Coating removal technology using starch based abrasives, a review of current Aerospace application using the Envirostrip dry stripping process.

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INTRODUCTION

Due to stringent environmental regulations enacted in the past 10 years, methylene chloride (MC) has been phased out in many industries because it is harmful to the environment and the workers exposed to it. The aerospace industry, historically a large user of MC, researched and adopted many environmentally acceptable alternatives to replace methylene chloride based paint strippers. This has proved to be a very difficult task as MC chemical strippers have been very effective in removing tough polyurethane/epoxy coating systems typically found on aircraft structures

A variety of new “environmentally acceptable (EA) chemicals” were developed in the last five years to replace MC. These EA chemicals are considered safer because the chemicals are not as volatile, having very low evaporation rates. However, some strongly believe that new EA chemicals may still pose unknown health risks to workers, as well as potentially damage aircraft structures due to long term ingress problems. Because MC strippers evaporate so quickly, problems associated with chemical ingress were rare. The potential for the new EA chemicals to damage and/or corrode sensitive aircraft structures is a new problem due to the low evaporation rates (low volatility) of these MC chemical substitutes.

Ten years ago, an alternative non-chemical, paint removal process was introduced to the aerospace industry. This process uses a dry abrasive media, called EnviroStrip® wheat starch, which is projected at low pressures to remove virtually every type of organic coating from most aerospace materials. The media was considered more gentle than other dry media used at the time (e.g. plastic media). EnviroStrip® wheat starch, as the trademark implies, is manufactured from wheat starch, a biodegradable renewable resource, giving the product an inherently high purity and uniformity.

Extensively tested, approved and used in production applications by Northrop Grumman, Raytheon, Cessna and Boeing, the EnviroStrip® process has been embraced for its coating removal effectiveness on metals and composite substrates. In 1998, a new sister product, named EnviroStrip® XL was commercially launched (ref.4). This newer abrasive product is made with a corn hybrid polymer and offers improved water resistance. Today, EnviroStrip® XL is successfully used by major companies in the aerospace industry.

This paper will describe the methods to manufacture these abrasive media products, the equipment used to apply the process, and the various applications for this technology in the Aerospace industry. Examples are selective stripping, metal bond adhesive removal and interior aircraft panel refurbishment. The production use of this dry stripping method on the Northrop Grumman B-2 bomber, the NASA Space Shuttle and other aircraft types will also be reviewed.

DISCUSSION – THE ENVIROSTRIP® TECHNOLOGY

The EnviroStrip® Abrasives

The starch-based media particles are irregular in shape and have sharp, angular edges (fig. 1-2). The media is amorphous in nature and semi-opaque to light. By weight the media has approximately 10-13 % moisture content. An interesting aspect of the media is the conditioning effect. After being projected several times, the media becomes more productive after each use. Two mechanism are at play: the average particle size range of the batch starts to widen to a more productive broader range (i.e. 12-100 mesh size) (ref 8) , and the media loses 1-2% of moisture which in effect sharpens the media. The principal difference between the wheat starch media and the corn polymer media is that the latter can better withstand contact with water.

The EnviroStrip® Manufacturing Process

EnviroStrip® wheat starch media and EnviroStrip® XL corn hybrid polymer are manufactured from pure native starches. A primary advantage of using a starch raw material is its purity and uniformity, and the absence of foreign particulate that are denser than the final starch abrasive product. The raw starch powder is fed to an extruder and heated in the presence of water to form a solid starch mass. Upon exiting the extruder, the starch material is formed into strands that are cut into pellets. These hard plastic-like pellets are cooled and tested for hardness. The starch pellets are then ground to various mesh sizes (e.g. 12/30 mesh).

The Process Equipment

When EnviroStrip® wheat starch was first introduced 10 years ago, it was used in dry media blast systems designed for light-abrasives such as plastic media. While EnviroStrip® media could be adequately used in these blast systems, it was found that certain design changes could improve overall process efficiency. The major blast equipment manufacturers have since implemented important equipment design changes, helping to fine tune the EnviroStrip® coating removal process. Increased pressure pot angles (60+ degrees), better media flow control valves, and enhanced dust removal techniques were incorporated into the new generation of light-abrasive blast systems. These enhancements have improved EnviroStrip® coating removal rates and reduced media consumption.

There continues to be great strides in both North America and Europe in improving dry media blast systems. Flat nozzle technology, introduced recently into the light-abrasive coating removal industry, has had a significant impact on EnviroStrip® media performance. Flat nozzles have demonstrated strip rate increases of over 100% when compared to conventional round nozzles. The computational fluid dynamic programs used to design the flat nozzle revealed that media can be more uniformly distributed to the surface through a flat nozzle, minimizing media overlap and the “hot-spot” typically found in round nozzles.

Closed-cycle (dust-free) dry media blast systems have also evolved to support aerospace coating removal requirements. Historically closed-cycle systems used small nozzles designed with a 90-degree impingement angle to the working surface. These systems were difficult to use, slow to remove coatings and did not provide the operator sufficient viewing of the blast area. Major advances have been achieved with the introduction of closed-cycle systems designed for EnviroStrip® media. The new closed-cycle systems utilize the more efficient flat nozzles that are set at an optimal 45-degree angle to the working surface. In addition, a viewing window on the applicator head now allows the operator to see the blast process in progress. This helps operators to improve strip rates and, when possible, selectively strip coatings (i.e. remove top coat, leaving primer intact). Most closed-cycle systems are portable and can be used for both on and off aircraft paint and adhesive removal applications.

Benefits of Automation

The aforementioned improvements in media process equipment and nozzle design for starch media have allowed automation to yield further process benefits. High production rates on sensitive aircraft parts, providing controllable and repeatable surface finish, can now be accomplished with current automated system technology. Past work (ref 9) has shown that production strip rates increase by up to 300% when using semi and fully automated blast systems. Automated production work is presently being conducted on aerospace structures at several locations worldwide. For example, the Boeing-ASTA facility in Australia has implemented an automated starch media system for both composite coating removal and composite surface treatment. The composite surface preparation process is performed on Boeing manufactured carbon fiber parts. The system, using a large flat nozzle, has proven its ability to meet and exceed production demands without damage to the sensitive composite substrates.

Automated control of the nozzle movement allows a larger nozzle size and media flow rates to be applied. This, in turn, delivers higher strip rates and lowers material costs. Precise control can be assured, minimizing surface damage at higher production rates. Automation of the starch-based dry media process has proven to be an effective production technology in off-aircraft component stripping.

Mechanical Effects on Aerospace Materials

Most coating removal processes can induce unwanted surface effects on aerospace materials. Dry stripping causes two types of mechanical effects, residual stress and surface modifications. Residual stresses produced by dry media blasting are compressive in nature and are concentrated at the surface, similar to the effects produced by shot-peening. Within limits, compressive stresses at the surface of metals can actually be beneficial. Shot-peening studies have shown that compressive stresses can retard the onset of fatigue and corrosion in metals. However the potential of a dry stripping media to induce different compressive stress intensities(partial coverage) (ref 6) can negatively affect the fatigue life of thin skin aluminum control surfaces and fuselage sections. With such concerns in mind, the Boeing Commercial Aircraft Division issued service letters (1993, 1995) restricting the use of plastic media on Boeing civil aircraft structures. In turn, Boeing allowed EnviroStrip® wheat starch to be used an unlimited number of times on aluminum (>0.032-inch thick) as a preferred non-chemical alternative to remove coatings from thin aluminum surfaces.

The standard method used for years to gauge residual stress inducement in a substrate is the Aero Almen method. Developed by the USAF in the early 1980’s, the method was borrowed from the shot-peening industry. Instead of using steel specimens, the USAF method uses 2024 T-3 aluminum strips which are 3 inches long by 0.75 wide inches and 0.032-inch thick. An Almen strip and strip holder are shown in fig 3. The higher the arc height or deflection of the Almen strip when blasted with an abrasive media, the higher the potential negative effect on the fatigue life and fatigue crack growth rate of that particular substrate. Figures 4 and 5 shows two panels 0.032-inch thick. One panel was stripped with EnviroStrip® wheat starch and had a corresponding Almen arc height of 0.003-inch, while the second panel was stripped with plastic media (Type V) and had a corresponding arc height of 0.007-inch. Note the difference in the mid plane deflection of the panels. The USAF, a long-time pioneer in researching new depaint technologies, sets a criteria that arc heights for any mechanical process not exceed 0.006 inch. Figure 6 shows typical saturation curves for EnviroStrip® wheat starch, EnviroStrip® XL and plastic media blast (Type V Acrylic) processes. Finally aircraft components are often dry stripped prior to liquid penetrant inspections, the results of an AGARD report indicated that, using starch media gave better inspection results than the more agressive media types (ref 2)

EnviroStrip® Application Overview

Adhesive Removal

Removing adhesives and sealants from sensitive substrates has always been a challenging operation. Historically mechanical methods have utilized hand scraping or mechanical sanding. These methods are slow and often cause unacceptable damage (fig. 7). EnviroStrip® abrasives have the ideal characteristics of being able to efficiently remove various adhesives without compromising the bond primer found under the adhesive layer (fig 8)

Northrop Grumman B-2

The world’s most sophisticated aircraft have been processed with EnviroStrip® wheat starch since 1994 (ref 13). After an exhaustive evaluation of all alternative methods, the EnviroStrip® wheat starch was the only process found to remove special thick coating systems without affecting the carbon fiber substrate found on the B-2.

Space Shuttle

The EnviroStrip® process is used to strip the thermal protection system (TPS) adhesive from the Space Shuttle vehicles. Over 3000 ft^2 of the Shuttle vehicle's upper wings, side body, and payload bay doors were processed. (ref 7)

Selective stripping

Selective stripping is a coating removal technique where the top-coat is removed and the base primer coat is largely left intact. There are several advantages to this technique. Leaving the primer coat intact eliminates surface effects on various substrates, which is particularly beneficial for composite structures. Another advantage is a reduction in toxic metals found in the starch media waste. This occurs because the heavy metals (e.g. chromium) are predominantly found in the primer coat, and are thus not removed when selective stripping is performed. (ref 10) Airbus Aircraft recommends selectively stripping coatings from their aircraft.

Composite Structures

The most widely used media for composite stripping, EnviroStrip®, is presently used by several repair and overhaul facilities. At these locations, various coating systems are removed from commercial airliner composite structures. As an example, the following Boeing materials are approved for stripping with EnviroStrip® wheat starch.

SUBSTRATES APPROVED FOR WHEAT STARCH MEDIA BLASTING

SUBSTRATE TYPE	BOEING MATERIAL SPECIFICATION	SELECTIVE FINISH REMOVAL CYCLES	COMPLETE FINISH REMOVAL CYCLES
Fiberglass 250 F Cure	BMS 8-79	Unlimited	Two
Fiberglass 350 F Cure	BMS 8-139 BMS 8-331	Unlimited	Five
CFRP (Carbon/Epoxy) 250 F Cure	BMS 8-168	Unlimited	Two
CFRP (Carbon/Epoxy) 350 F Cure	BMS 8-212 BMS 8-256 BMS 8-276	Unlimited	Five
Aramid (Kevlar/Epoxy)	BMS 8-218 BMS 8-219	Unlimited	None
Wire Mesh Lightning Strike Protection	BMS 8-336	Unlimited	None
Aluminum Flame-Spray Coating	BAC 5056	Unlimited	None

Ref: Boeing D6-56993

Aluminum Structures

The majority of fuselage skins have a thin layer of pure aluminum, known as Alclad, which covers a high strength aluminum alloy. This clad aluminum layer provides corrosion protection for the underlying alloy, and therefore it is imperative any alclad removal is minimal and that the resulting surface roughness is within acceptable limits. For example, the general guideline for surface roughness should not exceed 125 µinches (R_a) on 0.032-inch thick clad aluminum skins.

Today's aging aircraft have been subjected to multiple chemical paint strip cycles and some have very little clad left on their skins due to the aggressive scrubbing needed to remove residual paint. EnviroStrip® wheat starch surface roughness data reported by Beech Aircraft in 1992 (ref 5) is shown in the table below. These results are typical and have been validated in numerous test programs worldwide. Note that clad thickness is 5% (front and back) of total thickness of skins up to 0.063 inch, above 0.063 inch , aluminum clad skins are 2.5% front and back. With increasing clad layer thickness, the resulting surface profile will become slightly rougher.

Clad Skin Thickness	Clad Layer Thickness	After blasting Roughness µinches (Ra)
0.020 inch	0.0010 (5%)	40
0.025 inch	0.0013 (5%)	70
0.032 inch	0.0016 (5%)	90
0.040 inch	0.0020 (5%)	142
0.080 inch	0.0020 (2.5%)	132

DISCUSSION – CHEMICAL STRIPPING – SOME HAZARDS STILL REMAIN

Methylene chloride, also known as Dichloromethane, is considered a very toxic chemical. It can damage the liver, heart and central nervous system (ref 14). Past studies concluded that its use was so wide spread in various industries, that most of the general population was exposed to it . The main route of exposure is via inhalation.

ESTIMATED DAILY INTAKE OF DICHLOROMETHANE
BY THE GENERAL POPULATION

Route of Exposure	Estimated Dichloromethane Intake (µg/kg-day) of Various Age Groups				
	0 – 6 mo	7 mo – 4 yr	5 – 11 yr	12 – 19 yr	20+ yr
Ambient Air	0.04 – 0.30	0.06 – 0.40	0.07 – 0.46	0.06 – 0.38	0.05 – 0.34
Indoor Air	3.88	5.22	6.04	5.00	4.46
Total Air	3.92 – 4.18	5.28 – 5.62	6.11 – 6.50	5.06 – 5.38	4.51 – 4.80
Drinking Water	0.01 – 0.07	0 – 0.04	0 – 0.03	0 – 0.02	0 – 0.01
Food	0.03	0.11	0.09	0.05	0.05
Total Intake	3.96 – 4.28	5.39 – 5.77	6.20 – 6.62	5.11 – 5.45	4.56 – 4.86

Source: Government of Canada 1993.

Despite its toxic nature, Dichloromethane has proven to be very effective in removing aircraft coating systems, with its main advantage being speed. When compared to the myriad of new environmentally acceptable (EA) strippers, methylene chloride (MC) is still by far the most effective. For example, if it takes MC 2-6 minutes to remove a given coating system, the EA chemical alternatives will take at least 50 times longer
(i.e. 2-8 hours).

There have always been hazards to the airframe when chemical strippers are applied. One of the most severe incidents involved a commercial aircraft which lost a 5ft by 10 ft section of its rudder during a trans Atlantic flight (ref 12). The failure was attributed to residual chemical stripper coming into contact with the composite tail rudder. The chemical damaged the resin matrix allowing to water to enter the composite structure. The resulting failure was a delamination of the composite skin plies from the rudder assembly. Other reported examples of chemical damage are cases where the wrong chemical was used or improper chemical application was involved, resulting in damage to various parts of the aircraft including a forward landing gear.

Environmentally Acceptable Chemical Strippers

When using the new EA chemicals one must consider the different types of products available and the potential risks involved. There are basically three types of EA chemical strippers: alkaline, acid and neutral. A neutral pH (i.e. pH 7 ± 1) chemical is preferred provided it remains stable, while acid or alkaline strippers present different corrosion risks.

ALKALINE: “Aluminum is a reactive metal, but develops an aluminum oxide coating or film that protects it from corrosion in many environments. This film is quite stable in neutral and many acid solutions but is attacked by alkalies.”(ref 1)

ACID: High Strength steel such as AISI 4340 is used on aircraft in very critical applications, they include landing gear components, engine parts and critical fasteners and bolts throughout the aircraft. If an acidic solution comes in contact with high strength steel, hydrogen embrittlement can easily occur. Hydrogen embrittlement is caused by the introduction of nascent atomic hydrogen into the steel microstructure. . Hydrogen embrittlement can occur during a plating process or exposure to an acidic agent. The only known method to remove the hydrogen, is by baking the part/component at 300 - 375 °F for 12-23 hours. If and when accidental exposure occurs, there are no known non-destructive methods for determining if hydrogen was introduced. The presence of hydrogen in steel promotes a significant loss of ductility and strength, which can lead to sudden brittle failures well after hydrogen exposure (refs 3,15)

NEUTRAL: Neutral solutions are considered by far the safest to use on aircraft structures. However, a slight deviation in formulation by manufacturers may cause a neutral stripper to be slightly acidic. For example (ref 11), a solution of pH 5,7 will cause hydrogen embrittlement on AISI 4340 steel. One should also consider that the stability of a given chemical stripper. The pH of a particular solution may change with time through evaporation, or when exposed to other chemicals and/or materials.

One the most important factors in evaluating a potential chemical is exposure or dwell time, particularly in the case of ingress into aircraft structures. An argument often used when potential damage is observed with new EA chemicals is that standard test results show that it is no worse than methylene chloride. However, the question is raised of what dwell time is appropriate in comparative tests. For example, if pure benzyl alcohol is left to evaporate in an open laboratory pan, it will still be there after 12 months. The same amount of methylene chloride completely evaporates within 7days.

Thus to assess the potential damage associated with chemical ingress into aircraft structures, the fact that EA strippers will reside and act on aircraft materials for a much longer time horizon should be taken into account. The risk of ingress occurring is also impacted be the longer application times required with the new EA chemicals. The greater potential for ingress through longer contact times suggests that the risk of damage may be underestimated.

Conclusions/ Future Work

Dry stripping with starch-based media should be considered the safest alternative to methylene chloride, now and for the future. The current popularity of EA chemical strippers does not imply that they can be used without undue risk. And with the increasing use of advanced composite materials on newer aircraft, the concerns regarding chemical stripping effects on aircraft structures will be even greater.

New starch-based media types are currently under development at ADM that will eventually offer a wider variety of media products with differing characteristics and benefits.

ADM will continue to work closely with equipment manufacturers and the aerospace community to promote and enhance the starch dry stripping process.

ADM is actively working with environmental agencies and different industries to initiate an environmentally responsible media lease/recycling program supporting customers spent media disposal needs.

FIGURE 1 NEW MEDIA

FIGURE 2 TYPICAL PRODUCTION MIX

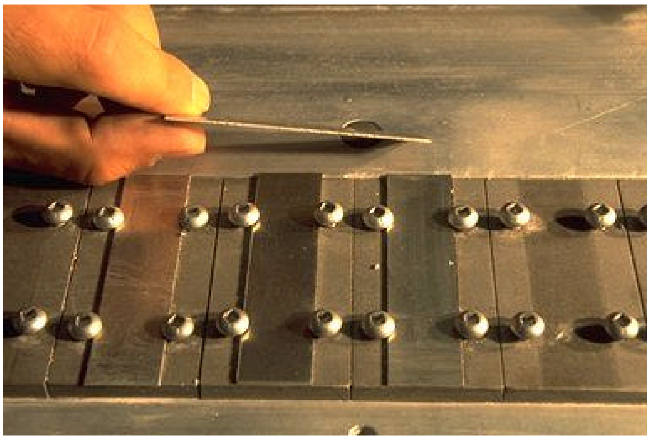

FIGURE 3   ALMEN STRIP AND HOLDER

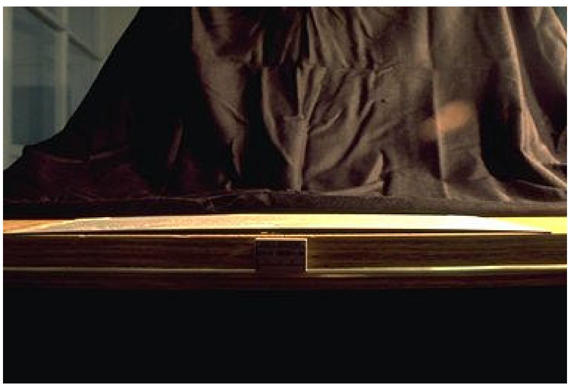

FIG 4 DEFLECTION WITH ENVIROSTRIP

FIG.5 DEFLECTION WITH PLASTIC MEDIA

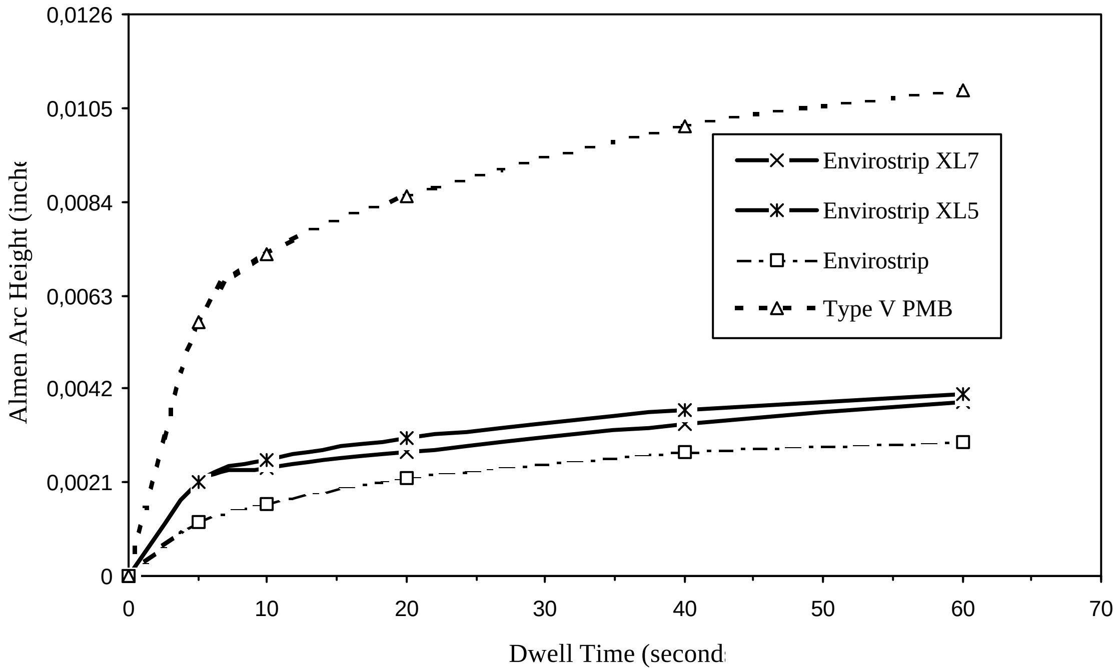

FIGURE 6   SATURATION CURVES FOR ENVIROSTRIP, XL AND PLASTIC MEDIA (TYPE V)

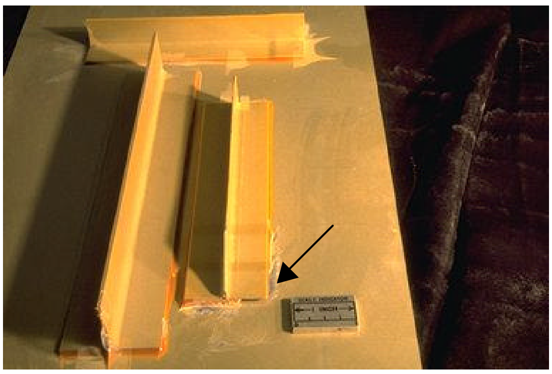

FIGURE 7 NOTE MECHANICAL DAMAGE AT ARROW

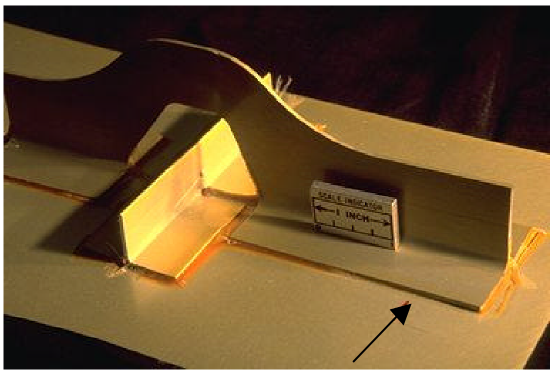

FIGURE 8 ADHESIVE REMOVED WITH ENVIROSTRIP, NO DAMAGE

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