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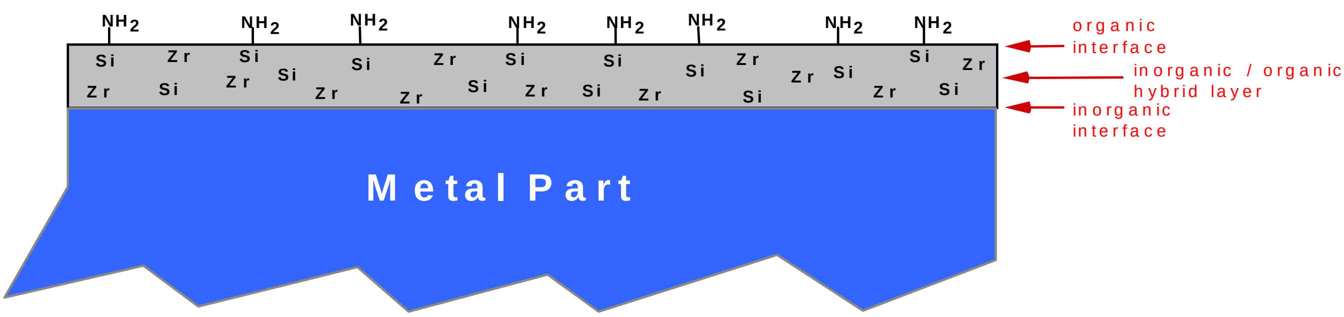
BOEING - PUGET SOUND'S ENVIRONMENTALLY COMPLIANT
SOL-GEL SURFACE TREATMENTS FOR METAL BONDING

Corrosion and fatigue of aircraft structure are two of the biggest problems limiting the lives of military aircraft. Adhesively bonded repair/reinforcement is a key approach for maintaining the Air Force's aging fleet, especially as a remedy for fatigue cracks. Bonding is also important for maintaining other DoD weapons systems. Bonded repairs provide substantial cost savings and reduced aircraft downtime when compared to component replacement. Bonded repairs have several advantages over traditional repair approaches using mechanical fasteners: improved structural efficiency, improved fatigue life due to elimination of fastener holes, and weight savings.

Metal treatment prior to bonding is a key factor for both the initial adhesion of a bonded joint and its long-term environmental durability. Standard metal prebond surface preparations, especially for on-aircraft repair, are either inconvenient or complex to use, contain hazardous materials (strong acids, hexavalent chromium, volatile organic compounds), and/or do not provide the performance necessary for successful long-term durable bonds. Past bond failures, primarily due to inadequate surface preparation, have been a limiting factor in the current use of bonded repairs, especially for primary structure.

Conventional approaches of preparing metal surfaces for bonding (anodizing and etching) promote adhesion by producing a high surface area structure which has both mechanical and physical (Lewis acid-base, dispersion, hydrogen bonding, etc.) interactions with the adhesive primer.

Previous work by Boeing and others has demonstrated the potential for sol-gel technology to revolutionize metal adhesive bonding by providing an environmentally compliant, high-performance, simple and inexpensive approach for surface preparation. The term "sol-gel" is a contraction for "solution-gelation" which involves the growth of metal-oxo polymers through hydrolysis and condensation reactions to form inorganic polymer networks.



Schematic of sol-gel coating on a metal part

Sol-gel chemistry is a versatile process that is capable of producing adherent thin films on metals and composites. Using appropriate precursors, films promoting adhesion of organic resins, such as adhesives, paints, and coatings can be produced. Adhesion is a result of the chemical interaction at the interfaces between the metal and the sol-gel and the sol-gel and the primer. Our approach is to use waterbased sol-gel chemistry to develop thin film coatings that effectively produce a gradient from the metallic surface, through a hybrid inorganic/organic layer, to the organic resin.

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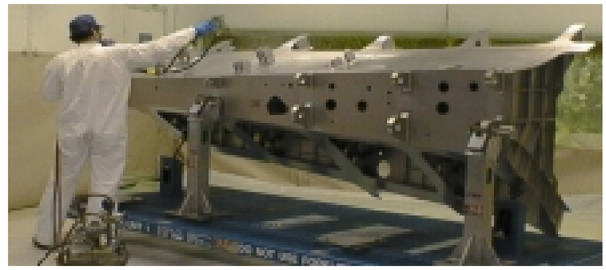
Aluminum: Adhesive-bonded repairs on aluminum aircraft range from adhering composite patches on damaged portions of aluminum skin, bonding of doublers, and reinforcement of corrosion degraded areas, to moisture-induced delamination of aluminum skins from aluminum honeycomb core.

Standard surface preparation techniques use phosphoric acid anodize or Pasa Jell 105 to provide a surface for bonding. These methods involve hazardous materials and generate waste materials that must be disposed of in an appropriate fashion. More recently, the grit blast/silane process has been used as an environmentally friendly alternative process technique. Drawbacks of this process include the need to contain and collect grit blast residue, and excessive process times. With the sol-gel process, it is possible to achieve a reproducible surface that results in durable bonded interfaces using readily available materials. Using appropriate materials and conditions, sanding, used in conjunction with the sol-gel prebond treatment and a bond primer, can yield a robust, durable bond interface system for use at depot sites, repair facilities, or on-aircraft in the field. Demonstrations of this process have been conducted on an F-15 belly skin and a B-52 fuselage component.

Demonstration of the sol-gel prebond process on a composite patch repair of fatigue cracks on a B-52 fuselage component

Titanium: The bonding of titanium using standard surface preparation techniques has not been an easy process for aerospace hardware. There are several programs that have used titanium bonding successfully; however, the surface preparation techniques that are used are often arduous and involve hazardous chemicals and processes. Additionally, there is not a universally acceptable technique available for the repair of titanium bonded structures in the field.

Using these sol-gel technologies, durable bonded interfaces on titanium alloys can be achieved for both original equipment and bonded repair. Methods for epoxy adhesives and coatings were developed and successfully implemented in several areas. A sol-gel coating to promote adhesion of epoxy and polyurethane paints was implemented in 1997 on F-22 hardware.



A sol-gel prepaint process was implemented on the F-22 titanium forward boom

More recently, a process was implemented to produce flight hardware for the X-32/JSF program, bonding titanium-to-titanium and titanium-to-composite structures. The process was also implemented on a B-2 in the first quarter of 1999 to produce some titanium honeycomb bonded spare parts. Cost savings opportunities for Ti bonding are being pursued on several programs including F/A-18, CH-47, F-22, JSF, and Boeing Commercial Aircraft (BCA).

Steel: Steel bonding, particularly in use for helicopter rotor blade erosion caps, has exhibited a surface treatment durability issue. Certain applications, such as the erosion caps on the Apache AH-64 rotor blades, require adhesive bonding of stainless steel hardware. The surface preparation process being used for bonding of this stainless AM355 or 301 hardware is a ferric chloride/hydrochloric acid etch (FCHAE) process. The process is based on an immersion technique and uses hazardous materials generating rinse water that needs to be treated and disposed of properly. The sol-gel techniques demonstrated for Al and Ti alloys have initially shown great promise for extended durability for these stainless applications. Plus, it has the added benefit of being easier to employ for repair of the Apache blades at the Army depot sites. Development efforts are focused on evaluating and optimizing the process for this application.

Current Efforts: Current efforts in sol-gel development include a Tri-Service DoD contract whereby the Air Force, Navy, and Army are partners in the program carrying out development and testing in their own laboratories. An evaluation program with Boeing is being negotiated, which would evaluate these materials for repair use on commercial airliners. Initial discussions have been carried out with Cytec which would make them the initial supplier for the sol-gel kits. The High Speed Research (HSR) program evaluated a sol-gel version for Ti sheet, honeycomb, and TiGr composite materials with polyimide adhesive materials. At St. Louis, shop trials of sol-gel metal bonding surface treatments for the F/A-18 program are in the planning stage. Additional implementation opportunities are being pursued.

This article describes only one aspect of the sol-gel development program. Related efforts developing this family of materials for corrosion control, conversion coating replacements, sealant adhesion promoters, high temperature adhesives, composite substrates, space coatings, oxidation control, waterproofing coatings, nanocomposites, and other specialty coatings show the versatility of this polymer family.

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BOEING-ST. LOUIS RECEIVES MISSOURI POLLUTION PREVENTION AWARD

Dr. Pinckert receiving the Governor's Award for Boeing St. Louis from Governor Carnahan.

Missouri Governor Mel Carnahan presented Boeing with the sixth annual Governor's Pollution Prevention Award for State Region 2 on July 21, 1999. "These awards honor Missouri businesses who have taken on the responsibility of protecting the environment by finding ways to prevent pollution," Carnahan said. The Missouri Chamber of Commerce, the Missouri Department of Natural Resources and the Governor conducted the award ceremony.

Boeing in St. Louis was honored for its success in implementing a multidiscipline Environmental Strategic Operations Plan (ESOP). The ESOP is a joint effort of EA and SHEA (Safety, Health and Environmental Affairs). Credit was received for the overall environmental planning process and specific projects including ODS elimination, VOC reduction, degreasing changes, waterborne chem mill maskant implementation, FLASHJET™, and the household hazardous waste collection project.

One result of this plan is the elimination of many of the solvent-based cleaners and coatings used in aircraft paint processes. These changes cut hazardous waste by 77 percent, reduced toxic air emissions by 80 percent, and improved worker safety.

Receiving the award on behalf of Boeing were Mike Dwyer, Bryan Kury, Dick Pinckert, Larry Sanders and David Shanks.

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BOEING-MESA'S ENVIRONMENTALLY DRIVEN DATABASE SEARCH SYSTEM.

Mesa has recently implemented their in-house-developed Global Search and Replace System (GSRS), a tool for working efficiently across enterprise databases. GSRS owes its creation to environmentally driven changes, such as the replacement of Class 1 Ozone Depleting Substances (ODS), but it now provides a lower cost way of searching and changing data among related, standalone databases.

Design change is typically in response to a specific improvement opportunity, isolated to an area of the product that involves a unique change to relatively few parts and drawings. Compliance driven changes, such as the ODS replacement, usually involve a common change to a large number of parts and drawings. Change management and implementation at Boeing-Mesa is primarily a 'touch labor' process. Organizations responsible for implementing design change across the enterprise are required to manually enter the change information into their respective systems in engineering and manufacturing.

Of course, before changes can be authorized, we must find the references (all of them) that require change. In 1993, eight people were assigned to review databases to find ODS callouts; it took them 10 months to complete the task. Although it provided a basis to begin evaluating ODS replacement alternatives, the result was a 'snapshot' of the databases. We could not afford an eighty man month exercise to determine where materials were used each time a compliance question was raised. The search also highlighted a wide variety of ways a given material could be 'named' in databases (including misspellings), as well as the complication of identifying callouts where the offending material was only an ingredient in the material specified.

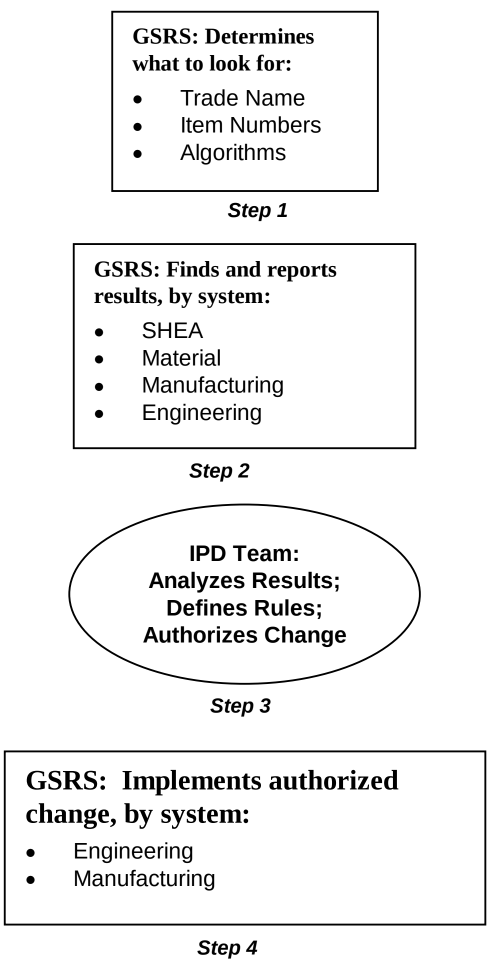
GSRS supports responses to environmental inquiries by performing a series of data searches starting with a chemical search of Boeing's MSDS Web Site System. A series of engineering, material and manufacturing databases are then searched successively, using the output of one search as the input for the next. All 'hits' are stored in the GSRS database, which relates inputs to outputs and the company system from which the output was generated. Results may be viewed 'on line' or reports may be generated for any or all search levels. GSRS also supports general inquiries.

Valid input values may be manually entered and the search initiated at the corresponding level.

Implementation is controlled via the standard change management process. However, authorized change is accomplished by GSRS performing synchronized data manipulation in the engineering product structure, notes and automated drawing systems. The change then flows to manufacturing and planning data systems.

GSRS supports implementation of alternates or replacements. This is accomplished by 'rules' that define which material reference is to be acted on, what the new reference should be, whether it is to be added as a replacement or an alternate, and the authority for the change.

The GSRS Process



Inquiries and change implementation can be constrained to include or exclude specific product lines. This allows changes to be implemented across the board or uniquely by product line.

The search feature of GSRS first became operational in early 1997. The replace feature for engineering systems and manufacturing planning is expected to be operational in September of 1999.

The first production application of GSRS was to identify ODS Class 1 references in the Apache design and then validate that the manual "clean up" was complete.

GSRS searches have become an integral part of the Material Process and Standards (MP&S) change board process. By providing accurate and complete visibility of where a specification is referenced, proper impact analysis can be performed prior to authorizing a specification change.

In support of work share for international production, GSRS is used to determine whether specific material or process references are present in the related design package and, if so, where. These requests, which previously took a minimum of several man months with varying accuracy, are routinely serviced overnight.

GSRS supports National Aerospace Standard 411 reporting on a semi-annual basis for two programs. The original estimate was 54 man months per program. Both are being produced by one individual on less than a half-time basis.

Manufacturing has used the replace feature to support a wiring Single Process Initiative and mass replacement of several superceded part references in the Manufacturing Bill of Material.

<u>GSRS Benefits</u>

- ✓ Effective use of existing data.
- ✓ Timely, accurate determination of "where used" for material (and process) references.
- ✓ Timely, accurate, consistent and complete change implementation.
- ✓ 30% to 70% labor cost avoidance, compared to manual search and replace methods.
- ✓ 5:1 return on development investment in first 2 years of operation.

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