher air quality levels. For ozone attainment, additional emission reductions in volatile organic compounds and nitrogen oxides are needed. For fine particulate attainment, emission reductions are also needed from sources of sulfur, diesel emissions, ammonia, and several other combustion by-products. The following regulatory issues apply:

8-Hour Ozone NAAQS Review

The U.S. Supreme Court ruled that EPA's 1997 eight-hour ozone and PM (particulate matter) 2.5 NAAQS did not constitute unconstitutional delegation of legislative authority. On 3/26/02 the D.C. Circuit Court of Appeals ruled that the 1997 NAAQS are not arbitrary or capricious, clearing the way for EPA completion of the NAAQS. A Nov. 2001 EPA proposal addresses the court's requirement to consider beneficial effects of ground-level ozone in blocking solar radiation. EPA considers any such beneficial effect to be uncertain and small, and proposes to retain 0.08 ppm NAAQS. EPA is also updating the 1996 ozone criteria document, for the next round of NAAQS revision, which should occur every five years.

FORM OF O3 NAAQS

Form of Standard	1-hr NAAQS	8-hr NAAQS
Avg time	1-hour	8-hour
Level	0.12 ppm	0.08 ppm
Form	exceedance-based	concentration-based
Air Quality Indicator	daily max 1-hr conc within day	daily max 8-hr conc starting within day
NAAQS Statistic	annual estimated exceedances	annual 4th high 8-hr daily max conc
Rounding	0.125 ppm–smallest number greater than the 0.12 ppm NAAQS level	0.085 ppm–smallest number greater than 0.08 ppm NAAQS level
Compliance period	three consecutive years	three consecutive years
Attainment Test	avg expected exceed'c rate <= 1.0	avg annual 4th high daily max 8-hour conc <= 0.08 ppm

Figure 1 – EPA's comparison of the two ozone NAAQS

8-Hour Ozone NAAQS Attainment Strategy

The U.S. Supreme Court (Whitman v. American Trucking Assoc., 2/27/01) found EPA's 8-hour Ozone Implementation Policy to be contrary to statutory requirements for classifications based on ozone design value. EPA must integrate the statutory classification requirements (based on 1-hour NAAQS) with an attainment strategy for the 8-hour NAAQS *(See Fig 1)*. EPA received public comment on options at 3/5/02 and 3/7/02 meetings. EPA background documents at http://www.epa.gov/ttn/rto/ozonetech/o3imp8hr/o3imp8hr.htm describe numerous options. Some technically valid, common sense options have uncertain statutory support, and could be rejected by the court. Eight-hour attainment SIP's (State Implementation Plans) will be due around 2007. On 6/21/01, EPA issued "Ozone Flex Guidelines" for areas that are in 1-hour NAAQS attainment but may not meet the 8-hour standard. Under Ozone Flex, EPA would recognize and credit early emission reductions in future SIPs. Ozone Flex guidelines are at http://www.epa.gov/ttn/oarpg/t1/memoranda/o3flexguidelines.pdf.

Ozone Attainment Designations, 8-Hour Standard

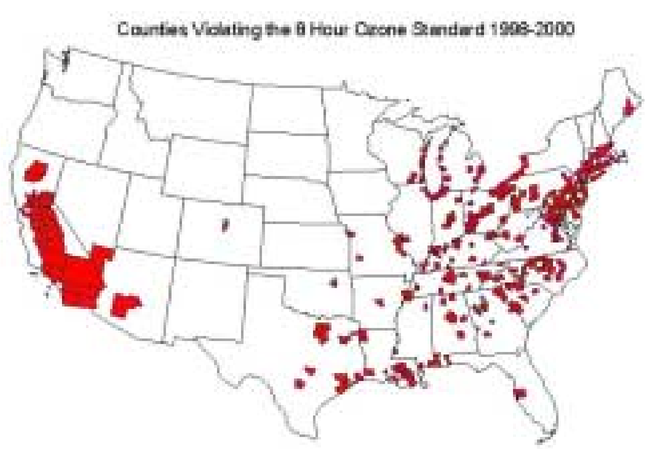

Figure 2 – Latest available EPA data on counties in 8-hour non-attainment

Due to court remand of EPA's 8-hour ozone implementation policy, EPA plans to make 8-hour attainment designations in 2004, based on 2001-2003 data. Environmental groups seek designations before 2004, but have not filed legal action. Texas seeks delayed designation for areas like Austin that enter into voluntary early reduction programs. Using 1998-200 data, some 329 counties would be in 8hr non-attainment. A County list is at http://www.epa.gov/oar/aqtrnd00/carboz00.html *(See also Figure 2)*. C/MSA (Consolidated/Metropolitan Statistical Area) boundaries are presumptive non-attainment boundaries, but States may vary these, especially if adjacent areas contribute to non-attainment.

Particulate NAAQS Review

Ambient monitoring shows exceedances of the 15 $\mu g/m^3$ annual NAAQS for PM 2.5 in CA and eastern U.S. (except FL and the far northeast). See http://www.epa.gov/oar/oaqps/pm25. EPA will complete a review of the particulate NAAQS prior to designating non-attainment areas for 1997 PM 2.5 NAAQS in 2005. American Lung Assoc and CA OEHHA/CARB (Office of Environmental Health Hazard Assessments/California Air Resources Board) staff think the 24-hour PM 2.5 NAAQS should be much lower than 65 $\mu g/m^3$. CARB will consider a proposal in late June to set a CA 24-hour PM 2.5 standard of 25 $\mu g/m^3$.

A third draft of EPA criteria document for PM was released 5/08/02 at http://cfpub.epa.gov/ncea/cfm/partmatt.cfm?ActType=default. EPA will receive public comment until 7/10/02. CASAC (Clean Air Science Advisory Committee) will review the draft PM criteria document on July 18-19, 2002 and an EPA Staff Paper on Sept. 18-19, 2002. A March 2002 epidemiological study indicated that risk of lung cancer and heart disease mortality from fine PM in urban areas is equivalent to risk from secondhand smoke. The White House Office of Management and Budget seeks more research to support speciation of PM 2.5 particles, to focus on those that pose greatest health risks. An EPRI (Electrical Power Research Institute) study of Atlanta, to be published summer 2002, ties, cardiovascular health effects to fine carbon particulates, and identifies highest carbon PM sources. Largest Atlanta carbon PM sources in winter are vegetation/wood burning and diesel engines. Largest summer sources are secondary organics, diesel, and meat cooking. EPA will complete its PM NAAQS review before speciated PM risk data can be developed to allow a speciated PM NAAQS, but SIPs could use emerging speciation studies to develop a risk-based approach to PM attainment.

Recent studies have shown that bio-solids (sludge) from publicly owned treatment works contain bio-accumulative contaminants that may act as endocrine disruptors. One of which is brominated diphenyl ether (BDE), a chemical used in electronic and plastics flame-retardants. The following regulatory issues apply:

EPA Review of BDE Fire Retardants

The presence of brominated diphenyl ether (BDE) in wastewater bio-solids and human tissue has prompted an EPA review of health effects and presence of BDE in the environment, at the direction of EPA Administrator Whitman. The National Research Council is conducting a study of BDE in bio-solids. The National Institute of Environmental Health Sciences, EPA, and industry (under a voluntary Children's Chemical Evaluation Program) are doing health effect studies. The U.S. Geological Survey has found trace levels of fire retardants in lakes and streams.

European Restrictions on Brominated Fire Retardants

On 4/10/02, European Parliament deputies approved a legislative proposal to ban the use of pentabromodiphenyl ether (pentaBDE) by 7/2003, due to detection in human milk, wildlife, etc. Conciliation talks are necessary to resolve differences with another EU proposal that would also ban related compounds octaBDE and decaBDE, by 2006. These proposed bans may require increased fire risk studies.

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