PP1056-2

DoD EPA DOE SERDP
Strategic Environmental Research And Development Program
Improving Mission Readiness Through Environmental research

Low Volatile Organic Compound (VOC) Chemical Agent Resistant Coating (CARC)

Final Technical Report

Project #PP 1056

Strategic Environmental Research & Development Program

SERDP

April 2000

Lead Agency: U.S. Army Armament Research, Development & Engineering Center (AMSTA-AR-WEA)

Project Manager: Robert W. Katz
Phone 973-724-6518 FAX 974-724-6503
E-mail <rkatz@pica. army.mil>

Report Documentation Page		*Form Approved* *OMB No. 0704-0188*

1. REPORT DATE **APR 2000**	2. REPORT TYPE	3. DATES COVERED **00-00-2000 to 00-00-2000**
4. TITLE AND SUBTITLE **Low Volatile Organic Compound (VOC) Chemical Agent Resistant Coating (CARC)**		5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)		5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **U.S. Army Armament Research Development and Engineering Center,Picatinny Arsenal,NJ,07806-5000**		8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)		10. SPONSOR/MONITOR’S ACRONYM(S) 11. SPONSOR/MONITOR’S REPORT NUMBER(S)
12. DISTRIBUTION/AVAILABILITY STATEMENT **Approved for public release; distribution unlimited**		
13. SUPPLEMENTARY NOTES		
14. ABSTRACT		
15. SUBJECT TERMS		

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**167**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

Foreword

This document is provided to satisfy the Strategic Environmental Research & Development Program (SERDP) reporting requirement for a Final Technical Report for Project PP 1056/789, Low Volatile Organic Compound (VOC) Chemical Agent Resistant Coating (CARC).

This document is comprised of an Executive Summary followed by three sections that cover the major phases of this program: Phase 1 - Coating Formulation, Phase 2 - Application Study, and Phase 3 - Stripping and Disposal.

Each section has been numbered separately in accordance with the following convention:

"ES" pages designate the Executive Summary (prepared by the Army Armaments Research & Development Center)
"A" pages designate the Phase 1 - Coating Formulation Study (prepared by the Army Research Lab)
"N" pages designate the Phase 2 - Application Study (prepared by the Naval Surface Warfare Center)
"AF" pages designate the Phase 3 - Stripping and Disposal Study (prepared by the Air Force Research Lab)

Acknowledgement

The tri-service Low VOC CARC SERDP Team wishes to thank the SERDP Program Office for their technical and financial support of this project. In particular, Mr. Bradley Smith, Dr. Jeffrey Marqusee, Mr. Charles Pellerin, Dr. Robert Holst and Mr. Sandeep Jandwadkar are gratefully acknowledged.

Table Of Contents

Executive Summary

Performing Organizations:

The Armament Systems Process Division of the U.S. Army Armaments Research, Development & Engineering Center (ARDEC), Picatinny Arsenal, NJ was the lead organization responsible for the overall management and coordination of this project.

The Weapons and Materials Directorate of the Army Research Lab (ARL), Aberdeen Proving Ground, MD was responsible for the Coating Formulation Study Phase.

The Carderock Division of the Naval Surface Warfare Center, Philadelphia, PA was responsible for the Application Study Phase.

The Wright Laboratory Materials Directorate of the Air Force Research Lab, Wright Paterson Air Force Base, OH in conjunction with the Southwest Research Institute was responsible for the Stripping and Disposal Study Phase.

Project Background:

When the Chemical Agent Resistant Coating (CARC) system was first used on tactical equipment by the Army in the early 1980s, it was in compliance with environmental regulations in effect at that time. However, Federal and local regulations resulting form the Clean Air Act and its amendments have resulted in subsequent restriction on the amount of Volatile Organic Compounds (VOC) emitted during the application of protective coatings. Current topcoats in the CARC system have VOC limits set at 3.5#/gal, but local governments are permitted to set lower limits, and many, such as the San Diego Air Quality Management District (which has a limit of 2.8#/gal), have done so. In addition, total emission restrictions imposed on some facilities are such that a limit of 1.8#/gal must be achieved for the facility to stay in production. Finally, many of the solvents are Hazardous Air Pollutants (HAPs) either as listed by the Clean Air Act Amendments of 1990 or targeted by the EPA 33/50 Industrial Toxics Project.

Army regulations (which are also followed by the Marine Corps) require that all tactical equipment (including combat, combat support, essential ground support equipment, tactical wheeled vehicles and aircraft) be hardened against performance degradation by chemical warfare agents or decontamination procedures. The Air Force uses Army CARC on all vehicles and equipment procured through the Army and has drafted a Mission Need Statement for Advanced Aircraft Coating Compatibility stating that existing coating systems have a limited ability to protect against chemical agents and must be improved. Thus the CARC requirement is of significant importance to the tri-service coating community and the environmental deficiencies must be addressed to ensure the continued operation of the defense facilities.

Objective:

The objective of this project was to develop a low VOC CARC system suitable for use on military equipment by all services, in which the materials and processes for the reformulation/ application, stripping and disposal are optimized and in compliance with the current and anticipated regulatory requirements. The primary objective was to reduce the VOC of the polyurethane topcoat from 3.5#/gal to 1.8#/gal. A secondary objective was to eliminate the HAPs and toxic solvents used in the current topcoat formulation. In addition to the environmental objectives, it was mandated that there could be no degradation in performance properties of the reformulated low VOC coating as compared to the current CARC. Also, it was considered highly desirable that the new CARC topcoat be essentially a "drop-in" replacement; i.e., no significant alterations to the currently used process for application and stripping of the CARC coatings.

Technical Approach:

The technical approach for the reformulation work focused on high performance, water reducible (WR) polyurethane binder systems, which had the potential for chemical agent resistance and meets the performance requirements of the Army, Air Force and Marines. Candidate polymers were obtained from raw material suppliers, screened for live agent resistance, and formulated into camouflage topcoats. Requirements for the WR CARC included compatibility with current camouflage pattern painting procedures and universal use under all current and foreseen VOC regulations. The pigmentation was also investigated as another source of helping to reduce the VOC content as well as improving the overall performance. The use of non-siliceous extenders (e.g. polymeric beads) could offer reduced binder demand in the formulation and improve such performance properties as durability and flexibility.

The approach to the application study was to quantify non-film paint properties, and post-application properties, to conduct rheological characterization, and through a Design of Experiment (DOE) study to quantify the cause and effect relationships between application parameters and film performance. The DOE results, when coupled with a weighting methodology, will allow for application parameters to be specified in order to provide desired film performance. This will allow for the "fine-tuning" of application procedures to allow the optimum film performance to be achieved. In this manner, each Agency will be able to tailor properties according to the results desired.

The approach to the stripping work was to focus on evaluation of currently used methods of removal to optimize the processes for de-painting and disposal of the CARC developed under this project. Towards this end a review was made of current technology including those projects conducted by: the National Defense Center for Environmental Excellence (NDCEE), the Joint Depot Environmental Panel (JDEP), the three services under the SERDP, as well as a review of existing CARC stripping operations at depots, original equipment suppliers and other manufacturing/maintenance facilities. Selected technologies were tested to determine the applicability to strip the new CARC as applied to a variety of substrates (aluminum, steel, and composites). Emphasis was given to non-chemical means of stripping due to the large quantities of hazardous wastes which are generated by the use of chemicals.

Summary/Conclusions:

1. The U.S. Army Research Laboratory (ARL) has developed a low VOC water-reducible (WR) chemical agent resistant polyurethane topcoat, which meets current and anticipated regulatory limits. The topcoat provides increased resistance to accelerated weathering plus improved low temperature flexibility, impact and mar resistance as compared to the CARC topcoats currently in use.

2. U.S. Patent #5,691,410 has been awarded for the WR low VOC CARC formula that was the basis for this SERDP project. The formulation has been validated for all five colors of interest (camouflage green, brown, black, desert tan and Air Force gray) and has been produced in pilot plant and production size batches by an industry partner.

3. The WR CARC topcoat is essentially a drop-in replacement for the coatings currently used. No significant alterations anticipated to current production application processes are anticipated to achieve the desired film performance.

4. Strippability of the WR CARC is not expected to present an adverse impact to de-paint operations for the various dry media blasting operations (walnut hull, zirconia alumina, garnet, steel shot, plastic media) commonly used by the depot community. Chemical strippability data suggests that the stripping productivity, using various chemicals currently in use by the depot community, should not be impacted significantly.

5. Initial implementation and technology transfer will be via the Environmental Security Technology Certification Program (ESTCP) Project #200024, which will demonstrate/validate the SERDP technology at three DOD depot facilities during the FY2000-2001 time frame.

6. A new Military Specification for the WR topcoat with an associated Qualified Products List (QPL) is being prepared as part of the ESTCP effort. Until the specification is issued, an approved supplier list for the WR Low VOC CARC topcoat will be available from ARL.

U.S. Army Research Laboratory

Low Volatile Organic Compound (VOC) Chemical Agent Resistant Coating (CARC)

Phase 1 – Coating Formulation

Final SERDP Technical Report

US Army Research Laboratory
Weapons and Materials Research Directorate
Jeffrey L. Duncan
John A. Escarsega
Dawn M. Crawford

April 2000

INTRODUCTION: The US Army Research Laboratory (ARL) is participating in a tri-service effort funded by the Strategic Environmental Research and Development Program (SERDP) to develop a low-Volatile Organic Compound (VOC) Chemical Agent Resistant Coating (CARC) for use on Army, Marine Corps, and Air Force tactical equipment. The primary motivating factor for this program is to develop a camouflage CARC that is more environmentally acceptable than the current solvent-based topcoats. Environmental factors influencing the formulation come from limits on VOC emissions found in the Clean Air Act (CAA) and its Amendments, from worker safety issues in Occupational Safety and Health Administration (OSHA) regulations on exposure to workplace hazardous materials, and from the constraints associated with the National Environmental Standards for Hazardous Air Pollutants (NESHAP) for the Miscellaneous Metal Parts and Products category, due for enforcement in the year 2003. The low-VOC CARC developed must meet current and anticipated regulatory limits without compromising the performance necessary to meet survivability requirements, including chemical agent resistance, camouflage, and durability in extreme environments.

The developmental process has been divided into three separate tasks, formulation, application, and stripping. The ARL is responsible for the formulation effort, the Naval Surface Warfare Center, Carderock Division (NSWCCD) is responsible for characterizing the application process, and the Air Force Research Laboratory (AFRL) Materials Directorate, in conjunction with Southwest Research Institute (SwRI), is responsible for the stripping studies. The ultimate goal of the process is to demonstrate that the low-VOC CARC can provide a “drop-in” solution to the environmental issues associated with the solvent-borne CARC currently in use, providing equal or better performance and involving no significant changes to the application and stripping procedures currently being used. This report summarizes the formulation phase performed by ARL, and it covers the period from October 1997 through March 2000.

BACKGROUND: Chemical warfare causes many problems on the battlefield, among which is decontamination of exposed equipment. Because of this threat, the US Army has required the use of a CARC system on its equipment, beginning in FY85. The equipment covered by this requirement includes all combat, combat support, and essential ground support equipment, plus tactical wheeled vehicles and aircraft. These coatings resist penetration of the paint film by chemical agents and make decontamination procedures easier, either by neutralization of the agents with DS2 decontaminating solution or by enabling the natural environmental breakdown of the agents because they remain on the surface of the paint. The current topcoats are aliphatic polyurethanes meeting either MIL-C-46168 or MIL-C-53039 military specifications. While they provide the quality performance characteristics of a commercial automotive-type finish, such as exterior durability and excellent chemical resistance, they must also be able to withstand decontamination procedures and provide camouflage properties in the visible and near infrared regions of the spectrum. In response to a variety of environmental regulations and worker safety issues, the original material, first developed in 1974, has evolved into a much more environmentally acceptable coating. In the years since CARC first appeared, the coating has been reformulated to be lead and chromate free and lower in VOC content. The former is particularly important because many of the materials used in manufacturing protective coatings generate hazardous wastes (important from the worker safety aspect noted above) and the associated high costs of disposal.[1] The high solids versions of the CARC topcoats do not meet

VOC regulations in certain localities, so different technology was needed to develop a CARC to solve current and anticipated VOC problems.

From a historical perspective, the two main avenues to VOC reduction in coatings are lower molecular weight polymers and the use of waterborne (WB), water dispersible (WD), or water reducible (WR) polymers. Usually, reducing a polymer's molecular weight reduces its viscosity and the consequent need for solvents to control the system viscosity during application. This is the traditional high solids solution to VOC problems. Alternatively, systems in which water can be used for this viscosity control can greatly alleviate the need for solvents altogether. Up until just a few years ago, water-compatible coatings often had problems achieving the performance of their solvent based analogs, but recent developments in polymer technology have made possible the development of high performance polyurethane systems with excellent performance and chemical agent resistance.

Any reformulation effort to reduce VOC must result in a product that retains current performance levels. The components of a typical coating can be divided into three main groups. The polymer (commonly called the binder) provides the required performance level of the product, the pigments provide the desired color and gloss, and the solvents/additives control package and application viscosities and aid in film formation. In CARC, the chemical agent resistance (CAR) is provided by the aliphatic polyurethane binder and the camouflage properties are provided by the appropriate selection of tinting pigments for visual color and near-infrared reflectance, plus extender pigments for gloss control. The camouflage requirements have always complicated development of Army coatings because of the need for a low gloss, which in turn leads to a proportionally higher pigment to binder ratio. The system is essentially pulled in opposite directions by the need for more binder to enhance CAR and the concurrent need for more pigment to reduce gloss for camouflage. Since camouflage tinting pigmentation systems are well established, the focus of this effort was to replace the solvent borne polyester and polyisocyanate binder components of the current CARC. At the same time, we wanted to develop an improved pigment package that would help to eliminate some of the problems (such as marring and reduced flexibility) that result from a coating with the high pigment loading required for low gloss camouflage.

Pigment Package Development

The color selected for basic pigment formulation development was the Green 383 color, because it is the basecoat for CARC application, and pattern colors (Brown 383 and Black) are applied over it. (Other colors important for different applications include Tan 686A for desert camouflage environments, Aircraft Green for rotary-winged aircraft, and gray for potential Air Force applications.) As is typical in two component polyurethanes, the pigments and additives are added to the polyester/Component A portion of the system. The polyisocyanate "catalyst" becomes Component B, and the system is adjusted with solvent to practical package viscosity for both components while ensuring proper stoichiometry of the reactive components upon their mixing in a practical (e.g., 2 to 1 by volume) kit format. The "solvent" for a WB/WD/WR system is water. A generic starting point formulation for a Green 383 with siliceous-based pigmentation is shown in Table 1 below.

Table 1 – Standard Green 383 Pigmentation

Pigment	Weight %
Tinting Pigments	
Cobalt green spinel	16.5
Chromium Oxide	23.6
Magnesium Ferrite	5.6
Carbazole Violet	0.3
Extender Pigments	
Diatomaceous Silica	23.8
Magnesium Silicate	26.5
Amorphous Silica	3.7

In evolving toward replacement of these extenders with non-siliceous varieties, multiple sources of supply and composition were considered, along with several blends of polymeric and siliceous extenders. Some early considerations included resistance of the substitute extender system to hydrocarbon exposure, DS2, and chemical agents. Once polymeric beads with satisfactory resistance properties were discovered, performance (primarily flexibility and mar resistance) was the primary criterion in judging acceptability and will be discussed below. In general, however, the most dramatic performance improvements came about due to total replacement of the siliceous portion of the extender system. This was made possible due to the greater efficiency in flattening (gloss control) associated with the polymeric beads; i.e., for a given gloss level, less weight and volume were necessary than for siliceous extenders. This led, in turn, to a more "resin rich" paint film with better performance; i.e., a film with a lower pigment volume concentration (PVC). As noted above, the limitation on performance of any CARC is the inherent need for a highly filled film in order to achieve the low gloss necessary for camouflage. When the amount of pigment decreases, the performance goes up correspondingly. One typically expects an increase in performance in areas such as flexibility, mar resistance and impact resistance. A key variable is not only the PVC, which is defined as

$$PVC = Vp/(Vp + Vb)$$

where Vp = pigment volume and Vb = binder volume in the film, but the critical pigment volume concentration (CPVC), which is defined as the level of PVC in a dry paint film where just sufficient binder is present to fill the voids between the pigment particles. The CPVC of a paint represents the densest package of the pigment particles with respect to the degree of dispersion of the system. This definition places a significant influence on the CPVC value in relationship to the degree of pigment dispersion. Therefore, if the selection of the binder/resin system has a lower dispersive capacity, it will give a reduced CPVC value in proportion to the flocculation that remains undispersed in the paint system. Yet if a binder system has a higher dispersive capacity, it may produce a highly dispersed pigment state yielding a maximum CPVC value. This observation is directly related to the oil absorption (OA) properties the prime pigments and extenders used and the formulator must realize that variations in oil absorption are found using different binders. Yet using a standard like linseed oil to determine OA type measurements is still a very useful qualitative guideline for making certain pigment selections for a given binder system. Finally, a CPVC value determined for an OA measurement indicates a specific region separating two completely different pigment/binder conditions. Above a CPVC value, insufficient binder is present in the paint film to fill the particle voids completely. Conversely, below the CPVC value, binder is present in excess of that necessary to fill all voids. General graphical representations for the characteristics property have been published.[2] In principle, the point of inflexion or break at the CPVC presents ways of detecting the CPVC itself, but in practice the various properties show a different sensitivity to the volume of air voids and there will be a spread in the apparent CPVC value.[3] Using these guidelines, it appeared that a weak or critical link was to address both the CPVC and the type of extender material or active flattening agents one would use. The first material is blend of urea resin containing negligible quantity of free methlylol groups. As a result of this chemical composition it functions as polymer cross-linker agent during film formation. The primary particles with an average grain diameter of .1-. 5 μm form agglomerates of approximately 4-5 μm. This results in a high pore volume and a steep grain distribution, two important factors that form the precondition for excellent matting effect. As a result of the almost ideal spherical form of the particles, virtually no influence is exerted on the coating rheology, as opposed to the more needle shaped silica. With very high matting effects or extremely low gloss, silica extenders are associated with a considerable increase of thioxotropy, which in most cases is undesirable. The other active flattening agent is of a polyurethane composition with a medium particle size of 18 μm with a relatively low OA measurement of 40-60. It is also a spherical vesiculated type material that has enhanced matting properties and is extremely chemical resistant as well. The combination of these two materials provides a very dynamic and active flattening package.

Binder Development

The generic (bifunctional) urethane reaction is given by:

$$\mathrm{OCN - R - NCO + HO - R' - OH \rightarrow -[-CO - NH - R - NH - CO - O - R' - O -]-}$$

(polyisocyanate) (polyol) (polyurethane)

If designed properly, crosslinking in this system provides high performance coatings such as CARC. However, the necessity to ensure water is not present in non-aqueous two-component polyurethane formulations has been paramount due to its reaction with isocyanate. The reaction forms an unstable carbamic acid, which quickly decomposes to generate carbon dioxide and an amine.[4,5]

$$\mathrm{RNCO + H_2O \bullet [RNHCOOH] \bullet CO_2\bullet + RNH2}$$

The amine then reacts with further isocyanate to yield the substituted urea.

$$\mathrm{RNH_2 + RNCO \bullet RNHCONHR}$$

In a solvent borne, two-component system, this reaction may inhibit or adversely affect the stoichiometry and development of crosslinking that is crucial to the integrity and performance typical of two-component polyurethanes. However, recent developments in waterborne polyurethane technology have enabled high performance coatings to be formulated using water dispersible polyisocyanates and hydroxyl-functional polyurethane dispersions.[6] While there is a competing reaction occurring with water, the kinetics, raw materials and proper indexing of isocyanate (NCO) to hydroxyl (OH) groups used in the formulations ensure that sufficient crosslink density is established in the film.

The crosslink density of the cured film is controlled by adjusting the NCO:OH ratios. Solvent-based systems are formulated with a slight excess of isocyanate. NCO to OH ratios approximately equal to 1.1 : 1.0 are typical for solvent-based polyurethane coating formulations. The excess NCO ensures complete reaction of the polyol and provides optimal film properties. In water-borne formulations, a greater excess of NCO is required to account for the competing reaction between isocyanate and water. Typically, water-borne formulations are indexed using excess NCO ranging from 1.5 to 3.5. Early efforts within our laboratory focused on formulations with NCO to OH ratios between 2.0:1.0 and 3.5:1.0. While these films exhibited enhanced properties compared to the solvent-based coating, they did not have sufficient performance to pass the Army's chemical agent resistance requirement. For this reason, further investigation led to the most recent formulations with NCO to OH ratios of 5.0:1.0. This level of indexing provided chemical agent resistance without a significant change in coating properties. The formulation efforts involved a significant amount of research in the area of additives, pigmentation and dispersion techniques to assemble a camouflage topcoat that has significantly improved performance properties and offers state of the art technology with respect to environmental compliance for industrial maintenance type coatings. This research effort has resulted in a patent award (U.S. Patent #5,691,410) for the coating.

RESULTS AND DISCUSSION: Beginning with the earliest generations of WD polyesters and polyisocyanates (e.g., Bayhydrol XP-7044 and Bayhydur XP-7007) physical performance of the resulting WD coatings was generally acceptable in laboratory testing, but achieving chemical agent resistance was very difficult. Although all of the performance tests in CARC specifications MIL-C-46168 and MIL-C-53039 are important, the critical ones used in screening proposed WD systems are summarized in Table 2. They attempt to evaluate real-world performance of a coating. For example, hydrocarbon (HC) resistance tests a coating's ability to withstand fuel spills, water resistance checks its rain or immersion properties, DS2 resistance verifies color stability and coating integrity upon field decontamination after chemical warfare, and accelerated weathering checks for colorfastness upon long-term exposure to the sun.

Table 2 – Resistance Testing in MIL-C-46168

Test	Reference paragraph in MIL-C-46168	Test Method
Color & spectral reflectance	4.3.2	ASTM E 308
VOC	4.3.7.1	ASTM D 3960
Specular gloss	4.3.10	ASTM D 523
Water resistance	4.3.19	ASTM D 1308, & 6.4
Hydrocarbon resistance	4.3.20	ASTM D 1308, & 6.4
Accelerated weathering	4.3.23	ASTM G 26
DS2 resistance	4.3.24	-
Chemical agent resistance	4.3.25	-

As noted above, early studies were based on formulations with NCO to OH ratios ranging from 2.0 to 3.5 to obtain optimum film properties. The data below are for formulations based on NCO to OH ratios of 3.5 to 1 involving fully pigmented systems for Green 383, and represent an intermediate stage in the formulation process. The formulations prepared were based on the generic formula presented in Table 3. The particular formulas differ in pigmentation, additives, and modifiers used as well as the placement of water for proper package/system viscosity. It should be noted that the formulations and data are based on Bayer, Corp. hydroxyl-functional polyurethane Bayhydrol XP-7110 and Bayhydur XP-7007 water dispersible polyisocyanates. These materials provided the most promising results for chemical agent resistance and film properties at this point in the formulation effort. Prior materials such as Bayer's Bayhydrol XP-7044 had provided insufficient crosslink density and demonstrated poor chemical agent resistance. In addition, the approach to the validation of this material has been to conduct a variety of tests and exposures to ensure its performance in worst case scenarios. Such tests included extended water immersion with cross hatch and dry tape adhesion evaluation, sub-zero flexibility testing, recoating of less than ideal surfaces and then further exposure and testing of those recoated samples. Therefore, the data presented provide a more realistic and comprehensive baseline to assist in further evaluation and recommendations with respect to formulation development and final application of the material.

Table 3 – Basic WD CARC Formulae

COMPONENT A			COMPONENT B		
Material	Weight	%	Material	Weight	%
WD Polyester	246.66	43.36	Polyisocyanate	158.09	75
Pigments	219.32	38.55	Cosolvent	52.69	25
Additives	56.71	9.97			
Deionized water	46.17	8.12			
Total	568.86	100		210.79	100.00

General Test Results

All samples were sprayed unless noted otherwise, and color and specular gloss were determined using standard opacity charts (Leneta, form 2A) as a substrate. All tests were performed with a dry film thickness (dft) of 1.8 - 2.2 mil. Formula I is a standard water reducible formulation using hydroxy-functional polyurethane Bayhydrol XP-7110 and Bayhydur XP-7007 water dispersible polyisocyanates using conventional siliceous type extenders for flattening purposes. Formula III uses the same resin system without siliceous extenders, incorporating instead active polymeric flattening agents to achieve low gloss values.

Table 4 – Basic Performance Testing

TEST	MIL-C-46168 REQUIREMENT	FORMULA I	FORMULA III
Color/reflectance	$E_{NBS} \leq 2.0$	$E_{NBS} \approx 2.96$	$E_{NBS} \approx 1.0$
VOC	VOC ≤ 3.5 lbs/gal	VOC ≈ 1.50	VOC ≈ 1.50
Specular Gloss	60° ≤ 1.0, 85° ≤ 3.5	60° ≈ 1.3, 85° ≈ 2.2	60° ≈ 0.6, 85° ≈ 2.0
Water resistance	168 hr. immersion	Pass	Pass
HC resistance	168 hr. immersion	Pass	Pass
Polish resistance Gloss	100 strokes 85° ≤ 12.0	Pass 900 strokes 85° ≈ 11.5	Pass 200 strokes 85° ≈ 10.9
Chemical Agent Resistance	≤ 180 micrograms	borderline	borderline

Adhesion Testing

Because water reducible materials exhibit a higher surface tension than solvent-borne coatings, they require surfactants to increase wetting and flow properties. Unfortunately, even with these additives and modifiers, most water based formulations will have a greater sensitivity to adhesion performance than a comparable solvent based system. Notably, such sensitivity is especially apparent in wet environments and areas with poor surface preparation. Table 5 summarizes the performance of the WD formulas. Dry adhesion testing was conducted after seven days air dry on a variety of substrates with and without primers and on some CARC panels that had completed two years of outdoor exposure. Wet adhesion evaluations were performed on the same materials and coatings. After air drying for one week, samples were scribed and immersed in deionized water for twenty-four hours, and then adhesion was evaluated according to method 6301.2 of Fed-Std-141-C. The "material substrate" column in the table defines the panel type and subsequent topcoats applied, if any. The WD formulae were then sprayed over these substrates.

Table 5 - Adhesion Evaluation

MATERIAL SUBSTRATE PANEL TYPE/PRIMER/TOPCOAT	DRY ADHESION WD FORMULAE	WET ADHESION WD FORMULAE
CRS*/None/None [1]	Pass	Pass
CRS*/MIL-P-52192/2 Years Weathered CARC	Pass	Pass
Aluminum/Powdercoat 071-32-5/None	Pass	Pass
Aluminum/Powdercoat PEL91583/None	Pass	Pass
CRS*/MIL-P-53022/None	Pass	Pass
CRS*/MIL-P-53084/None	Pass	Pass
CRS*/Powdercoat 269-10220/None	Pass	Pass

1 Blistering of WD topcoat occurred after four hours, although adhesion was still satisfactory

** Cold rolled steel (CRS) pretreated with zinc phosphate conforming to TT-C-490, Type I*

DS2 Resistance

DS2 is an alkaline-based material used for field decontamination after chemical agent exposure. Its basic formulation is specified by MIL-D-50030 and consists of Diethylenetriamine (70%), Sodium Hydroxide (2%) and Ethylene Glycol Monomethyl Ether (28%). DS2 resistance requires color stability and coating integrity. Color difference and Pencil Hardness were used to determine the DS2 resistance of the films. Formulas I and III plus clear coats with NCO to OH indexes of 2.0 to 5.5 and a standard two-component CARC were evaluated, and the results tabulated in Table 6.

Table 6 - DS2 & Hardness Evaluation

MATERIAL	NBS[1] COLOR DIFFERENCE UNEXPOSED/EXPOSED	PENCIL HARDNESS ASTM D3363 (6.01) UNEXPOSED/EXPOSED
Formula I	0.06	F/F
Formula III	0.18	HB/HB
Standard MIL-C-46168 Two-Component CARC	0.57	HB/HB
2.0 Index (Clear Coat)	37.11	B/2B
2.5 Index (Clear Coat)	24.06	B/B
3.0 Index (Clear Coat)	14.71	HB/B
3.5 Index (Clear Coat)	5.03	H/F
4.0 Index (Clear Coat)	6.56	B/B
4.5 Index (Clear Coat)	1.54	HB/HB
5.0 Index (Clear Coat)	0.67	HB/B
5.5 Index (Clear Coat)	9.84	HB/3B

[1] *Hunter's revised National Bureau of Standards (NBS) color difference equation*

Flexibility Testing

When formulating this material, it has been our attempt to develop a working formulation that will meet our current specification requirements or exceed them whenever possible. The possibility of exceeding specific requirements is often at the expense of other properties of the coating. Yet in our development of this material we realized a significant improvement in flexibility without any compromise to the durability or properties of the film. Flexibility has not been a major or critical element with respect to tactical type equipment, so consequently CARC formulations are satisfactory at ambient temperatures, but have difficulty at zero and sub-zero temperatures. Our current formulations have exceptional flexibility at ambient and sub-zero temperatures. Testing was conducted using No. 31 gage cold rolled luster finish steel panels prepared in accordance with procedure B, phosphoric acid etched, method 2012.1 of FED-STD-141-C. The panels were sprayed to a dft of .0009 to .0011 inches and air dried in a horizontal position for 72 hours at ambient temperature and then baked for 96 hours at 105° C. The panels were then conditioned at ambient temperature for 30 minutes. Flexibility was evaluated in accordance with method 6221 of FED-STD-141-C, all zero and sub-zero evaluations followed the same procedure, except the mandrel and panels were conditioned for four hours at the given temperature and tested within the chamber to ensure the stability of the environmental conditions. Table 7 summarizes the flexibility data using a 1/8" mandrel.

Table 7 – Flexibility Evaluation

TEMPERATURE	FORMULA I	FORMULA III
75° F	Pass	Pass
32° F	Pass	Pass
-28°F	Pass	Pass
-65° F	Not Available	Pass

Accelerated Weathering

Accelerated weathering is another important screening device used to ensure that formulations developed may adequately provide the necessary performance with respect to colorfastness and durability. We evaluated the formulations using both QUV and Xenon type weatherometers. The Xenon testing was conducted using an Atlas Ci-65 chamber with 102 minutes of light and 18 minutes of light and deionized water specimen spray. A black panel setting of 63° C, 50% relative humidity, and irradiance at 0.35 W/m2 was used. The QUV exposure used an Atlas Ultra-Violet Condensation Screening Device (UVCON) programmed for 4 hours of UV and 4 (no UV) condensate hours per cycle. Fluorescent UVA-340 bulbs with a 60°C temperature setting during the UV cycle and 50°C temperature setting for the condensation were used. All panels were sprayed to a dft of 1.8 -2.2 mils and air dried for seven days. The results are graphed and tabulated using NBS color difference versus total hours of exposure. Only formulas I and III are being evaluated since they offer the most extensive exposure time and subsequent data. Finally, we randomly selected commercial batch samples of two-component polyurethanes to provide a comparative baseline. Samples were tested until they exceeded the 2.5 NBS color change limit currently used for two-component polyurethanes in MIL-C-46168. The data in both QUV and Xenon exposure suggest exceptional accelerated weathering resistance for formulas I and III with minimal gloss reduction.

Table 8 – QUV Accelerated Weathering

EXPOSURE TIME (HOURS)	FORMULA I		FORMULA III		CARC SAMPLE	
	COLOR CHANGE (ΔE_{NBS})	GLOSS 60E/85E	COLOR CHANGE (ΔE_{NBS})	GLOSS 60E/85E	COLOR CHANGE (ΔE_{NBS})	GLOSS 60E/85E
200	-	-	.448	0.7/1.9	.223	0.5/1.1
400	.187	1.5/2.0	.697	0.7/2.0	.317	0.5/1.1
600	.308	1.4/2.0	.771	0.7/2.1	.461	.05/1.1
800	.507	1.3/2.0	.899	0.8/2.3	.790	0.6/1.1
1000	.783	-	.996	0.8/2.4	1.35	0.6/1.1
1200	.923	1.2/1.8	1.11	0.8/2.4	2.49	0.6/1.2
1400	1.28	1.1/1.8	1.19	0.9/2.5	2.48	0.6/1.3
1600	1.68	1.1/1.7	1.22	0.9/2.6		
1800	2.31	1.1/1.8				
2000	2.45	1.0/1.7				
2200	3.21	1.0/1.7				

Figure 1 - NBS Color Changes - QUV

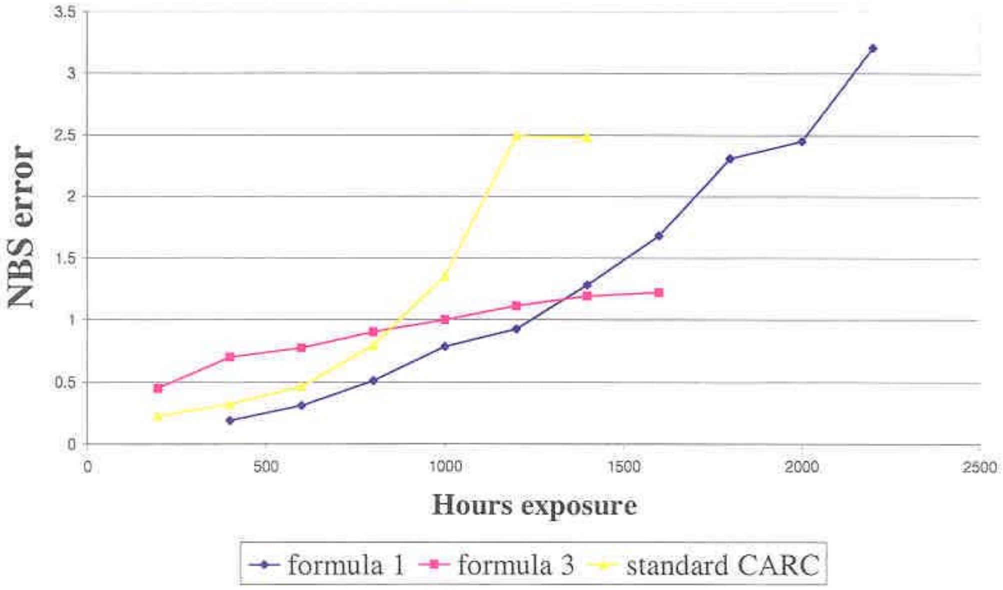
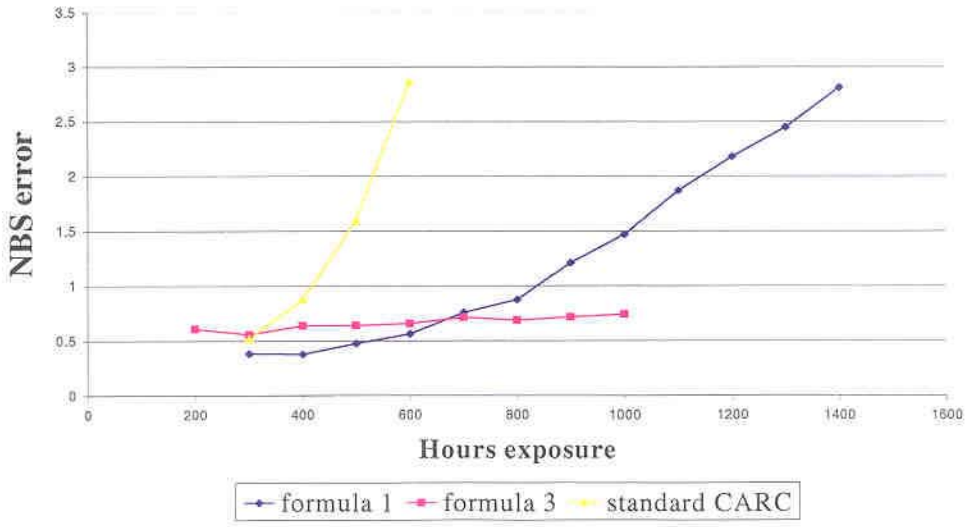


Table 9 – Xenon Arc Accelerated Weathering

EXPOSURE TIME (HOURS)	FORMULA I		FORMULA III		CARC SAMPLE	
	COLOR CHANGE (ΔE_{NBS})	GLOSS 60E/85E	COLOR CHANGE (ΔE_{NBS})	GLOSS 60E/85E	COLOR CHANGE (ΔE_{NBS})	GLOSS 60E/85E
100	-	-	-	-	-	-
200	-	-	.610	0.6/2.0	-	-
300	.383	1.4/2.0	.557	0.6/1.9	.519	0.5/1.1
400	.378	1.3/2.0	.637	0.6/1.9	.873	0.5/1.1
500	.476	1.2/2.0	.640	0.6/2.0	1.59	0.5/1.1
600	.565	1.1/1.8	.660	0.6/2.0	2.86	0.6/0.9
700	.761	1.0/1.7	.716	0.6/2.0		
800	.877	.08/1.8	.690	0.6/2.0		
900	1.21	0.9/1.7	.718	0.6/2.1		
1000	1.47	-	.741	0.6/2.1		
1100	1.87	0.8/1.7				
1200	2.18	0.8/1.6				
1300	2.45	0.7/1.6				
1400	2.81	0.7/1.5				

Figure 2 - NBS Color Changes - Xenon



Refining the Indexing

As noted above, early efforts within our laboratory focused on formulations with NCO to OH ratios between 2.0:1.0 and 3.5:1.0, but these films could not pass the Army's chemical agent resistance requirement. For this reason, further investigations used formulations with NCO to OH ratios of 5.0:1.0. In an effort to further quantify physical properties, three polyurethane coatings were evaluated using Dynamic Mechanical Analysis (DMA) to investigate the relationship between dynamic mechanical properties and durability properties of coated test panels.[7] The current polyurethane solvent-based formulation, used as a chemical agent resistant camouflage topcoat on all military tactical vehicles, was investigated along with newly developed WR polyurethane coatings. The WR coatings offer significantly reduced VOCs compared to the solvent-based system, and thus represent environmentally compliant coatings. DMA investigations revealed that the two classes of polyurethane coatings exhibit different dynamic mechanical properties, which are attributed to different crosslinking mechanisms involved in film formation. The more uniformly crosslinked solvent-based coating provides the best chemical agent resistance but the poorest mechanical properties. DMA properties were sensitive to the degree of isocyanate to hydroxyl indexing in the WR formulations as well as the drying time of coatings prior to evaluation. DMA investigations indicated that longer cure times at ambient temperature (6 or more months) might adversely affect the mechanical properties of the solvent-based system and potentially enhance chemical agent resistance of the WR coating.

DMA was performed on free coating films. These films were prepared by spraying the coating onto release paper. The films were dried for varying lengths of time at ambient temperature (25 ± 2°C) before separating them from the release paper. Coating film thickness varied between 160μm-280μm. Data was normalized according to individual sample dimensions. DMA of the coating films was performed using an Imass Inc. autovibron (automated Rheo-200 rheovibron, Toyo Instruments). The samples were evaluated from -100EC to +150EC at a heating rate of 2EC per minute. Data was collected at 1.1 Hz. Formulations were pigmented conforming to color number 34094 (Green 383) as stated in MIL-C-46168D, the U.S. Army specification for two-component polyurethane coatings. Water-reducible formulations are designated "WR" followed by the specific NCO indexing. The solvent-based system is designated as "SOL". Coating panel tests were conducted according to MIL-C-46168D.

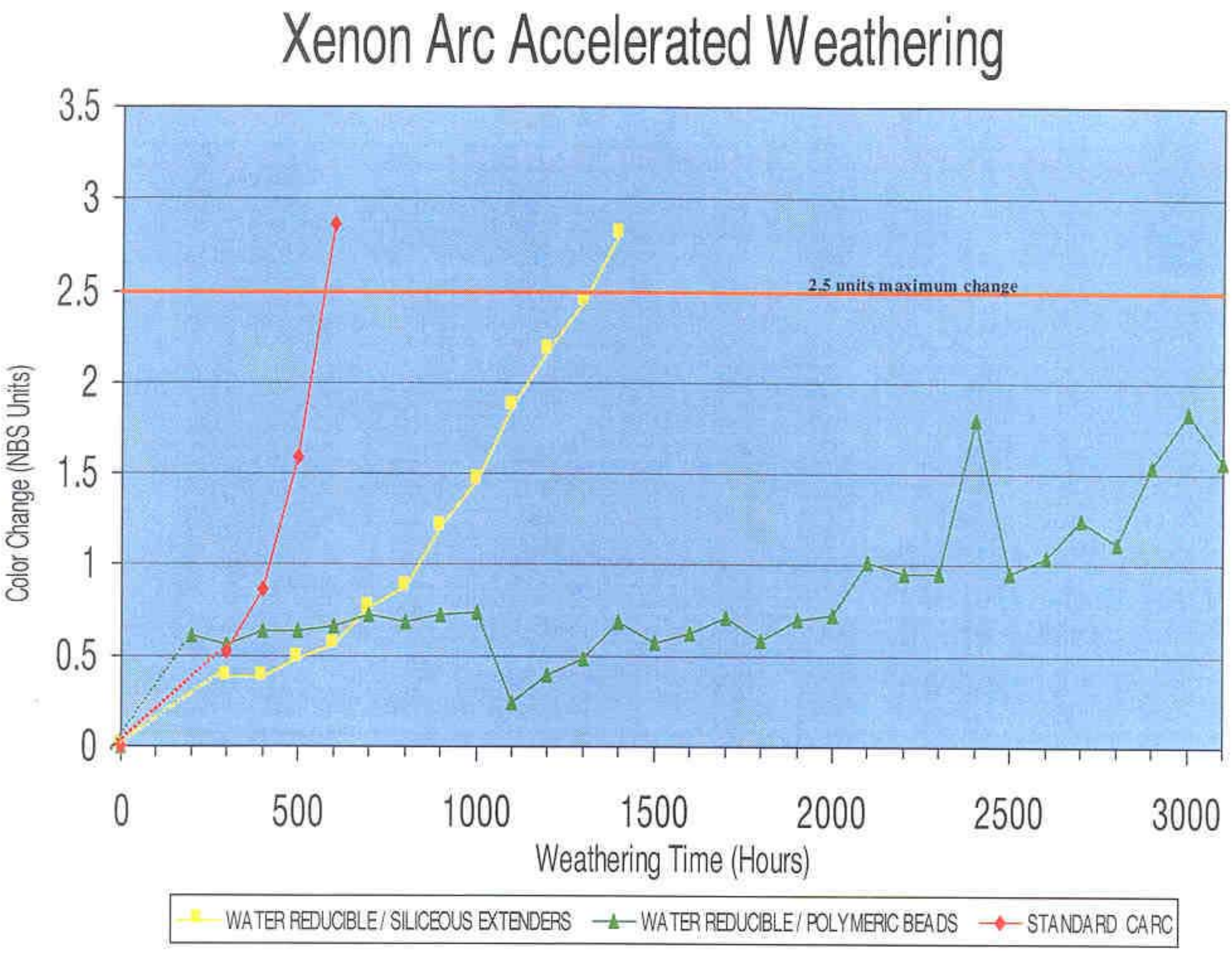
DMA was performed on both the water-reducible and solvent-based polyurethane coatings in an effort to better understand the differences in the properties of the different formulations. WR 3.5 and WR 5.0 both pass all of the specification requirements with the exception that WR 3.5 does not meet the necessary requirement for chemical agent resistance. Both WR formulations exhibit greatly reduced VOC compared to the conventional solvent-based system. Additionally, the WR formulations exhibit significantly improved impact resistance and low temperature flexibility. These properties, determined in accordance with MIL-C-46168D, are shown in Table 10.

Table 10 – Selected Properties of Coated Panels

Sample	VOC ($\leq$ 420 g/L)[a]	CAR ($\leq$ 180μg)[a,b]	Forward Impact Resistance (in-lbs)	Low Temperature Flexibility[b,f]
SOL	~ 420 g/L	~ 20μg	52 [c], 48 [d], 28 [e]	F
WR 3.5	~ 180 g/L	~ 510μg	160 [c], 148 [d], 148 [e]	B
WR 5.0	~ 180 g/L	~ 98μg	148 [c], 84 [d], 100 [e]	P

[a] MIL-C-46168 requirement shown in parenthesis
[b] data reported after a 7 day dry time
[c] data reported after a 10 day dry time
[d] data reported after a 17 day dry time
[e] data reported after a 24 day dry time
[f] P = pass, B = borderline/pass, F = fail (Failure is indicated by visible cracking in the coating after bending the coated panel around a mandrel at 0° C.)

While WR 5.0 meets CAR requirements, WR 3.5 exhibits the most enhanced mechanical properties which are important for long term durability under broadly varying environmental conditions observed in service. It was determined that the type of crosslinking required for superior CAR is different from that required to optimize mechanical properties. The dynamical mechanical properties of SOL were shown to be much more sensitive to dry time compared to the WR coatings, which may adversely affect coating properties of the solvent-based system in service. Also, since cost is always a consideration, continuing efforts will be focused on reducing the indexing of NCO to OH and still achieving chemical agent resistance. In addition to the improvements noted above in impact resistance and flexibility, much improved durability has been achieved as evidenced by the accelerated weathering results noted in Figure 3 below. These results compare color change in NBS units for solvent borne CARC versus the WB CARC with siliceous extenders versus the WB SERDP CARC with polymeric beaded extender system.



Developing the Supplier List

As ARL reached the point at which the formulation has been optimized, work began on two fronts to enable its use. First, a military specification is being drafted with an associated Qualified Products List (QPL). The plan at this point is for it to be a "detail" specification with both performance and composition requirements, due to the critical nature of the chemical agent resistance requirement. Initially, the document will contain two types, Type I with a siliceous extender system, and Type II with the non-siliceous extender system (SERDP WD CARC).

Secondly, while proceeding with the Standardization process above, ARL is using its established Experimental Products Program (EPP) to develop a supplier list for the SERDP WD CARC. The EPP was established as a parallel process to the specification/QPL process as a way of evaluating performance-based products offering either environmental benefits not found in an existing specification (e.g., a lower VOC level) or performance beyond specification requirements (improved corrosion resistance, etc.). It can also be the means by which ARL can establish a consensus in the composition requirements to be placed in a specification by negotiating among the various EPP supplies toward a generic starting-point formulation. One historical example of this process was with the development of the current Type IV (high solids version with a VOC limit of 3.5 pounds per gallon) of MIL-C-46168. After developing a coating in the laboratory that seemed to work, we asked current QPL vendors to submit high solids EPP samples while we were in the process of revising the material specification. Those products which passed this performance testing were placed on the QPL for the Type IV in MIL-C-46168 when the revision was completed. The composition requirements were developed in a joint effort with the paint companies.

Once ARL developed the patented SERDP WD CARC formulation, we began soliciting samples from current QPL vendors for the solvent borne CARC specifications. Through the use of non-disclosure agreements, we were able to exchange the basic technology for the system while protecting ARL's intellectual property rights. Working with these paint manufacturers, we have been able to develop a growing list of suppliers for SERDP WD CARC. As a result of the EPP testing completed at this point, we have verified acceptable chemical agent resistance results for the manufacturers by Type and color as shown in Table 11 below, and we expect to issue final approval letters once a small amount of our laboratory testing on the paint is finished.

Table 11 – Selected Properties of Coated Panels

WD CARC Type	Manufacturer	Color
I	Sherwin-Williams	Green 383
I	Sherwin-Williams	Brown 383
I	Sherwin-Williams	Black
I	Sherwin-Williams	Tan 686A
I	Niles Chemical Paint Co.	Green 383
I	Niles Chemical Paint Co.	Brown 383
I	Niles Chemical Paint Co.	Black
I	Niles Chemical Paint Co.	Tan 686A
I	Spectrum Coatings	Green 383
I	Spectrum Coatings	Brown 383
I	Spectrum Coatings	Black
I	Hentzen	Green 383
I	Hentzen	Brown 383
I	Hentzen	Black
I	Stic-Adhesive	Brown 383
II	Sherwin-Williams	Green 383
II	Hentzen	Green 383

The next stage in the implementation process will be via the Environmental Security Technology Certification Program (ESTCP) project #20024. This effort will demonstrate/validate the technology developed in this SERDP effort by applying material manufactured by one of the above suppliers at three DoD production sites, Barstow (MC)[3], Ogden AFLC, and Tobyhanna AD.

CONCLUSIONS:

1. The Coatings Technologies Team of the US Army Research Laboratory in Aberdeen, MD has developed a water-reducible, two-component polyurethane topcoat implementing water-dispersible hydroxy-functional polyesters and water dispersible polyisocyanates. It has a VOC of less than 180 g/L, and through the use of a novel pigment system, provides chemical agent resistance plus improved low temperature flexibility, impact resistance, and weathering durability.

2. Additives to control flow, wetting, and dispersion are much more critical in WB/WD/WR systems than in standard solvent systems and their placement and amount must be optimized.

3. Patent # 5,691,410 was awarded for the WD low VOC CARC formula that is the basis for the SERDP effort.

4. ARL has transitioned from Dugway Proving Ground to the Soldier and Biological Chemical Command (SBCCOM) at Edgewood Proving Ground for its source of chemical agent resistance testing. SBCCOM has validated new procedures for both HD and GD testing.

5. ARL has validated the formulation and verified the performance of all five colors of interest in the SERDP effort (Green 383, Brown 383, Black, Tan 686A, and Gray #26251) at the ARL laboratory level, at the laboratory level of a coatings industry partner, at the level of a pilot plant batch size manufactured by the industry partner, and at the level of a production size batch by the industry partner.

REFERENCES:

1. Duncan, J.L. "Reduced VOC Chemical Agent Resistant Coating (CARC)," ARL-MR-191, September 1994.

2. Patton, T.C., "Paint flow and Pigment Dispersions, 2nd Ed.," John Wiley Interscience, New York, 1979.

3. Graystone, J.A., "Paint & Surface Coatings," John Wiley Interscience, New York, 1987.

4. Woods, G., "The ICI Polyurethanes Book," John Wiley & Sons, New York, 1990.

5. Oertel, G., "Polyurethane Handbook," Hanser Publishing, New York, 1985.

6. Jacobs, P.B. and Yu, P.C., "Two-Component Waterborne Polyurethane Coatings," Journal of Coating Technology, 1993.

7. Escarsega, J.A., Crawford, D.M., Duncan, J.L., and Chesonis, K.G., "Water-Reducible PUR Coatings for Military Applications," Modern Paint and Coatings, 1997.

Appendix
Technical Publications

Conference Proceedings.

ARL hosted a DoD/User/Supplier CARC Workshop on September 1 – 2, 1999. The purpose of this gathering was to lay out the future of CARC, including plans for implementation of the SERDP CARC, via the dem/val process that the Low VOC CARC SERDP/ESTCP team will be pursuing in the upcoming year. Briefings by ARL included formulation efforts, the Experimental Products Program and Qualified Products List processes by which it will be implemented, and the future potential for including signature management requirements. The workshop was attended by DoD representatives from all services, coatings manufacturers, and members of the user community.

"Low VOC and HAP-free Camouflage Coatings for DoD Applications", presented at the 10th Annual International Workshop on Solvent Substitution on September 14, 1999.

"Characterization and Performance Testing of Water Reducible Polyurethane Coatings for Military Application", presented at the DOD/Industry Aerospace Coatings Conference in Monterey, CA on May 19, 1999.

"Water-Reducible Camouflage Coatings for DoD Applications", presented at the 25th Environmental Symposium & Exhibition in Denver, CO on March 31, 1999.

"CARC As A System," presented at the Army Pollution Prevention Technology Integration Review in Pocono Manor, PA on July 16, 1998.

"Environmentally Benign Chemical Agent Resistant Coatings" (poster), presented at the Rodman Building in Aberdeen Proving Ground, MD on June 12, 1998.

"CARC As A System," presented at the Army Acquisition Pollution Prevention Program IPR, in Dayton, OH on June 3, 1998.

"Environmentally Acceptable Protective Coatings For Army Tactical Equipment And Ammunition," presented at the Aircraft Coatings Workshop in Aberdeen Proving Ground, MD on April 30, 1998.

"Low Volatile Organic Compound (VOC) Chemical Agent Resistant Coating (CARC)," presented at Aberdeen Proving Ground, MD on April 22, 1998.

Open Literature Publications.

ARL-TR-1950, "Development of Polyurethane Coatings for Military Applications", published in May 1999.

“ Thermal Characterization of Novel Polyurethane Coatings for Military Applications” by D. Crawford and John A. Escarsega, North American Thermal Analysis Society Conference /Proceedings, September 1998.

“Fourier-Transform Infrared (FTIR) Characterization of Chemical Agent Resistant Coatings (CARC) Durability Using Infrared (IR) Cards and Silicon Wafers” by W. Lum, P. Patterson and J. Escarsega, Polyurethane Expo 98, September 1998.

“Coatings Emissions and Relative Ozone Formation” by J. R. Wells, J. S. Baxley, and John A. Escarsega, Metal Finishing, Vol 96, No 4, pg 33-37 Elsevier Science Inc., April 1998.

NAVSEA
PHILADELPHIA

Low Volatile Organic Compound Chemical Agent Resistant Coating Program

Phase II
Application Study
Final SERDP Technical Report

By: Malay Patel
Anthony Eng
Forrest Pilgrim
Lisa Weiser

April 2000

INTRODUCTION

The Strategic Environmental Research and Development Program (SERDP) has funded a tri-service effort to develop a low Volatile Organic Compound (VOC) Chemical Agent Resistant Coating (CARC) system for use on Army, Marine Corps, and Air Force equipment. The chemical agent resistant and camouflage coating must comply with current/anticipated regulatory requirements for VOC and eliminate hazardous air pollutants (HAPs) and toxic solvents used in current CARC formulations. Additionally, the new formulation must meet performance requirements for all three agencies.

The technical effort has been broken into three phases—formulation, application, and stripping, with each agency overseeing one of the phases. The Army Research Lab (ARL) is conducting the formulation efforts, Naval Surface Warfare Center, Carderock Division (NSWCCD) the application studies, and Wright Research Labs (WRL), along with Southwest Research, Inc. the de-paint or stripping studies.

This report will focus on the application studies conducted by NSWCCD. These studies include non-film paint properties, laboratory application analysis, post-application properties (both uncured and cured), and rheological characterization. A Design of Experiment (DOE) study is used to quantify the cause and effect relationships among application parameters and final film performance properties. The cause and effect relationships (revealed by the DOE) can then be used to tailor application processes to influence the final film properties, hence satisfying varying performance requirements.

The following report describes technical accomplishments in the application studies from October 1, 1997 through February 29, 2000.

EXPERIMENTAL

Materials

The primary material tested and analyzed was SERDP Low VOC CARC. This material was manufactured by Hentzen Coatings, Inc. as part of a pilot-plant, quality-conformance batch and was based on the formulation established by the U.S. Army Research Laboratory (ARL). This formulation was produced in low-gloss camouflage green (FED-STD-595 Color 34094) and low-gloss camouflage gray (FED-STD-595 Color 36251) with VOC content at 216 g/l. These materials will be referred to as WRCARC (34094) and WRCARC (36251), respectively. Color 34094 is also referred to as green 383 in many Army specifications. The Air Force uses or plans to use color 34094 for exterior shelters and a specific tactical aircraft. The standard Army solvent-borne CARC, MIL-C-46168, and the standard Marine Corps camouflage coating, MIL-C-29475, were tested as control (comparison) coatings. These control coatings are specified with VOC contents of 420 g/l and 216 g/l, respectively. Solvent-borne epoxy, MIL-P-53022, was used as the standard primer, since it is the most common primer for CARC systems in the DOD. This was confirmed by total GSA volume sales and by the information generated in the application survey of field maintenance units (see Appendix). The standard substrate was a SAE 1010 cold-rolled steel (CRS) coupon with 25 – 65 microinch textured roughness, which is representative of general-use, sheet-metal applications. Depending on the type of test, the coupon was either tested bare (i.e., non-pretreated) or with a zinc phosphate pretreatment per TT-C-490, Type I. 2024 T3 Alclad with MIL-C-5541 chromate conversion coating was used in a limited number of adhesion and permeation-resistance tests. Test substrates composed of 2024 T0 aluminum with a chromic acid anodize per MIL-A-8625, Type I were used for all flexibility and impact tests, due to the malleability of this material type. Dimensions of the standard steel substrate were 3″×6″×0.032″, excepting those required for the Taber abrasion test, which were 4″×4″×0.032″. All aluminum test panels had dimensions of 3″×6″×0.025″. The general test specimen configuration is depicted in Figure 1.

Tests and Equipment

The paint components and admixed materials were characterized using the following non-film paint tests according to the appropriate ASTM or military specification method:

Volatile Content or Weight-Percent Solids	ASTM D 2369
Wet Density or Weight per Gallon	ASTM D 1475
Fineness of Dispersion or Grind	ASTM D 1210
Flash Point (Pensky-Martens Closed Cup)	ASTM D 93
Ford Cup Viscosity and Pot Life	ASTM D 1200
Accelerated Storage Stability	MIL-C-29475
Freeze-Thaw Storage Stability	MIL-P-53030

In general, standard paint application methods were used to prepare test specimens—conventional air-atomizing spray with a siphon cup, 0.070″ fluid nozzle, 45-psi airline pressure, and horizontally oriented test coupons. A nonstandard application conformance test was also employed to determine the film formation characteristics of the WRCARC over a range of application variables (based on visual quantification at varied film thickness). The investigated variables were application equipment (conventional versus HVLP), nozzle size (0.055″ versus 0.070″), air line pressure (45 versus 60 psi), panel orientation (horizontal versus vertical), mixing procedure (recommended versus efficient), induction time (0 versus 2 hours), and primer application (absent versus present). These equipment options were appropriate for the candidate paints and also were the most common among the field activities (see Appendix). All coatings were applied in cross-coats (i.e., 90° offset between 2 successive deposition passes) and allowed to cure at room temperature (approximately 72°F) for 7 days unless the contrary is indicated.

The post-application and cured-film properties were characterized via the following ASTM, federal standards, and military specification test procedures:

Humidity Controlled Environment	ASTM D 5032
Sag Resistance	ASTM D 4400
Drying Time	ASTM D 1640
Discontinuity/Holiday Test	ASTM D 5162
Color [using CIELAB, D65 illuminant, 10° observer]	ASTM E 308
Color Change or ΔE	ASTM D 2244
20°,60°, 85° Gloss	ASTM D 523
Tensile Adhesion	ASTM D 4541, type IV
Tape Adhesion	ASTM D 3359, Method A
Tape Adhesion	FED-STD-141 Method 6301
Tape Adhesion	TT-P-2756
Taber Abrasion Resistance	ASTM D 4060
Mandrel-Bend Flexibility	ASTM D 1737
Gardner Impact Resistance	ASTM D 2794

GE Impact Flexibility	FED-STD-141, Method 6226
Water Immersion Resistance	TT-P-2756
Recoatability	MIL-C-46168

The X-cut tape adhesion test per ASTM D 3359 Method A and the parallel cut procedure per FED-STD-141 Method 6301 were combined to increase the severity of the tape adhesion test. As depicted in Figure 2, two parallel scribe cuts were applied to the same test area as the specified X-cut, prior to tape application and removal. This combination produces a wider range of scribe-cut intersection angles and also increases the number of potential failure zones from 4 to 12. In addition, the application and removal of the tape is performed twice (but in opposite directions) over the same test area to increase the probability of a debonding failure. Also, in order to further increase the severity of the standard ASTM tape test, the water temperature and time of immersion are both elevated from those specified in TT-P-2756.

Recoatability testing was performed in accordance with MIL-C-46168. The specification requires no lifting, softening, or other film irregularities on unprimed zinc-phosphate-treated 1010 CRS test panels after recoating at 2-hr and 24-hr intervals. Recoat durations of 72 and 168 hours were also evaluated. Quantitative evaluation of these test specimens was conducted via tensile adhesion testing (ASTM D 4541, type IV) over primed and unprimed substrates after all of the coatings had cured for at least 5 weeks.

The compatibility of the WRCARC topcoat and the standard control topcoat (MIL-C-46168) with a variety of primers was quantified via tensile adhesion testing (ASTM D 4541, type IV) at coating cure durations of 3 days and 7 days. Since the present effort is multi-service DOD oriented, primers typically used by the Army, Air Force, Navy, and Marine Corps were evaluated (i.e., MIL-P-53022, MIL-P-53030, MIL-P-23377 class C, MIL-P-85582 class N, TT-P-2760, TT-P-2756, BMS-1011, MIL-P-26915, Bar Rust 235). To prevent flexing of the painted test coupon during adhesion testing, the painted test coupons (3"x6"x0.032" 1010 CRS with TT-C-490 treatment) were bonded to 12"x12"x0.25" steel plates.

Rheological Testing

Introduction

To better characterize the water-reducible SERDP chemical-agent-resistant coating (WRCARC), its rheological properties are being examined and compared to those of solvent-borne chemical-agent-resistant coating, MIL-C-46168. These formulations are all available in the standard camouflage colors; rheological data presented in this interim report will be limited to the camouflage green (34094) and gray (36251).

Rheology is the study of the flow and deformation of matter, and a basic understanding is an important part of proper coating formulation. Study of rheological data also allows one to make accurate predictions relating to real-world coating performance[1].

Some important definitions necessary for a basic understanding of Rheology are presented below:

Shear Stress (τ) is the shear force acting on the material per unit area. Typical units are Pascals (Newtons/meter^2) and Dynes/centimeter^2.

Shear Strain (γ) is a measure of magnitude of deformation relative to the sample length. For a material undergoing shear deformation in the positive x-axis direction, the shear strain is the difference in the final and initial sample length divided by the sample thickness. Shear strain is frequently reported in percent (%).

Shear Rate ($d\gamma/dt$) or shear strain rate is simply the change of strain with time; it is equal to the velocity of the top layer of the sample divided by the sample thickness and has units of reciprocal time, e.g. s^{-1}.

Viscosity (η) is a measure of a material's resistance to flow and reflects the rate at which the material will dissipate deformational energy via flow. Viscosity can be calculated by the ratio (Shear Stress)/(Shear Rate) and has units Pascal-sec (Pa-s) or Poise (P), where 1 Pa-s = 10 P.

Yield Stress is the minimum amount of stress required to induce flow in a material.

There are two types of rheological testing: dynamic mechanical (oscillatory) testing and steady (linear testing). *Dynamic* testing is conducted by applying a sinusoidal stress to the sample material and then measuring the resultant strain. Because of the oscillatory nature of dynamic testing, the strain measurement will typically lag behind the applied stress—this is characterized by a phase angle. *Steady* testing takes place during the application of a stress that is constant in amplitude or is linearly ramped. Since there is no oscillatory application of stress, there is no associated lag in strain. Similarly, *transient* testing involves controlled steady stress measurements taken following a step stress, from one stress amplitude to another.

When a dynamic test is conducted, the equipment applies stress in a sinusoidal waveform; some key parameters are

τ = applied stress
γ = strain
δ = phase angle lag of the strain to the applied stress – this lag is the basis for dynamic testing
ω = frequency – analogous to velocity or the "processing speed"

The sinusoidal waveform stress is applied in the form

$$\tau = \tau_o \sin(\omega t) \qquad (1)$$

where τ = stress at time t
τ_o = initial stress and the amplitude of the wave
ω = frequency of the applied stress

The response to the applied stress depends on whether the material is elastic, viscous or viscoelastic. For a purely elastic response, the resultant strain follows the stress directly and the lag $\delta = 0$. The response follows **Hooke's Law,** which states that

$$\tau = G\gamma(t) \qquad (2)$$

where, G = elastic modulus
$\gamma(t)$ = strain as a function of time

In a purely elastic response, there is no lag, and from equations (1) and (2) it is seen that

$$\tau = G\gamma_o \sin(\omega t) \qquad (3)$$

where γ_o = amplitude of the strain wave function.

For a purely viscous response, **Newton's Law** is obeyed

$$\tau = \eta\gamma(t) \qquad (4)$$

Through some mathematics it is seen that

$$\tau = \omega\gamma_o \sin(\omega t + \pi/2) \qquad (5)$$

Basically, the strain lags behind the applied stress by 90° for an ideal fluid.

In reality, all polymers (including those in this study) have both elastic and viscous properties, and are, therefore, referred to as **viscoelastic** materials. For a viscoelastic material, the "resultant" stress can be broken up into two waveform components: an elastic stress in phase with the strain and a viscous stress in phase with the strain rate. The resultant stress is a complex stress comprised of the two component stresses:

$$\tau' = \tau_o \cos\delta \text{ (elastic stress)} \qquad (6)$$

$$\tau'' = \tau_o \sin\delta \text{ (viscous stress)} \qquad (7)$$

These stresses are commonly expressed in terms of a complex stress, τ^*, where

$$\tau^* = \tau' + i\tau'' \qquad (8)$$

This allows a **complex modulus**, G^*, to be defined

$$G^* = \tau^*/\gamma \qquad (9)$$

The complex modulus is often separated into its components

$G^* = G' + iG''$ where G' = elastic or storage modulus
G'' = viscous or loss modulus

The storage modulus, G', is a measure of a material's elasticity, and is associated with the energy stored in elastic deformation. The loss modulus, G'', is a viscosity term associated with the dissipation of viscous energy. The ratio G''/G' is equal to $\tan\delta$, which can give valuable information on coating properties.

There are two common types of rheometers used to carry out rheological testing: (1) **controlled stress**, and (2) **controlled strain**. In the former, a stress is applied and the instrument measures the strain; in the latter, a strain is applied and the stress is then measured. The coatings in this study were evaluated with a **controlled-stress rheometer**.

Experimental

The rheological testing is being performed with a stress-controlled rheometer, manufactured by Rheometric Scientific™ (Model SR-2000). Figure 3 depicts the SR-2000[2].

Viscosity profiles were generated via Steady Stress Sweep tests. This important procedure is used to generate a viscosity profile (sometimes called a flow curve) of the coating. A Steady Stress Sweep applies a range of stress levels, each at constant amplitude. Successive measurements are taken at each stress level. Stress amplitude can be incremented or decremented, with stress increments scaled either logarithmically or linearly. Temperature is held constant during the test. By observing how the viscosity changes with increasing (or decreasing) shear rate, it is possible to predict important material behavior, such as resistance-to-sagging, settling, leveling, and sprayability.

Figure 4 (taken from reference 3) demonstrates how viscosity/strain-rate data can be used to predict the performance of two coating systems. Very low shear rates (up to around 0.1 s^{-1}) are indicative of those resulting from gravitational forces and can be related to the magnitude of shear rate the coating would undergo during storage or post-application. During storage the coating would experience very low shear rates (those induced by gravity) which can be sufficient to cause pigment settling. The shear rates associated with transport (truck or train, e.g.) are higher than gravitational shear alone—these slightly higher shear rates may be enough to induce pigment settling (which would not necessarily occur during storage). Post-Application shear rates are also low and are related to leveling and sagging effects. Intermediate shear rates (10 to 100 s^{-1}) are effected when a coating is stirred, and these levels are associated with the feel and appearance of the coating. High shear rates (greater than 1000 s^{-1}) are generally seen during the application process—spraying, brushing, or rolling.

Procedure

To perform the rheological testing, samples of recently mixed coating are introduced into a double-wall couette cup (Figure 5), and stress is then applied to the samples by means of a rotating bob. Couettes are designed for testing low viscosity fluids and for use whenever very low stresses are required. The couette system consists of a titanium bob and stainless steel cup (see Figure 5)—the bob is attached to the stress head and is inserted into the couette cup during testing. This tool will provide shear rates from 0 to 1048 sec^{-1} and strains from 0.5% to 500%.

The samples were prepared in the following manner.

WRCARC (34094 and 26251) – These are three-part water-reducible coatings, consisting of a polyol base (part A), an isocyanate catalyst (part B), and deionized water (part C). It is mixed in a 2:1:1 (A:B:C) ratio. To prepare the sample, part A is thoroughly mixed with part B. Deionized water is then added and mixed with parts A and B. The mixture is allowed to sit for 5 minutes and then introduced via pipet into the double-wall couette.

MIL-C-46168 (34094 and 36251) – These two-part solvent-borne coatings consists of a polyol base (part A), and an isocyanate catalyst (part B). The mix ratio is 4:1 (A:B). Parts A and B are mixed for 20s and then tested after 5 minutes.

Design Of Experiment

The formulation of a polyurethane WRCARC for use by multiple services presented a unique challenge with respect to application procedures. The material is intended to be a "drop-in" substitute for currently used coatings by the Army, Marine Corps, and Air Force. Compatibility with the equipment and processes used by all three services, along with the varying final film performance requirements for each Agency, dictated the need for a thorough understanding of the cause and effect relationships between application parameters and final film performance.

To determine these cause and effect relationships, a Design of Experiment (DOE) test matrix was developed.

The specific DOE matrix is a two-level fractional factorial design. A major use of fractional factorial designs is screening experiments, in which many factors are considered with the purpose of identifying those factors (if any) which have large effects. Of the many factors that a screening design examines, a few important terms can stand out in comparison to the others. Also, because the goal of the experiment is usually to optimize some response rather than show statistical significance, the factor(s) that influence the predicted response are of overriding interest.

For this effort, NSWCCD simultaneously evaluated the effect of twelve independent variables (application parameters) on ten different dependent variables (film performance properties). Each of the independent variables was evaluated at two levels. The independent variables, their corresponding test levels, and the dependent variables (or performance properties) are listed in Table 1. The DOE utilized a sixteen experiment test matrix with each experiment (or panel set) being prepared as summarized in Table 2. The dependent variables were measured via the twenty performance tests listed in Table 3. Each test was performed in accordance with the method cited in the table.

The test design used is classified as a Resolution III design. This is a design in which the main variables (independent variables) are not "aliased" with any other main variable. Alias is a term in experimental design describing two or more effects that cannot be distinguished as the specific cause, based on the design of the experiment. Stated differently, two or more factors will appear to have the exact same effect. The Resolution III design prevents aliasing among each of the independent variables, thus allowing independent analyses of each of the variables and their effects. However, main effects are aliased with two-factor interactions and two-factor interactions may be aliased with each other. Thus, independent variables that interact, to produce an effect, cannot be distinguished. This design also relies on the "Sparsity of Effects Principal" which states "When there are several variables, the system or process is likely to be driven primarily by some of the main effects and low-order interactions[4]." By identifying the aliasing structure, an intuitive decision can be made whether the interactions would have a significant effect. Other designs are available to evaluate the effect of these interactions.

The test parameters (sample size, number of experiments, number of readings, etc.) were chosen to provide a 95% confidence level in the results, and ultimately, the influences observed.

The cause and effect relationships discovered by the design will identify application parameters which may require increased control, to provide desired film performance. It may also provide a basis to predict performance if material has been applied outside of specified procedures.

RESULTS AND DISCUSSION

Non-Film Paint Properties

The non-film (prior to the application process) paint properties are presented in Table 4. The tests listed therein were utilized to establish and/or confirm baseline properties of the individual components and of the admixed paint. Weight-percent solids, wet density, fineness of dispersion, and viscosity/pot-life tests can be used in the lab or at field maintenance facilities to confirm the quality and stability of the material over the course of its shelf life. These tests are also often used as a basis for extending shelf life. Volume-percent solids is an invaluable test for approximating the dry-film thickness from wet-film thickness measurements. The term admixed in this table implies that the paint was immediately tested after being mixed according to the following recommended procedure: 2 volume parts of component A mixed thoroughly with 1 volume part of component B; then 1 part of deionized water is thoroughly mixed into the A/B component mixture. The mixing procedure and its effect on performance will be discussed later in this report.

The weight-percent-solids and wet-density data deviated from the manufacturer's data by 0.1 to 1.9%, which is certainly acceptable. The fineness of dispersion of the pigmented components for both the green and gray colors were slightly less than the minimum requirement of 3.0 in MIL-C-46168. This should not be a problem since these paint batches represent the initial scale-up production batches of this novel technology. Also, the current gloss values of WRCARC are low enough that this material can tolerate an increased level of grinding, which could be necessary to increase fineness of dispersion to at least 3.0. Flash points for the pigmented component (part A) for both colors, as shown in Table 4, were greater than 212°F due to significant water content in the coating. An exact flash point could not be determined since the water started to boil at about 200°F.

Viscosity values conformed to those in the manufacturers' technical data sheets. Figure 6 shows the difference in initial viscosity and viscosity over time for the WRCARC, MIL-C-46168, and MIL-C-29475. WRCARC (34094) displays a slight and tolerable increase in viscosity up to about 4 hours, whereas WRCARC (36251) demonstrates no significant change in viscosity for up to 6 hours. MIL-C-46168 and MIL-C-29475 were tested using the Ford #4 cup for direct comparative purposes, despite the fact that this type of viscometer was designed for paints with efflux times between 20 and 100 seconds. A more appropriate and valid comparison of WRCARC to the control paints using a controlled stress rheometer is discussed later in the Rheology section of this report.

The conditioning procedures for the accelerated and freeze-thaw storage stability tests were obtained from MIL-C-29475 and MIL-P-53030, respectively, and were specifically chosen since they were the most severe of all appropriate water-borne military specifications. These storage stability tests were conducted to determine resin and/or pigment deficiencies at harsh, accelerated conditions. After the conditioning process, the stability and homogeneity of the components were evaluated before and after five minutes of mechanical shaking. Also, the admixed viscosity (Ford #4) and pot life were quantified. Accelerated storage conditioning for 30 days at 140°F (60°C), produced gelling of the entire pigmented paint component (part A) for both WRCARC (34094) and WRCARC (36251), but, following mechanical shaking, a free flowing consistency resulted. Four cycles of freeze-thaw storage stability conditioning produced some soft settling (moderate amount for green and slight amount for gray), but, again, reverted to uniform, defect-free condition after shaking. A single cycle consisted of 16 hours at 10°F, followed by 8 hours at 72°F. There were no defects observed during either test for the non-pigmented components (part B) for either green or gray. As shown by the viscosity data in Table 4, and depicted in Figure 7, freeze-thaw storage has very little effect on viscosity/pot life for WRCARC (34094), whereas accelerated storage has a moderate effect at 1 hour and a more prominent effect (~2X increase) on viscosity at about 2 hours. Figure 7 shows that, although freeze-thaw storage has a more adverse effect on viscosity than accelerated storage for WRCARC (36251), both coatings display a gradual increase in viscosity (which does not appear to be a problem).

Application Properties

In general, application of WRCARC (34094) produced a uniform appearance and consistent film deposition when applied with both conventional and HVLP spray equipment—using 0.070″ and 0.055″ fluid nozzles, and both 45 and 60-psi gun inlet pressure. No spray atomization (i.e., flow out of gun) or film formation/leveling problems were encountered with horizontally oriented test parts with final DFT up to 4.3 mils. The WRCARC possessed superior spraying/atomizing and leveling characteristics, compared to MIL-C-46168 and MIL-C-29475. However, significant film problems were encountered with vertically aligned parts once certain maximum film thicknesses were surpassed (see Table 5). On bare, unprimed 1010 CRS, the topcoat resisted sagging up to about 1.59 mils DFT (5 mils wet). However, at 2 and 3 deposition passes, the coating may have sloughed slightly without applicator detection, since the DFT standard deviation is relatively high (0.20, 0.34), despite the fact that no sagging was noticed during drying or after cure. Surprisingly, the cured film at 4 and 5 passes produced no defects other than the high DFT standard deviation. Nonetheless, gross sagging which was evident during the drying process and also in the cured film occurred at 6 deposition passes (11 mils wet). After applying MIL-P-53022 primer (at 0.9 mils DFT) to 1010 CRS substrate and allowing it to dry for 4 hours, no sagging of the WRCARC was observed at a single coating deposition pass (0.77 DFT). As shown in Table 5, an additional coating deposition pass produced sagging during drying, although no defects were noticed in the cured film. At 3 passes, gross sagging occurred and remained in the cured film. Spraying at 60 psi tended to produce a larger degree of sagging than spraying at 45 psi, but this was probably due to the greater material deposition at the higher air pressure. Quicker movement of the spray gun should negate this effect.

The effect of mixing procedure and induction time on the WRCARC (34094) was also investigated (see Table 6). Mixing this water-dispersible material using the most efficient method—combining 2 parts A, 1 part B, and 1 part water, then mixing—has an adverse affect on the application properties (particularly appearance and, possibly abrasion resistance), compared to the properties resulting from the recommended method—adding the water and mixing *after* parts A and B have already been combined and mixed. The color difference, which is noticeable to the unaided eye as confirmed by the ΔE data of 1.66 and 1.4, indicates that pigment instability is increased by the efficient mix method. The gloss, however, is not detrimentally affected by the efficient mix procedure. When the surfaces of these coatings were viewed under a 7x microscope, the increased porosity resulting from the efficient mix was clearly evident. Induction time was also investigated—induction times as short as 2 hours appear to affect the abrasion resistance of WRCARC (34094). Gloss and color, however, were not appreciably affected by induction time. Induction time is also investigated in the Design of Experiment Section.

Film Properties

Tables 7 – 8 show film properties that consist of post-application and cured-paint test data. The film properties in general were used to establish and/or confirm the baseline properties of the cross-linked paint.

Typical sag-resistance draw-down charts are shown in Figures 9 and 10. The sag resistance data quantified by the horizontal anti-sag index (HASI), which correlates to wet film thickness, is displayed in Table 7. By using the volume-percent solids of the admixed coating (calculated from the manufacturer's technical data sheets) and the HASI, an approximate, single-application, sag-resistant dry-film-thickness can be calculated. This data clearly indicates that, on a vertical surface, the 2.0 mil dry film thickness that is normally required for these topcoats, cannot be achieved in a single application of WRCARC without incurring sag related defects. Thus, application via multiple coats with flash times between coats would seem prudent if prevention of sag were desired for the current admixed formulation of WRCARC. Gross sagging occurred at significantly lower film thicknesses than in the films applied to both the bare and primed steel substrates, as discussed in the previous Application Properties section. To potentially increase sag resistance, removal of a portion of the water to increase viscosity is a relatively simple option that may have low impact on film performance but may not produce a concentration that is user friendly. Also, initial viscosity and pot life may be negatively impacted by water-content reduction. Reformulation of the rheological additive system of the WRCARC to improve sag resistance is another alternative but would incur additional performance testing, since the composition of the coating would certainly change.

Due to their more prominent shear-thinning behavior (viscosity decreases with increasing shear stain rate) compared to the WRCARC, MIL-C-46168 (34094) and MIL-C-29475 (34094) give the user a higher wet film ceiling to generate the desired 2 mils DFT. MIL-C-46168 (36251) has a surprisingly low HASI compared to the MIL-C-46168 (34094) material. This could be because the 36251 gray color is not a standard color for this specification and, therefore, the manufacturing process has not been optimized for this specific color.

The drying-time data (see Table 7) for WRCARC (34094) satisfies the set-to-touch but fails the dry-hard and dry-through requirements of MIL-C-46168. This should not be a problem since the dry-hard time is only about 1.5 hours greater than that of 46168, which can be simply accommodated for at field maintenance facilities by a slightly decreased production rate. Also, WRCARC (34094) conforms to the set-to-touch and dry-hard requirements of MIL-C-85285, which are widely used by the Air Force for exterior topcoat applications.

The CIE LAB color-coordinate values for the various coatings and colors are listed in Table 7. Generally, a ΔE of at least 1.0 indicates that a person with normal, unaided vision can perceive or detect a color difference between two colors. It seems reasonable that the green control-coatings have lower ΔE values than the WRCARC (34094), since these are standard production level colors/coatings for these specifications. Also, color conformance is not as tightly controlled for Army and Marine Corps land assets, since the applicable specifications allow for significant deviation from the centroid of the color ellipse. However, if required, the paint manufacturer could attain a closer color match when the full production run is produced. An excellent color match to the standard was obtained with the WRCARC (36251). Military aerospace (Air Force and Naval Air) specifications require a ΔE of no greater than 1.0, which this value obviously achieves.

20° gloss data is widely used in the automotive industry to characterize high gloss systems. Gloss at 85° sheen angle is typically used by the military sector for matte systems. Measurements at 60° are more universally applicable in that it is widely accepted across the various industries and for high-, semi-, and low-gloss coatings. The gloss data in Table 7 is provided for 20, 60, and 85 degrees, although applicable military specifications only require data at 60 and 85 degrees. In general, WRCARC exhibits excellent gloss control compared to MIL-C-46168 and MIL-C-29475; this is not entirely expected, since the topography is extremely smooth from a macroscopic perspective. Note that, based on a simple tactile evaluation of the cured film, MIL-C-46168 and MIL-C-29475 both were found to be considerably rougher and less mar resistant than WRCARC. Specifically, all of the green (34094) coatings conform to the gloss requirements (1.0 and 3.5 at 60° and 85°, respectively) of MIL-C-46168. The gray (36251) coatings exhibited gloss values slightly greater than the 60° requirement of 1.0. This is a minor deficiency that should be easily corrected during the full-scale production process. Nevertheless, this property should be monitored to ensure quality conformance.

A holiday test was conducted on the WRCARC (34094) and two control-coatings at varying dry-film thicknesses (from 1 – 3 mils) on test specimens with unprimed, metallic substrates. In general (assuming a constant volume of resin), a cured film from a particle coalescing resin system is thought to contain more porosity than a cured film from a solution resin system[6]. Also, isocyanates will react with water and eventually produce carbon dioxide. This ultimately can produce microvoids, and, under certain conditions, even macro-defects, such as visible blisters and craters. Thus, the WRCARC and MIL-C-29475, both containing coalescing polyurethane (polyol dispersion and water-dispersible aliphatic polyisocyanate) particle dispersion resin systems[7, 8] and containing significant amounts of water, would be expected to be more porous than MIL-C-46168. This, however, was not the case. All three coatings produced the similar levels of holidays. As indicated in Table 7, the entire surface tested positive for holidays for WRCARC as well as the control coatings at the various DFT's. This level of equality in porosity may be due to the level of sensitivity of the holiday meter and the relatively high pigment volume concentration in each of these extremely low-gloss coatings. From a pragmatic perspective, a primer would be applied, significantly minimizing the degree of electrolytic conduction.

The tensile-adhesion data ranges from 467 to 709 psi for the various coating/substrate combinations, as listed in Table 8. The dry-tape (room temperature) adhesion produced no failures or differences between the various systems. The wet-tape (immersion) adhesion tests, conducted under elevated temperatures and increased exposure time, tended to produce failures. This is not surprising since water has been shown to have a significant effect on reducing adhesion of paint films and contributing to cathodic disbondment.[9] The WRCARC (34094) clearly performed best over the standard primer (MIL-P-53022), pretreatment (TT-C-490), and substrate (1010 CRS). The tape-adhesion failures on Al, resulting after four- and seven-day immersion periods, were surprisingly poor. This poor performance could have resulted from the substrate-scribing procedure used by NSWCCD, which was more stringent than those outlined in MIL-P-53022 and FED-STD-141, method 6301. Nonetheless, this effect will be investigated further later in this effort. The water-immersion resistance at the various durations and temperatures produced expected failures where the pretreatment was omitted.

The flexibility data in Table 8 shows that the WRCARC has good flexibility properties. The unprimed topcoat conformed to the flexibility requirements of MIL-C-46168 (i.e., 0.25″ mandrel at RT) and to the low temperature flexibility requirements of MIL-C-85285 (2″ mandrel at -60°F). It failed, however, in the GE Impact flexibility test, which has a 40% requirement per MIL-C-85285. This GE impact flex deficiency may not be a significant problem since the typical flexibility for primers used with MIL-C-85285 type topcoats also have flexibility performance in that same 5 – 10% range.[10, 11] The primed topcoat data was tested for characterization purposes since it is not required in MIL-C-46168 and MIL-C-85285.

Table 9 presents Taber abrasion data for WRCARC (34094). After 500, 1000, and 1500 cycles, cumulative weight losses of 15mg, 34mg, and 41mg are observed, respectively. An overall thickness loss of 0.67 mils (using the harshest wheel and weight allowed by ASTM D 4060) results after 1500 cycles. Note that the recorded increase in weight up to about 300 cycles was attributed to the imbedding of fine rubber particles on the surface. Hirst and Hegedus [12] found that for typical polyurethane-based military aircraft coatings, wear properties via Taber abrasion were, in general, directly related to the degree of gloss of the coatings. Using the CS-17 wheel and 1000 g weight, they found that at 1000 revolutions, the weight loss for camouflage and gloss paints were about 90 and 45 mg, respectively. Thus, WRCARC (34094) is a very abrasion resistant coating, particularly for a low-gloss coating, compared to "typical" polyurethane, military, aircraft-coatings. A higher-gloss version of the WRCARC would be expected to increase the current level of wear resistance and flexibility.

To gain more significant wear data in an efficient time span such that minor changes in application processes could be characterized, the authors felt it necessary to modify the ASTM method. Instead of using the resilient (rubber and abrasive grain) wheels, a much more rigid and coarser H-10 (vitrified) wheel with a 500 g weight was chosen. Table 8 shows that WRCARC (34094) lost approximately 96 mg or 1.3 mils after 750 cycles or revolutions at the harsher conditions.

For CARC topcoats, recoatability is particularly important when multiple-color camouflage patterns are being applied to military equipment. Since the duration of drying/curing between one coat and a subsequent coat can affect film performance, an allowable window of operation must be evaluated and established. As shown in Table 10, film defects were not observed in the WRCARC nor in the control topcoat—regardless of topcoat color, primer (MIL-P-53022) presence, and recoat interval. The quantitative recoatability data via tensile adhesion, although ranging from 446 to 2009 psi, indicates that the recoat duration does not significantly affect performance between 2 hr and 168 hr, inclusively. This is more easily seen when the data are grouped together by recoat durations and averaged (i.e., 1155, 1064, 1197, 1216 psi).

The tensile adhesion data in Table 11 clearly shows that good adhesion, and thus good compatibility, exists between the 9 distinct primers and each of the topcoats, and an obvious increase in adhesion is realized with increased paint cure duration. When averaged by cure duration, tensile values of 1909 psi and 2650 psi are realized at 3 and 7 days, respectively. This same data averaged by coating type results in essentially equal inter-coating performance at 7 days (2738 psi for MIL-C-46168 vs. 2836 psi for

WRCARC). Color appears to have a negligible influence at a 7-day cure when the MIL-P-53022 primer is used—2853 psi for color 34094 vs. 2710 psi for color 36251.

Rheometer

NSWCCD performed steady stress sweeps to generate viscosity flow curves for the WRCARC (green and gray), and the 46168 (green and gray). These tests provided viscosity profiles that resulted in very useful data, which is confirmed by other laboratory procedures. All curves presented have been smoothed using the Fast Fourier Transform (FFT) method[5].

Steady stress sweep results are shown graphically in Figure 11; this plot is the analog of Figure 4, which is discussed in the experimental section. Viscosity is plotted as a function of increasing shear strain rate for each of the four coatings being examined. Temperature was held constant at 25°C. All coatings exhibit shear thinning—that is, viscosity decreases with increasing strain rate. Based on the same rationale used to explain Figure 4, the following predictions can be made. The sprayability of the WRCARC (green and gray) should be superior to the 46168 coating (green and gray). This is based on the observation that at high shear rates (greater than 10^3 s^{-1}), lower viscosity coatings are easier to spray (and also to brush or roll on). As seen from the figure, WRCARC has lower viscosities at high strain rates than does the 46168 coatings; this prediction is borne out in actual laboratory spray applications of the coatings.

Predictions concerning sagging and leveling of the coatings can also be drawn from Figure 11. At low strain rates (up to around 1 s^{-1}), consistent with post-application coatings, the viscosity of 46168 is higher than WRCARC. Again, as previously discussed in the experimental section, at low shear rates, higher viscosities tend to imply good sag resistance, but poor leveling properties. So, it is predicted that the 46168 would have better sag-resistance than WRCARC. Conversely, the WRCARC should have the best leveling properties. This, too, is observed in traditional laboratory testing.

Design Of Experiment

Overview

The following should be noted prior to the discussion of the results:

- The independent variable "Storage Duration" is evaluated at two levels—7 days and 28 days. This requirement essentially split the DOE into two test phases: the first phase consisting of panel sets derived from paint stored for seven days and the second phase consisting of panel sets derived from paint stored for 28 days. The paint used for the two phases was actually produced in two separate batches. Paint from the initial batch was used to prepare and conduct the testing for the panel sets subjected to storage for 7 days. The paint from this batch exceeded its shelf life prior to preparing and conducting the tests for panels subjected to 28 days storage. Thus a new batch was used for the second phase of testing. This situation essentially creates an aliasing situation between the "storage duration" variable and a variable not included in the design - batch (#1 or #2). Further discussion about this situation will be addressed in the independent variable analysis section.
- All sixteen experiments (panel sets) were prepared to achieve a dry film topcoat thickness of either 2 or 4 mils DFT. Table 12 shows the actual thickness applied to each panel set. The reported values are an average of nine individual readings taken within each panel set, and are representative of the topcoat film thickness for the entire panel set, during DOE calculations. The results show that the desired topcoat film thickness deviated from the desired thickness in some panel sets. This deviation can be, and was, accounted for during the DOE calculations.

Table 13 provides a summary of all of the test results obtained from the DOE. Distribution of data and DOE analyses were performed for each of the performance variables.

The distribution data consists of the following:

- Histogram - Each bar shows the frequency of occurrence of the value or range of values represented on the axis. If the variable is continuous, the axis is broken into intervals. If the variable is nominal, each discrete value is represented by a bar.
- Quantile Box Plot - The quantile box plot shows selected quantiles on the response axis. The box shows the median as a line across the middle and the quartiles (25th and 75th percentiles) as its ends. The means diamond identifies the mean of the sample and the 95% confidence interval about the mean.
- Outlier Box Plot - The Outlier Box Plot is a schematic that lets you see the sample distribution and identify points with extreme values, or outliers. The ends of the box are the 25th and 75th quantiles, also called the quartiles. The difference between the quartiles is the interquartile range. The line across the middle identifies the median sample value. The bracket along the edge of the box identifies the shortest half, which is the most dense 50% of the observations.
- Quantiles Report - Quantiles are values that divide a distribution into two groups where the Pth quantile is larger than P% of the values. For example, half the data are below and half the data are above or equal to the 50th quantile, also called the median.
- Moments Report - Moments report displays the mean, standard deviation, and other summary statistics.

The DOE analysis is a Screening fit analysis utilizing a Least Squares Analysis to generate Prediction Profile graphs for all of the independent variables studied. The prediction profile shows the effect of a particular independent variable (within the levels tested) on the dependent variable being studied. A flat line is indicative of a null effect while a sloped line indicates significance. The steeper the slope the greater the effect of that variable on the dependent variable. The profile also provides valuable information regarding the "direction" of the effect (increase or decrease in the magnitude of the performance variable)

The independent variables are further studied using an Effect Screening. In experimentation, it is often the effect size rather than the statistical significance that is of interest. In many cases there are no (or very few) degrees of freedom left after model fitting to estimate an error variance. One common approach is to assume that many of the effects are zero and that their estimates reflect random noise. Then make inferences based on the distribution of effect sizes (parameters).

A Normal plot is calculated. A Normal plot shows the normalized parameter estimates (coefficients of variables in a linear function) against the normal quantile score. Many inactive effects tend to be near the middle and to establish the line of the standard error. The effects that deviate from the line are active. This is a quick way to identify active variables.

Finally, a Pareto Plot is developed. The bars of this plot represent the percentage of the absolute values of the scaled estimates relative to the sum of the absolute values. In other words, it shows how much influence a particular variable has relative to the other independent variables considered. A cumulative line shows the advance to 100% of the sum of absolute values. This plot is the basis for making conclusions about the significance of any independent variable on the dependent variables. This percentage of influence will herein be referred to as the *variable influence contribution (VIC)*. Note that this does not provide a parametric estimate (coefficient of the variables in a linear function), rather a magnitude of the influence it has relative to the other variables considered. It is possible that another independent variable, not included in the test, may have greater significance. Nor does this percentage describe the direction of influence (increases or decreases the magnitude of the performance variable). That is obtained from the Prediction Profile.

The magnitude of a VIC that is considered significant is arbitrarily determined by the experimenters. A magnitude of 5% or greater was chosen as significant in this study.

The following should be considered prior to discussion of the individual performance properties:

- It is expected that the "paint type" variable would be significant for mechanical properties. This is the result of incorporating novel pigment technology into the film to improve the mechanical performance of the coating. Differences in resin type of the coatings will also contribute to this effect.
- It is expected that the "paint type" should not significantly effect the optical properties (color and gloss) as there are specific requirements for survivability requirements, regardless of the paint used.

- It is expected that color may have significant effects, as it is actually the result of the pigment technology utilized. Pigment technology has proven to be significant in a variety of mechanical and surface properties of cured paint films.

DOE Adhesion Test Results

Test results for the adhesion of the topcoat are provided in Table 13. These include tensile adhesion with and without primer, dry tape adhesion, and wet tape adhesion at various immersion and temperature intervals. Each reported value is an average of 6 pulls done on each panel set. Figures 12 through 17 show the distribution of data and DOE analyses for the six different adhesion tests.

Figure 18 shows that Paint type, color, and storage duration have the greatest influence on adhesion. DFT, induction time, and cure properties have lesser but equal significance. Storage temperature, mix time, equipment, and flash time have very little significance.

Pain type and color are expected to have significant influence. Pigment technology is known to effect internal stress, mechanical properties and the surface of films. All of these will effect adhesion. The large influence of storage duration is not expected. It is possible that the effect is actually an effect attributed to a difference in paint batches and not storage duration. Under this design, it is not possible to distinguish between the two.

The moderate influence of cure properties and DFT is also expected. Degree of crosslinking, and the effect of moisture and temperature on cure all significantly effect adhesion. DFT influences the level of volatile entrapment, internal stress, and degree of cure.

It is desirable that the variables directly associated with application - storage temperature, mix time, equipment and flash time were insignificant.

DOE Fluid Resistance Test Results

Test results for the fluid resistance, of the topcoat, are provided in Table 13. Tests include 23699 oil resistance, MEK resistance and water resistance at various immersion and temperature intervals. Because the responses are nominal, either "pass" or "fail", and not continuous, a least squares fit is not possible. A more appropriate analysis is to develop a probability distribution. Figure 19 shows the probability distribution analyses for these tests.

Virtually all panel sets passed water resistance (under each duration and temperature), 23699 oil resistance, and MEK resistance tests. The exception to performance was panel set #7, which failed all tests. The cause of failure is not apparent.

The MEK resistance results were exceptionally good; while the test only requires 25 double rubs for a "pass", no panel sets failed after 100 double rubs (with the exception of panel set #7). It can be concluded that none of the independent variables considered have any significant effect on the fluid resistance performance.

DOE Reverse Gardner and GE Impact Test Results

Test results for the impact tests are provided in Table 13.
Reverse Gardner impact resistance and GE impact flexibility were each characterized on unprimed substrates in order to isolate the effect on the topcoat. The effect of the independent variables on the topcoat with primed substrates was performed to gauge the overall system performance. Figures 20 through 23 show the distribution of data and DOE analyses for these tests.

Figure 24 shows that cure humidity and color have the greatest influence on impact resistance. Flash time and cure duration have fairly significant influences. Paint type, equipment, induction time, DFT, and cure temperature have smaller but moderate influences. Storage variables have very little influence.

It is expected that cure variables and color would have significant influence. Cure variables directly effect the level and type of crosslinking in the film, and thus the flexibility. Color is a property directly associated with the pigments, fillers, and extenders within the film. These additives are very influential in dictating mechanical properties of the film. The significance of flash time is not easily explained. It is possible that increased volatiles in the film (generally associated with a shorter flash time) will plasticize the film and thus provide increased flexibility. The prediction profiles of these tests indicate such a trend; as you decrease the flash time the impact resistance increases.

Variables directly associated with application - paint type, equipment, induction time, and DFT appear to have a moderate effect and should be closely monitored if flexibility is of great importance (as for aircraft).

DOE Taber Abrasion Test Results

Test results for the abrasion tests are provided in Table 13. Both weight loss and volume (mils) loss were measured. Figures 25 and 26 show the distribution of data and DOE analyses for these tests.

An H10 wheel and 500 gram load were utilized for these tests. All reported values are an average of 4 samples within each panel set.

Figure 27 shows that abrasion was significantly effected by the paint type, color, and DFT. Cure temperature and cure humidity were slightly less significant. All other variables were insignificant.

The paint type and color were expected to be significant for the reasons cited above. DFT is directly related to the internal stresses of a film, which will effect the resistance to abrasion. Cure variables effect the degree of crosslinking, thus they will have an effect on mechanical properties of the film. It is interesting to note that cure duration was not significant. The reason for this is not known.

The absence of influence from the other variables is very desirable.

DOE Optical Properties on Al Test Results

Test results for the optical properties of the topcoat are provided in Table 13. Figures 28 through 33 show the distribution of data and DOE analyses for these tests.

The CIELAB color scale, D_{65} illuminant, and 10° standard observer were used to quantify the color of the various coatings. The gloss of the coatings in these experiments was tested using the standardized incident angles of 20°, 60°, and 85°.

Figure 34 shows that the overwhelming influence on the color of the films was color. It is an obvious result. The real significance is the absence of influence from the other variables. This is very desirable.

Figure 35 shows gloss was significantly effected by color and moderately affected by all of the other variables, with the exception of flash time and cure duration. The reason for these influences may be explained for certain variables. The paint type influence may be the result of a difference in the resin system. Cure mechanisms and solvent type may contribute to the cure property influences. The remaining variables, more directly associated with application, cannot be immediately explained. Controls during application should be considered to achieve desired gloss.

Overall Independent Variable Assessment

Table 14 shows the significant VICs for each of the performance properties. Figure 36 shows the cumulative VIC for each independent variable, for all of the performance tests. Note that the following statements are relevant only within the levels the independent variables were tested. It is possible that outside of the levels tested, influences may occur that have not been revealed in this design.

- Paint Type – This is very significant. As mentioned earlier, it was anticipated that the "paint type" variable would be significant for mechanical properties. This is the result of novel pigment technology in the film, designed to improve the mechanical performance of the coating. Additionally, the resin technology of the two coatings tested differ. This variable is nominal, either MIL-C-46168 or WRCARC, and is not optimized. The user will choose one or the other.
- Color - Color has the greatest influence for the overall performance of the paints. This was also anticipated. Color is actually the result of the pigment technology utilized. Pigment technology has proven to be significant in a variety of mechanical and surface properties of cured paint films. Again, this variable is nominal and the user will choose either one color or the other.
- Storage Duration - Storage duration is fairly significant. Again, caution should be used when assessing the accuracy of this finding. The "batch" effect is aliased with this variable and may be the cause of this significance. Until further research is done to distinguish between the two, the manufacturers stated shelf life is the best metric for users.
- Storage Temperature – Storage temperature has proven do be fairly insignificant within the 75°F to 125°F temperature range. Certainly, there will be occasions where the storage temperature will be below 75°F. For water-reducible materials, storage below 40°F is not recommended. The upper limit should be set at 120°F.
- Mix Time – Mix time has proven to be insignificant for the "shaking" method of mixing. A minimum of 5 minutes shaking has shown to be effective for mixing. This says nothing about other mixing methods (e.g. mechanical mixers). Research, outside of this effort, has shown that shaking may not be the optimal method. Mechanical mixing appears to provide a more homogenous mix. This will be considered during the development of application procedures.
- Equipment – Equipment type has proven to be insignificant. More specifically there is no effect when using conventional spray equipment versus HVLP systems. This is a nominal variable and users can choose either one for application.
- Induction Time – Induction time has proven to be insignificant, thus no induction time should be necessary, assuming a proper mix is achieved. This is a continuous variable, and the optimal value for a production environment is zero – no induction.
- Flash Time – Flash time has proven to be insignificant, with the exception for impact resistance. The prediction profile data show that increased flexibility is achieved with shorter flash times, without any adverse effects to the other performance properties. Although this may effect production processes, it is in a desirable direction. The optimal flash time should not be zero, since it may result in volatiles being trapped in the film, eventually leading to blistering or popping. Further testing is needed to determine the optimal flash time. Currently a flash of 1 hour is recommended until further studies can be done. Note this is only relevant if a bake cycle is introduced into the process. Flash time is not relevant during ambient cures.
- DFT – DFT has proven to be moderately significant (within 1.2 – 4.7 mil range) to performance, specifically for the mechanical properties. It is insignificant for the optical properties. The prediction profiles show that increasing the film thickness increases adhesion and impact resistance, but reduces the abrasion resistance. Traditionally, increased thickness results in lower adhesion and impact resistance. This trend may be the result of using polymer bead fillers, but cannot be conclusively attributed to it. This variable is a continuous variable. Its upper limit is bound by the sag resistance of the coating, and its lower limit bound by a minimum film thickness requirement, for durability purposes. Additionally, production requirements dictate the use of a range of thickness, since it is impossible to achieve exact thickness. Although the optimal thickness (trade off between adhesion/impact resistance and abrasion resistance) is not known from this study, it appears it will be similar in range to currently used application parameters.
- Cure Duration – Cure duration has proven to be slightly significant, with the biggest influences on adhesion and impact resistance. This variable is continuous, but not necessarily controllable. Thermoset coatings will continue to cure indefinitely, regardless of the environment they are in. The significance in this effort is that a 7 day cure may be necessary to achieve the desired performance properties. What may be of greater significance is the cure duration of a bake cycle. However, cure duration is not a specified/controlled parameter for ambient cure. For bake cycles further research much be done to optimize the duration.
- Cure Temperature – Cure temperature has proven to be significant (within the 75°F to 125°F temperature range), primarily in the mechanical properties. Cure temperature will affect the ultimate glass transition of the material, thus influencing the mechanics of the film. For ambient conditions, cure temperature is bound by the required usable pot life of the material. This will be considered when

developing the application procedures. Cure temperatures in bake cycles must be studied in detail, as coating chemistry may differ significantly at higher temperatures.

- Cure Humidity – Cure humidity has proven to be significant (within the 40% - 80% relative humidity range), particularly for impact resistance. The WRCARC is especially sensitive to humidity, since water is both a volatile and involved in the chemical reaction of the material. Altering the moisture content of the ambient air will influence the final structure of the coating. Generally speaking, increasing humidity tends to have a negative impact on performance properties, as shown by the prediction profiles. Too low a humidity may cause water within the wet film to volatilize too quickly and also have an adverse effect. The optimal humidity is not known. Currently, it is advised to use the manufacturers' stated acceptable humidity levels.

The results show that the WRCARC is essentially a drop-in substitute for the current coatings being used. No significant alterations to current production processes are needed to achieve desired film performance. Significant cure studies (time temperature, and humidity) may provide insight into improving the overall performance of the WRCARC material. Flash time should also be considered in conjunction with the cure studies to assess its influence.

Application procedures will be developed based on the results of this effort and provided as a separate document.

SUMMARY/CONCLUSIONS

- The SERDP Low VOC CARC clearly provides superior performance properties compared to the control coatings (MIL-C-46168 and MIL-C-29475) in terms of abrasion/mar resistance and flexibility.

- Increased resistance to accelerated weathering, as quantified by project partner U.S. Army Research Laboratory, is another significant improvement compared to the control coatings.

- Advantages in initial viscosity and overall viscosity/pot life stability are provided by the WRCARC.

- Sag resistance, on the other hand, is less than optimum in comparison to the control coatings. As discussed earlier, this deficiency can be circumvented by adjusting processing procedures (i.e., including flash times between coats) of the current formulation by the applicator, by decreasing the water content of the current formulation, or by optimizing the additives package of the formulation.

- Several quality conformance properties, although relatively minor such as color, gloss and grind, should be monitored when the formulation is produced at the full-scale production level.

- Based on the laboratory study, the WRCARC has been found to be a high performance topcoat worthy of incorporation into the military system. The ESTCP demonstration phase of this program is expected to validate the present data.

ACKNOWLEDGEMENT

The authors wish to thank Steven Murray, James Katilaus, and David Fayocavitz for their technical support in the test/evaluation tasks and to gratefully acknowledge Theresa Steck for her managerial and editorial support of this effort.

REFERENCES

1. Schoff, C.K., "Rheology, Federation Series on Coatings Technology", *Federation of Societies for Coatings Technology,* September 1991.
2. Rheometric Scientific. (Pamphlet) *Dynamic Stress Rheometer SR-200, SR500.* 1996.
3. Van Doren, R.E., and Reynolds, W.A., "Basic Rheology of Coatings", *Paint and Coatings Industry (PCI),* 14, No. 10, 228-238 (1998).
4. Montgomery, D.C., *Design and Analysis of Experiments,* 4th ed., John Wiley & Sons, 1997, p. 372.
5. Rheometric Scientific. Controlled Stress Test Guide 902-00151 Revision B, June 1993.
6. Patton, T.C., *Paint Flow and Pigment Dispersion,* 2nd Ed, Wiley Interscience, New York, 1979.
7. Escarsega, J.A., Crawford, D.M., Duncan, J.L. and Chesonis, K.G., "Water-Reducible PUR Coatings for Military Applications", Modern Paint and Coatings, 87, No. 7, 21-30 (1997).
8. Hegedus, C.R., Gilicinski, A.G. and Haney, R.J., "Film Formation Mechanism of Two-Component Waterborne Polyurethane Coatings", 68, No. 852, 51-61 (1996).
9. Spadafora, S.J. and Leidheiser, H., Jr..,, *J. Oil & Colour Chemists' Assoc.,* 71, No. 9, 276-285 (1988).
10. Chattopadhyay, A.K. and Zentner, M.R., "Aerospace and Aircraft Coatings", Monograph Publication, FSCT, Blue Bell , PA, May 1990.
11. Hegedus, C.R., Pulley, D.F., Spadafora, S.J., Eng, A.T. and Hirst, D.J., "A Review of Organic Coatings Technology For U.S. Naval Aircraft", 61, No. 778, 31-42 (1989).
12. Hirst, D.J. and Hegedus, C.R., "F-14 Wing Lug Coating Investigation", Report No. NAWCADWAR-92045-6015, February 1992.

PRESENTATIONS

1. "USMC Compliant Coatings", Joint Depot Maintenance Analysis Group (JDMAG) Pollution Prevention Conference, May 1996, Tobyhanna, PA
2. "SEDRP CARC Research and Development", 1998 US Marine Corps Corrosion Prevention and Control Conference, April 1998, Barstow, CA
3. "Development of Application Procedures for LOW VOC Chemical Agent Resistant Coating (CARC)", 1998 SERDP Technical Symposium, Dec 1998, Arlington, VA
4. "Application Evaluation of New Tri-Service CARC", National Defense Industrial Association Technical Symposium, October 1999, Morristown, NJ

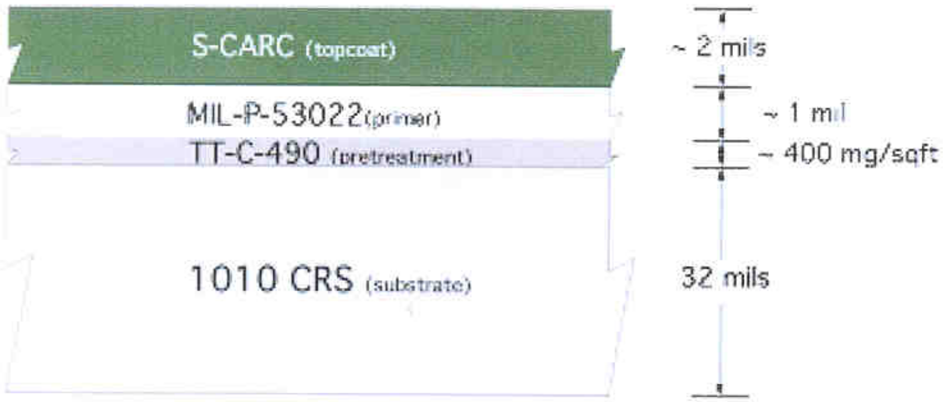


Figure 1 Cross Section of Standard Test Specimen

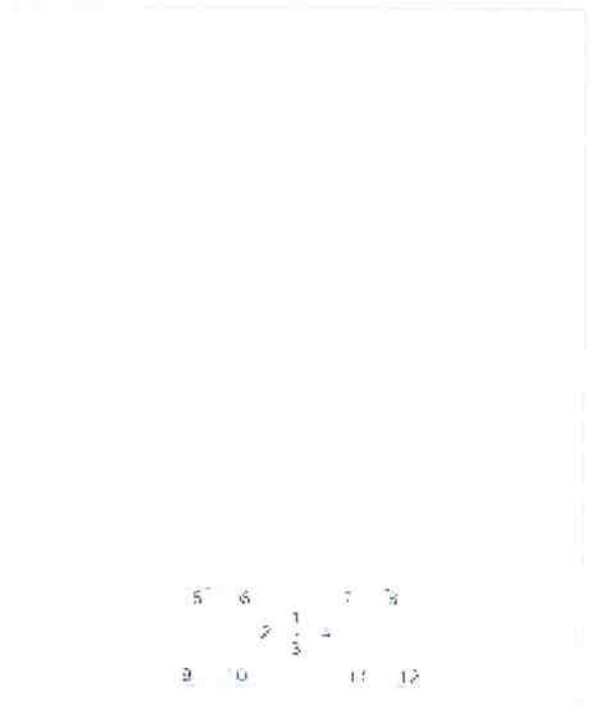
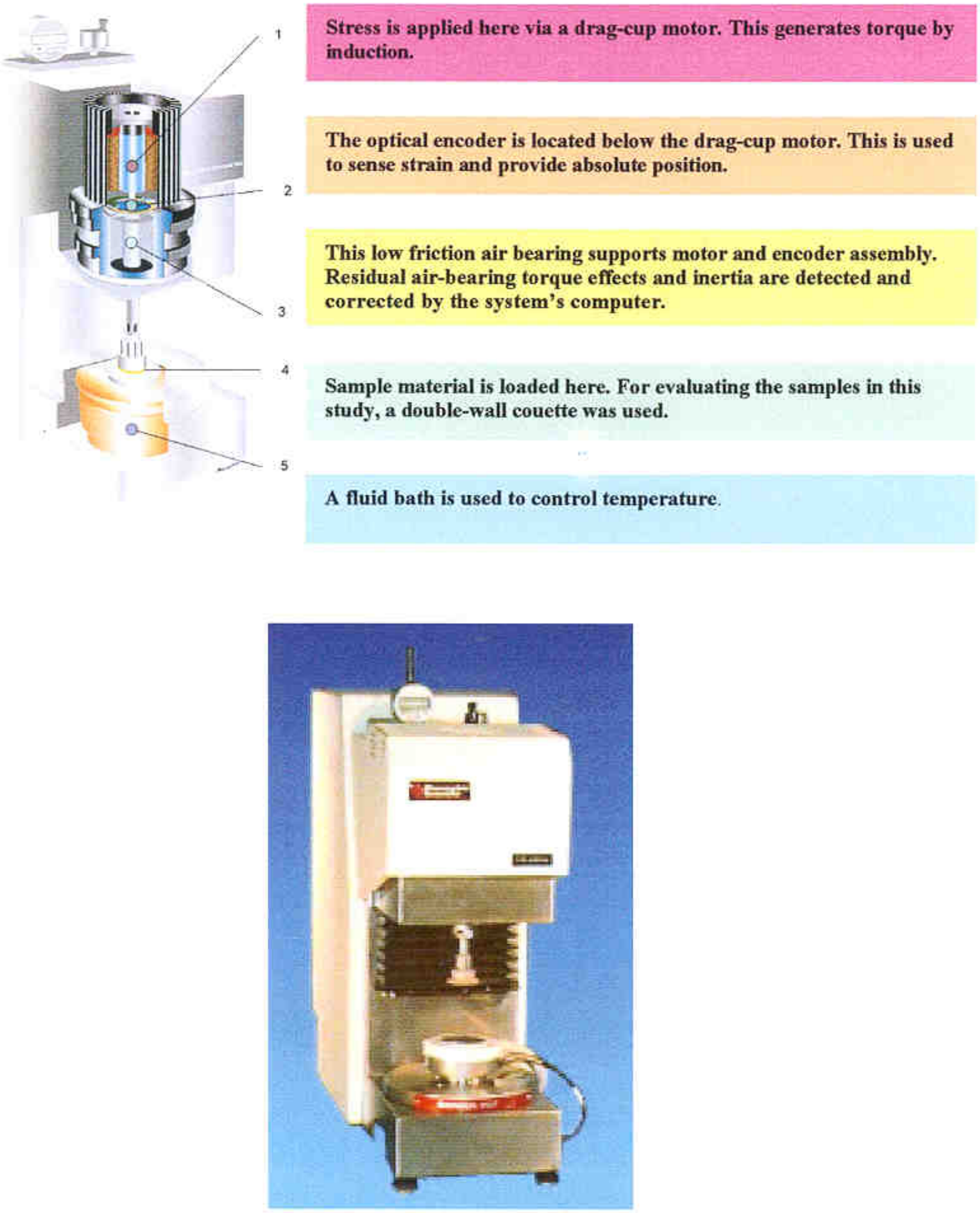


Figure 2 Modified Scribe Pattern for the Tape Adhesion Test



Stress is applied here via a drag-cup motor. This generates torque by induction.

The optical encoder is located below the drag-cup motor. This is used to sense strain and provide absolute position.

This low friction air bearing supports motor and encoder assembly. Residual air-bearing torque effects and inertia are detected and corrected by the system's computer.

Sample material is loaded here. For evaluating the samples in this study, a double-wall couette was used.

A fluid bath is used to control temperature.

Figure 3 Rheometric Scientific™ SR-2000 stress-controlled rheometer[5]

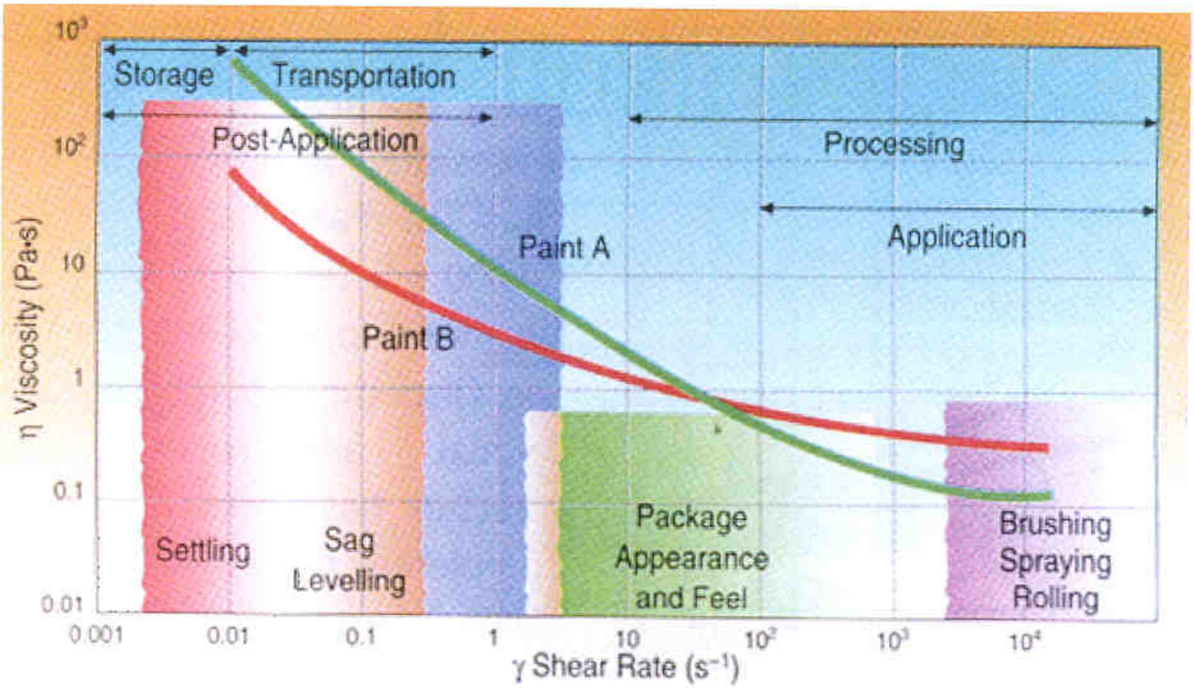


Figure 4 Coating properties as related to viscosity and shear rate[3]

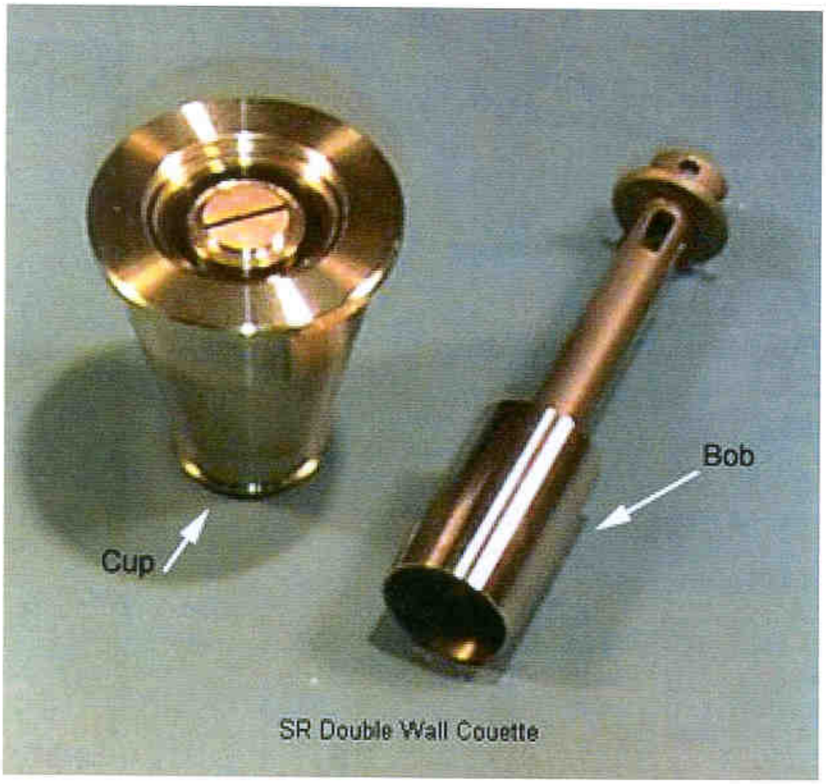


Figure 5 Double-Wall Couette bob and cup

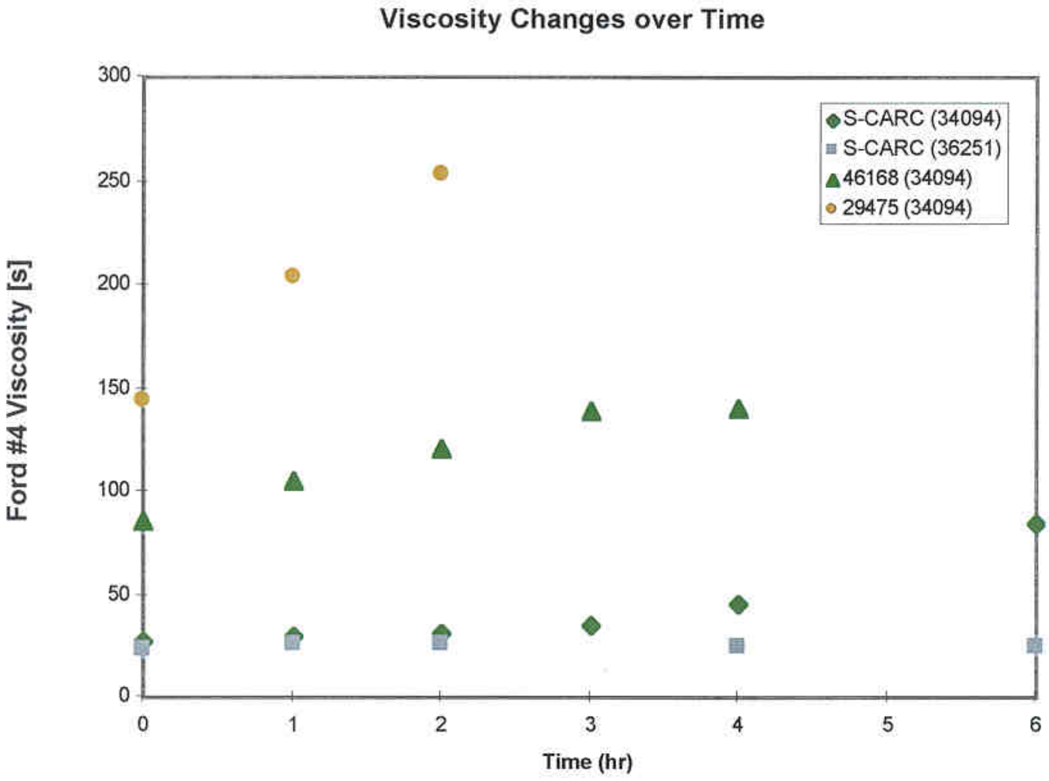


Figure 6 Viscosity of coatings increase with time.

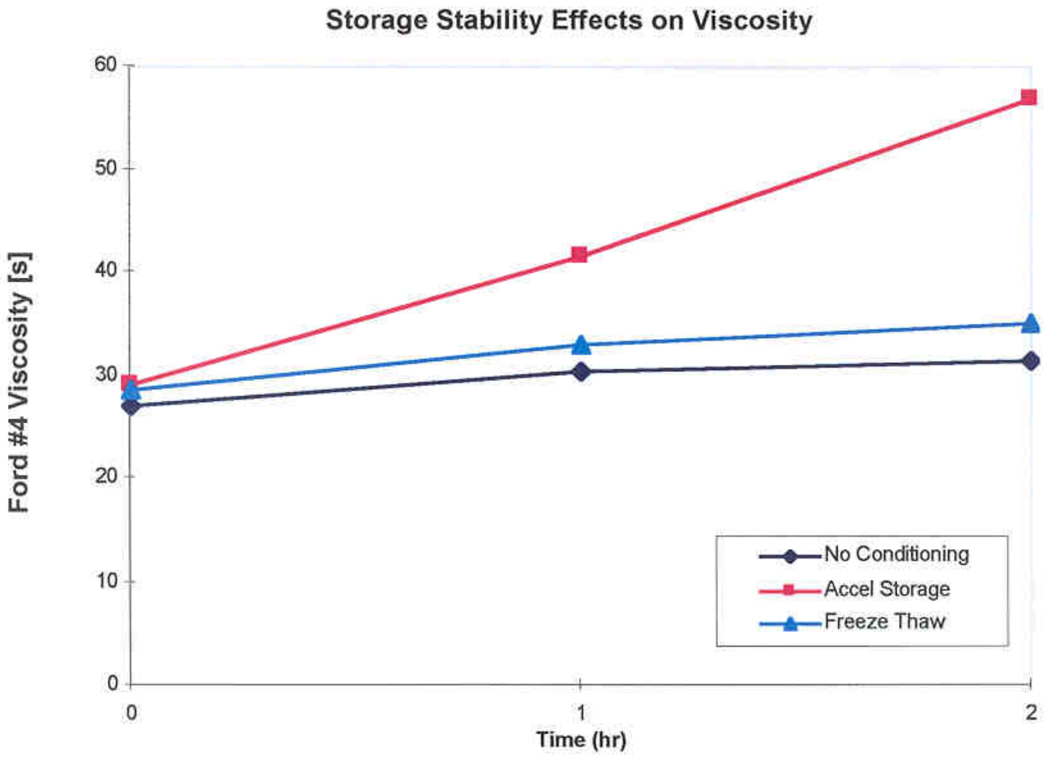


Figure 7 Effects of storage conditions on WRCARC (34094)

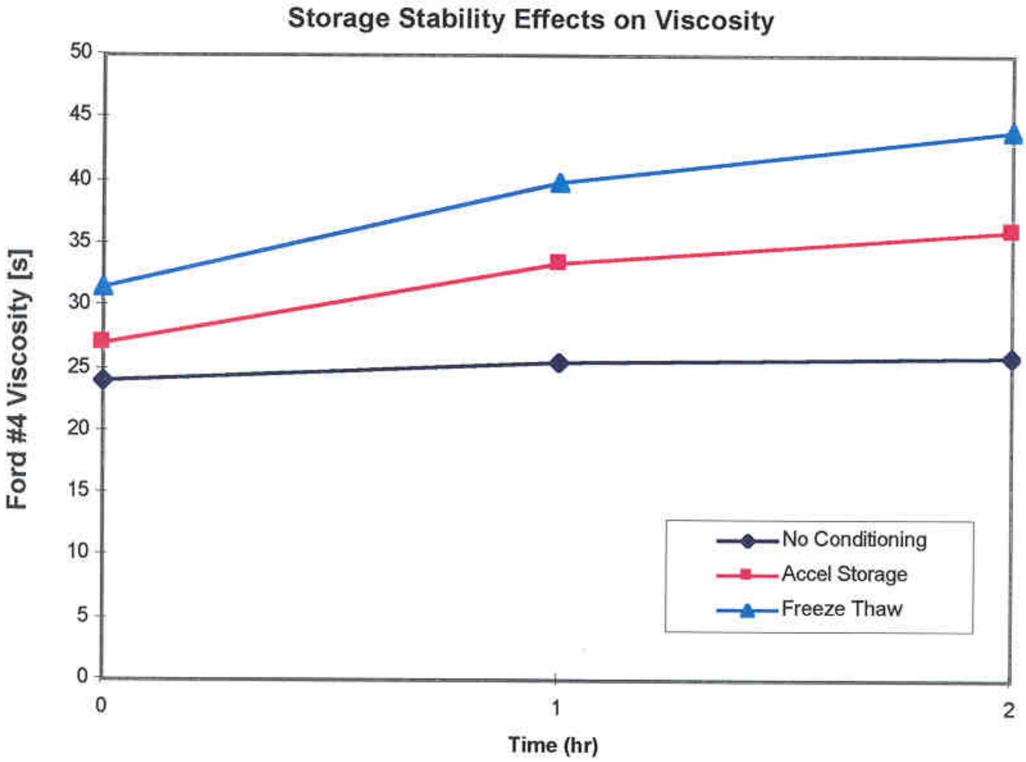


Figure 8 Effects of storage conditions on WRCARC (36251)

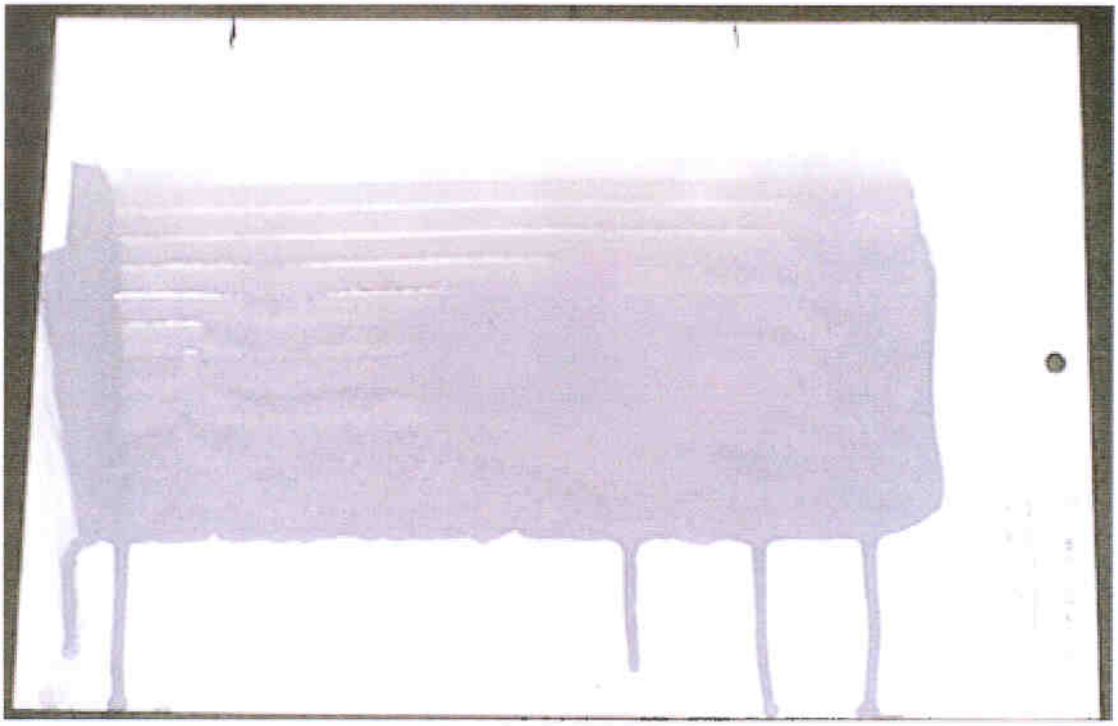


Figure 9 Sag Resistance of WRCARC (36251)

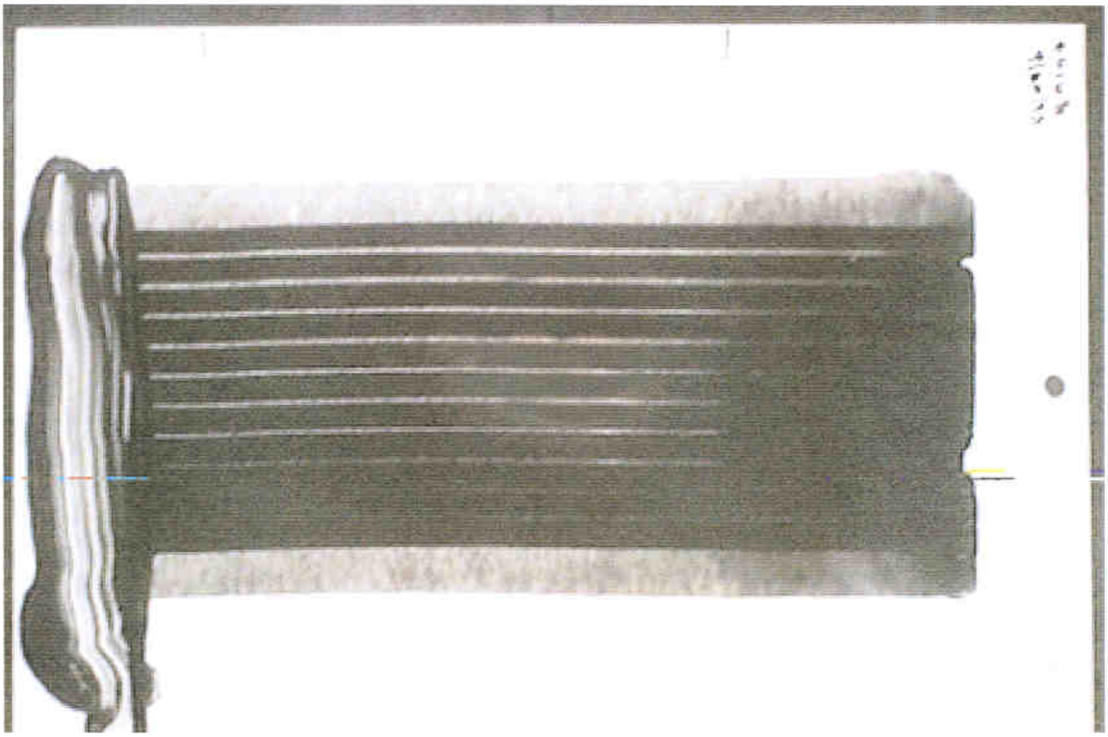


Figure 10 Sag Resistance of MIL-C-46168 (34894)

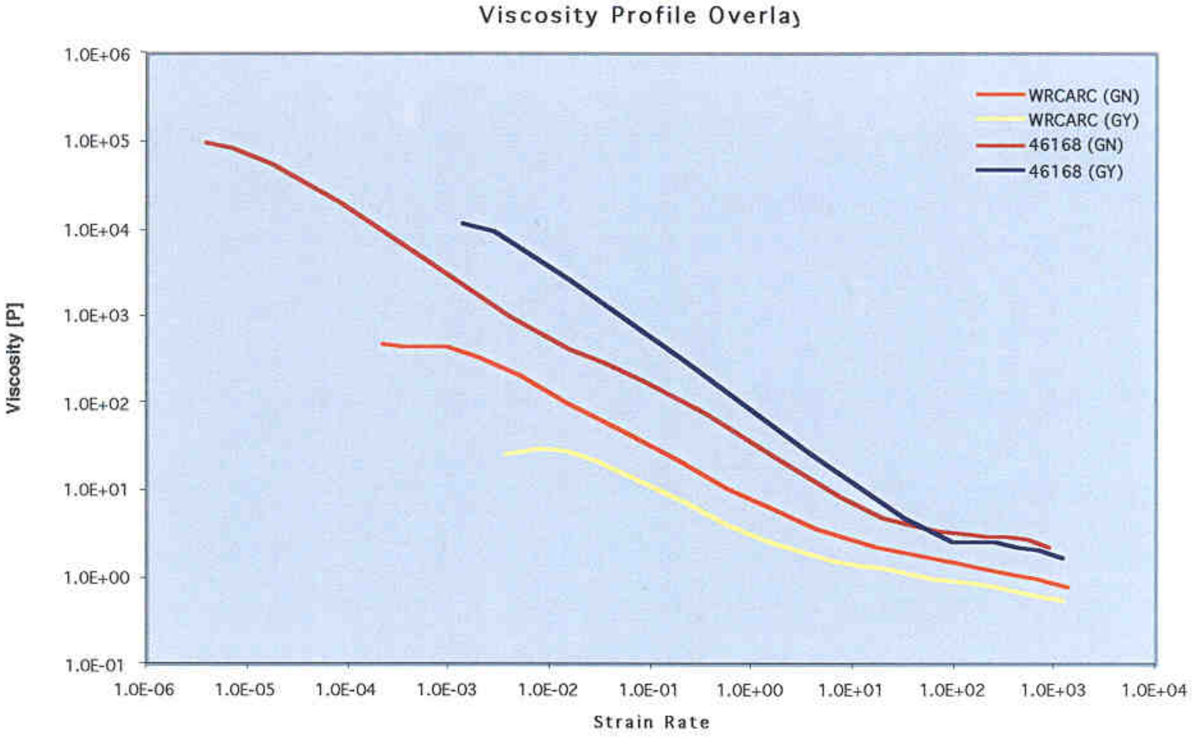
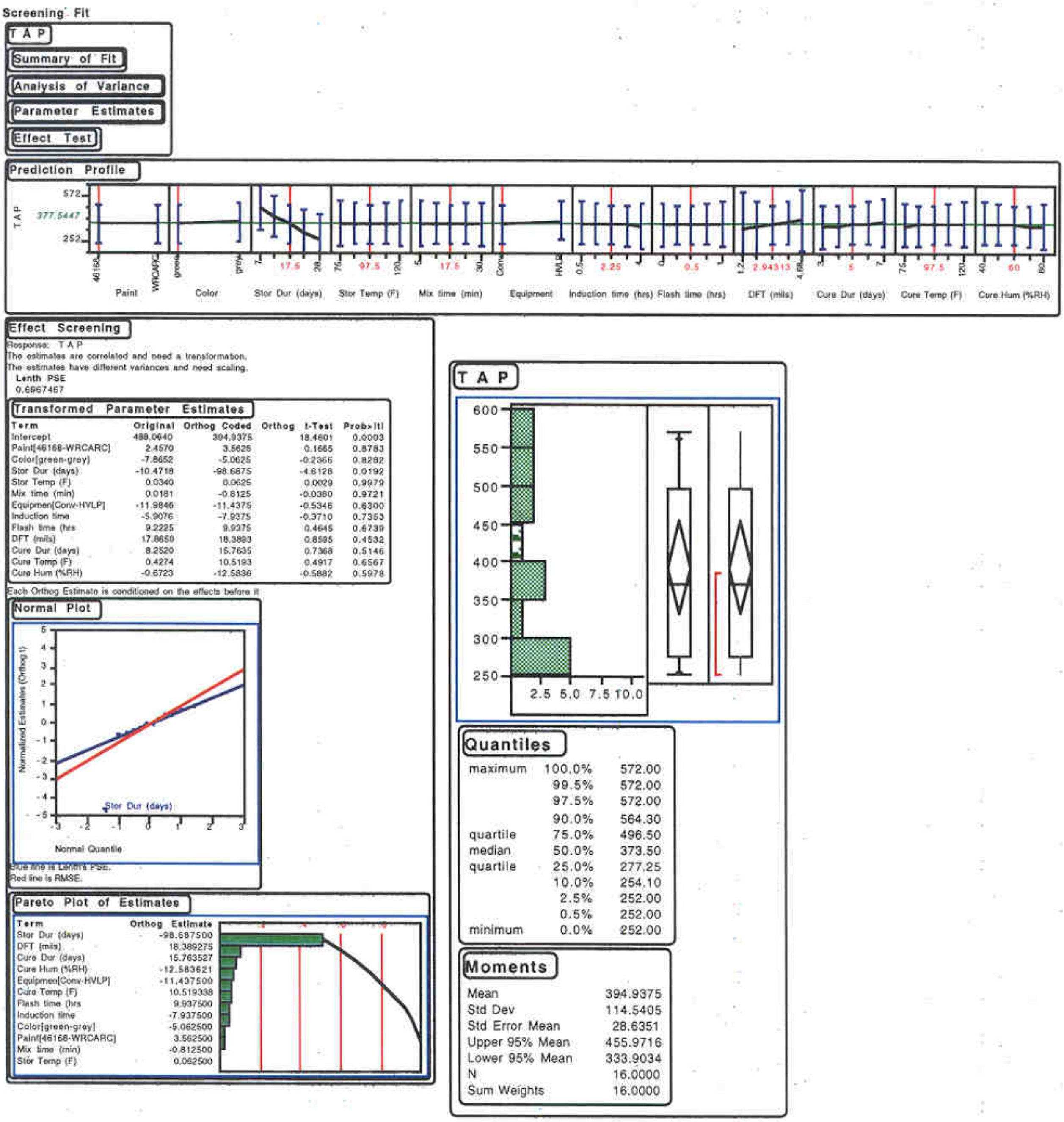


Figure 11 Viscosity as a function of shear strain rate.

Figure 12 Distribution of data and DOE analysis for tensile adhesion with primer



Effect Screening

Response: T A P
The estimates are correlated and need a transformation.
The estimates have different variances and need scaling.

Lenth PSE
0.6967467

Transformed Parameter Estimates

Term	Original	Orthog Coded	Orthog	t-Test	Prob>|t|
Intercept	488.0640	394.9375		18.4601	0.0003
Paint[46168-WRCARC]	2.4570	3.5625		0.1665	0.8783
Color[green-grey]	-7.8652	-5.0625		-0.2366	0.8282
Stor Dur (days)	-10.4718	-98.6875		-4.6128	0.0192
Stor Temp (F)	0.0340	0.0625		0.0029	0.9979
Mix time (min)	0.0181	-0.8125		-0.0380	0.9721
Equipmen[Conv-HVLP]	-11.9846	-11.4375		-0.5346	0.6300
Induction time	-5.9076	-7.9375		-0.3710	0.7353
Flash time (hrs	9.2225	9.9375		0.4645	0.6739
DFT (mils)	17.8659	18.3893		0.8595	0.4532
Cure Dur (days)	8.2520	15.7635		0.7368	0.5146
Cure Temp (F)	0.4274	10.5193		0.4917	0.6567
Cure Hum (%RH)	-0.6723	-12.5836		-0.5882	0.5978

Each Orthog Estimate is conditioned on the effects before it

Normal Plot

Blue line is Lenth's PSE.
Red line is RMSE.

Pareto Plot of Estimates

Term	Orthog Estimate
Stor Dur (days)	-98.687500
DFT (mils)	18.389275
Cure Dur (days)	15.763527
Cure Hum (%RH)	-12.583621
Equipmen[Conv-HVLP]	-11.437500
Cure Temp (F)	10.519338
Flash time (hrs	9.937500
Induction time	-7.937500
Color[green-grey]	-5.062500
Paint[46168-WRCARC]	3.562500
Mix time (min)	-0.812500
Stor Temp (F)	0.062500

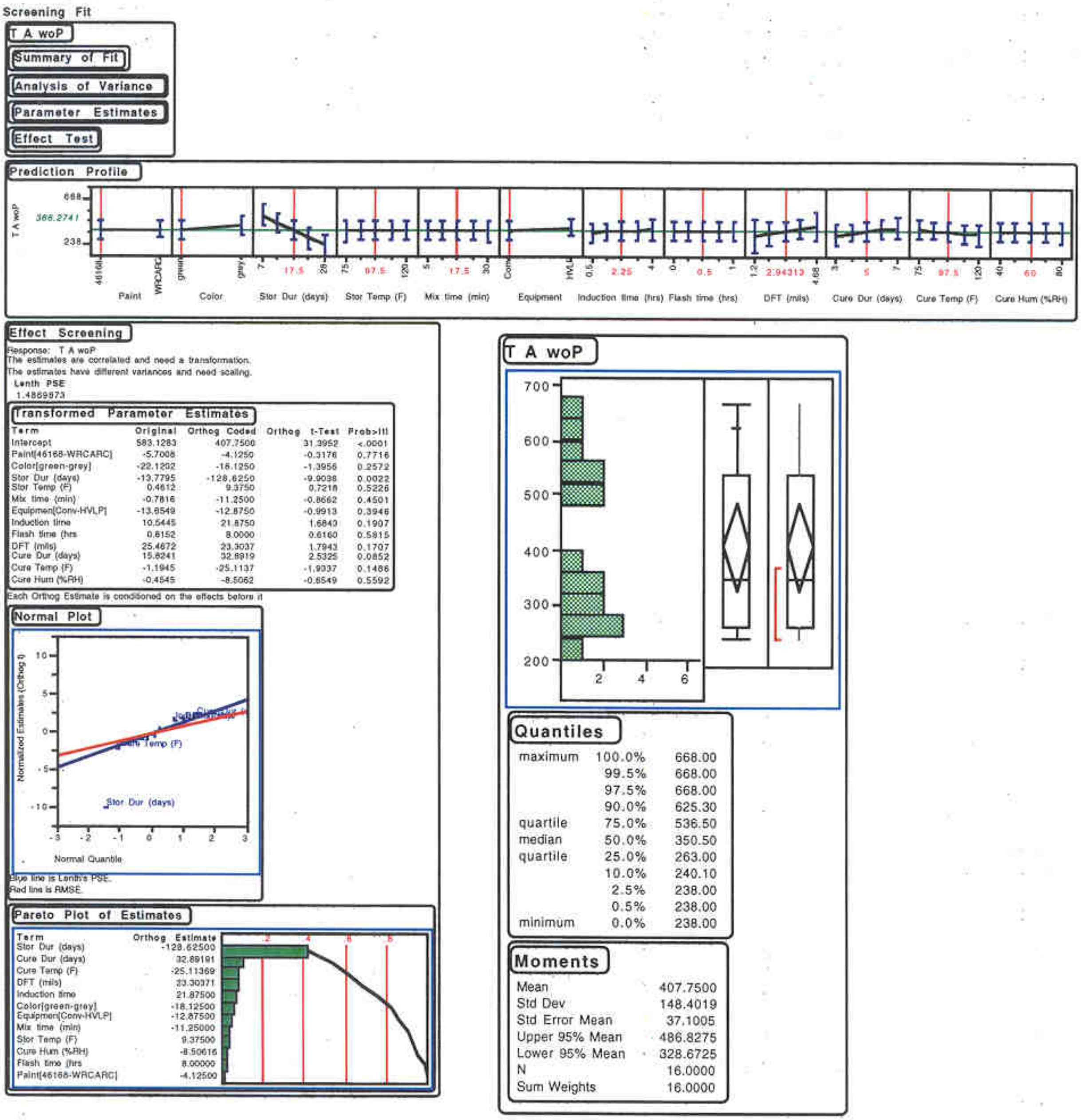
Quantiles

maximum	100.0%	572.00
	99.5%	572.00
	97.5%	572.00
	90.0%	564.30
quartile	75.0%	496.50
median	50.0%	373.50
quartile	25.0%	277.25
	10.0%	254.10
	2.5%	252.00
	0.5%	252.00
minimum	0.0%	252.00

Moments

Mean	394.9375
Std Dev	114.5405
Std Error Mean	28.6351
Upper 95% Mean	455.9716
Lower 95% Mean	333.9034
N	16.0000
Sum Weights	16.0000

Figure 13 Distribution of data and DOE analysis for tensile adhesion without primer



Effect Screening

Response: T A woP
The estimates are correlated and need a transformation.
The estimates have different variances and need scaling.

Lenth PSE
1.4869873

Transformed Parameter Estimates

Term	Original	Orthog Coded	Orthog t-Test	Prob>|t|
Intercept	583.1283	407.7500	31.3952	<.0001
Paint[46168-WRCARC]	-5.7008	-4.1250	-0.3176	0.7716
Color[green-grey]	-22.1202	-18.1250	-1.3956	0.2572
Stor Dur (days)	-13.7795	-128.6250	-9.9036	0.0022
Stor Temp (F)	0.4612	9.3750	0.7218	0.5226
Mix time (min)	-0.7816	-11.2500	-0.8662	0.4501
Equipmen[Conv-HVLP]	-13.6549	-12.8750	-0.9913	0.3946
Induction time	10.5445	21.8750	1.6843	0.1907
Flash time (hrs	0.6152	8.0000	0.6160	0.5815
DFT (mils)	25.4672	23.3037	1.7943	0.1707
Cure Dur (days)	15.6241	32.8919	2.5325	0.0852
Cure Temp (F)	-1.1945	-25.1137	-1.9337	0.1486
Cure Hum (%RH)	-0.4545	-8.5062	-0.6549	0.5592

Each Orthog Estimate is conditioned on the effects before it

Blue line is Lenth's PSE.
Red line is RMSE.

Term	Orthog Estimate
Stor Dur (days)	-128.62500
Cure Dur (days)	32.89191
Cure Temp (F)	-25.11369
DFT (mils)	23.30371
Induction time	21.87500
Color[green-grey]	-18.12500
Equipmen[Conv-HVLP]	-12.87500
Mix time (min)	-11.25000
Stor Temp (F)	9.37500
Cure Hum (%RH)	-8.50616
Flash time (hrs	8.00000
Paint[46168-WRCARC]	-4.12500

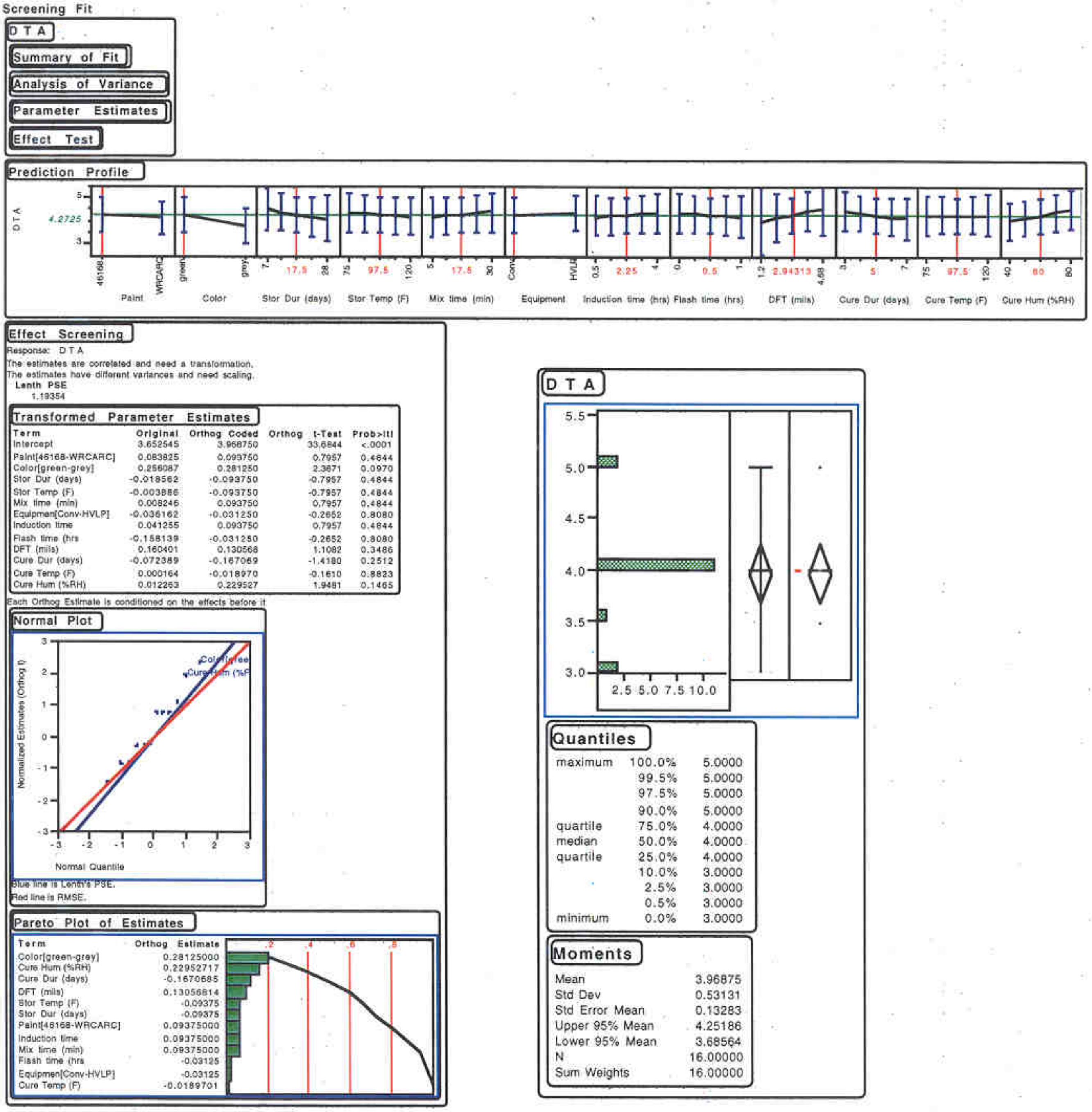
Quantiles

maximum	100.0%	668.00
	99.5%	668.00
	97.5%	668.00
	90.0%	625.30
quartile	75.0%	536.50
median	50.0%	350.50
quartile	25.0%	263.00
	10.0%	240.10
	2.5%	238.00
	0.5%	238.00
minimum	0.0%	238.00

Moments

Mean	407.7500
Std Dev	148.4019
Std Error Mean	37.1005
Upper 95% Mean	486.8275
Lower 95% Mean	328.6725
N	16.0000
Sum Weights	16.0000

Figure 14 Distribution of data and DOE analysis for Dry Tape Adhesion



Response: D T A

The estimates are correlated and need a transformation.
The estimates have different variances and need scaling.

Lenth PSE
1.19354

Term	Original	Orthog Coded	Orthog t-Test	Prob>|t|
Intercept	3.652545	3.968750	33.6844	<.0001
Paint[46168-WRCARC]	0.083825	0.093750	0.7957	0.4844
Color[green-grey]	0.256087	0.281250	2.3871	0.0970
Stor Dur (days)	-0.018562	-0.093750	-0.7957	0.4844
Stor Temp (F)	-0.003886	-0.093750	-0.7957	0.4844
Mix time (min)	0.008246	0.093750	0.7957	0.4844
Equipmen[Conv-HVLP]	-0.036162	-0.031250	-0.2652	0.8080
Induction time	0.041255	0.093750	0.7957	0.4844
Flash time (hrs	-0.158139	-0.031250	-0.2652	0.8080
DFT (mils)	0.160401	0.130568	1.1082	0.3486
Cure Dur (days)	-0.072389	-0.167069	-1.4180	0.2512
Cure Temp (F)	0.000164	-0.018970	-0.1610	0.8823
Cure Hum (%RH)	0.012263	0.229527	1.9481	0.1465

Each Orthog Estimate is conditioned on the effects before it

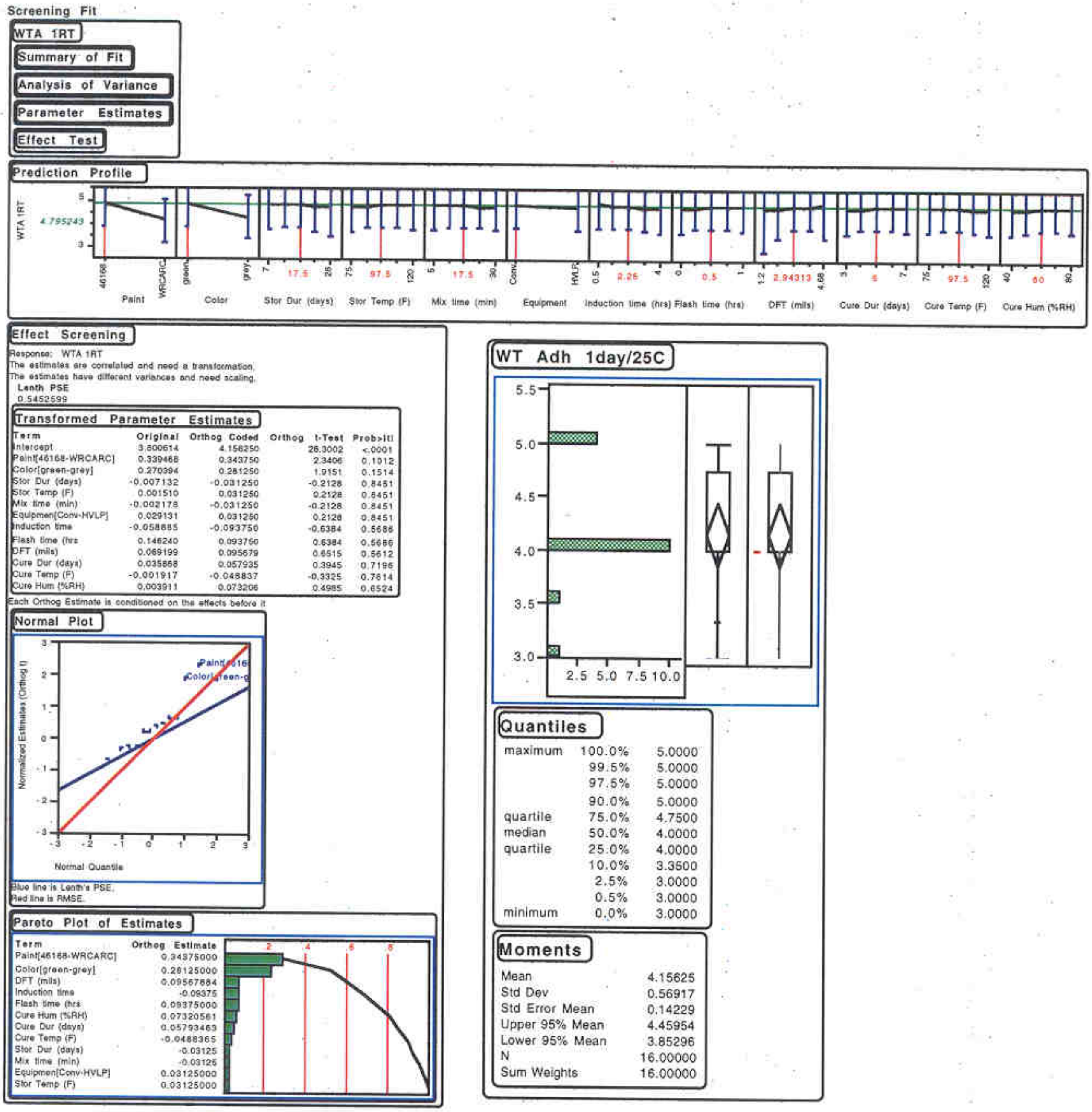
Blue line is Lenth's PSE.
Red line is RMSE.

Term	Orthog Estimate
Color[green-grey]	0.28125000
Cure Hum (%RH)	0.22952717
Cure Dur (days)	-0.1670685
DFT (mils)	0.13056814
Stor Temp (F)	-0.09375
Stor Dur (days)	-0.09375
Paint[46168-WRCARC]	0.09375000
Induction time	0.09375000
Mix time (min)	0.09375000
Flash time (hrs	-0.03125
Equipmen[Conv-HVLP]	-0.03125
Cure Temp (F)	-0.0189701

maximum	100.0%	5.0000
	99.5%	5.0000
	97.5%	5.0000
	90.0%	5.0000
quartile	75.0%	4.0000
median	50.0%	4.0000
quartile	25.0%	4.0000
	10.0%	3.0000
	2.5%	3.0000
	0.5%	3.0000
minimum	0.0%	3.0000

Mean	3.96875
Std Dev	0.53131
Std Error Mean	0.13283
Upper 95% Mean	4.25186
Lower 95% Mean	3.68564
N	16.00000
Sum Weights	16.00000

Figure 15 Distribution of data and DOE analysis for Wet Tape Adhesion (1 day/RT)



Response: WTA 1RT
The estimates are correlated and need a transformation.
The estimates have different variances and need scaling.

Lenth PSE
0.5452599

Transformed Parameter Estimates

Term	Original	Orthog Coded	Orthog t-Test	Prob>|t|
Intercept	3.800614	4.156250	26.3002	<.0001
Paint[46168-WRCARC]	0.339468	0.343750	2.3406	0.1012
Color[green-grey]	0.270394	0.281250	1.9151	0.1514
Stor Dur (days)	-0.007132	-0.031250	-0.2128	0.8451
Stor Temp (F)	0.001510	0.031250	0.2128	0.8451
Mix time (min)	-0.002178	-0.031250	-0.2128	0.8451
Equipmen[Conv-HVLP]	0.029131	0.031250	0.2128	0.8451
Induction time	-0.058885	-0.093750	-0.6384	0.5686
Flash time (hrs	0.146240	0.093750	0.6384	0.5686
DFT (mils)	0.069199	0.095679	0.6515	0.5612
Cure Dur (days)	0.035868	0.057935	0.3945	0.7196
Cure Temp (F)	-0.001917	-0.048837	-0.3325	0.7614
Cure Hum (%RH)	0.003911	0.073206	0.4985	0.6524

Each Orthog Estimate is conditioned on the effects before it

Blue line is Lenth's PSE.
Red line is RMSE.

Term	Orthog Estimate
Paint[46168-WRCARC]	0.34375000
Color[green-grey]	0.28125000
DFT (mils)	0.09567884
Induction time	-0.09375
Flash time (hrs	0.09375000
Cure Hum (%RH)	0.07320561
Cure Dur (days)	0.05793463
Cure Temp (F)	-0.0488365
Stor Dur (days)	-0.03125
Mix time (min)	-0.03125
Equipmen[Conv-HVLP]	0.03125000
Stor Temp (F)	0.03125000

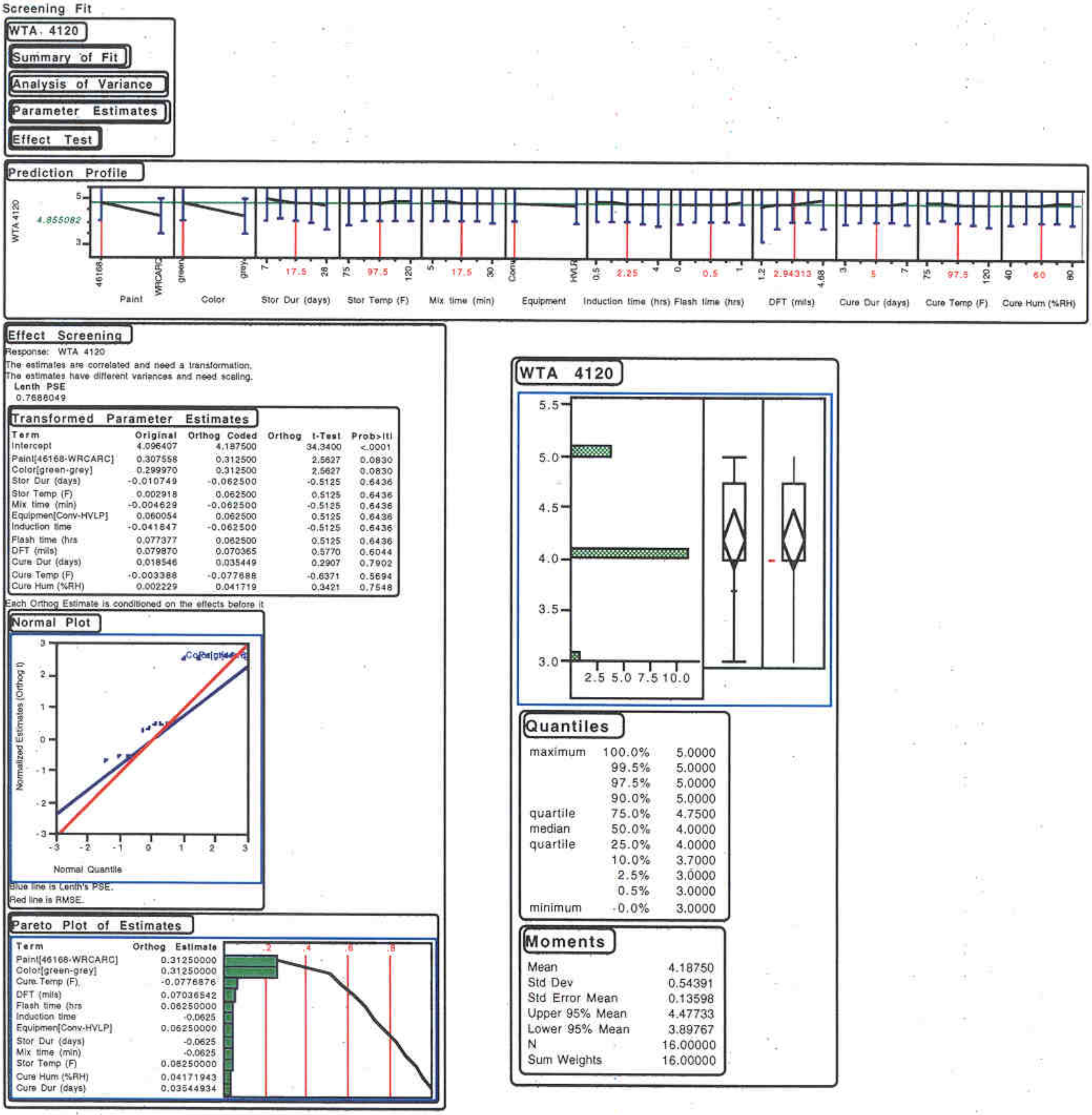
Quantiles

maximum	100.0%	5.0000
	99.5%	5.0000
	97.5%	5.0000
	90.0%	5.0000
quartile	75.0%	4.7500
median	50.0%	4.0000
quartile	25.0%	4.0000
	10.0%	3.3500
	2.5%	3.0000
	0.5%	3.0000
minimum	0.0%	3.0000

Moments

Mean	4.15625
Std Dev	0.56917
Std Error Mean	0.14229
Upper 95% Mean	4.45954
Lower 95% Mean	3.85296
N	16.00000
Sum Weights	16.00000

Figure 16 Distribution of data and DOE analysis for Wet Tape Adhesion (4 days @ 120°F)



Screening Fit

WTA 4120

Summary of Fit

Analysis of Variance

Parameter Estimates

Effect Test

Prediction Profile

Effect Screening

Response: WTA 4120

The estimates are correlated and need a transformation.
The estimates have different variances and need scaling.

Lenth PSE
0.7686049

Transformed Parameter Estimates

Term	Original	Orthog Coded	Orthog t-Test	Prob>|t|
Intercept	4.096407	4.187500	34.3400	<.0001
Paint[46168-WRCARC]	0.307556	0.312500	2.5627	0.0830
Color[green-grey]	0.299970	0.312500	2.5627	0.0830
Stor Dur (days)	-0.010749	-0.062500	-0.5125	0.6436
Stor Temp (F)	0.002918	0.062500	0.5125	0.6436
Mix time (min)	-0.004629	-0.062500	-0.5125	0.6436
Equipmen[Conv-HVLP]	0.060054	0.062500	0.5125	0.6436
Induction time	-0.041847	-0.062500	-0.5125	0.6436
Flash time (hrs	0.077377	0.062500	0.5125	0.6436
DFT (mils)	0.079870	0.070365	0.5770	0.6044
Cure Dur (days)	0.018546	0.035449	0.2907	0.7902
Cure Temp (F)	-0.003388	-0.077688	-0.6371	0.5694
Cure Hum (%RH)	0.002229	0.041719	0.3421	0.7548

Each Orthog Estimate is conditioned on the effects before it

Normal Plot

Blue line is Lenth's PSE.
Red line is RMSE.

Pareto Plot of Estimates

Term	Orthog Estimate
Paint[46168-WRCARC]	0.31250000
Color[green-grey]	0.31250000
Cure Temp (F)	-0.0776876
DFT (mils)	0.07036542
Flash time (hrs	0.06250000
Induction time	-0.0625
Equipmen[Conv-HVLP]	0.06250000
Stor Dur (days)	-0.0625
Mix time (min)	-0.0625
Stor Temp (F)	0.06250000
Cure Hum (%RH)	0.04171943
Cure Dur (days)	0.03544934

WTA 4120

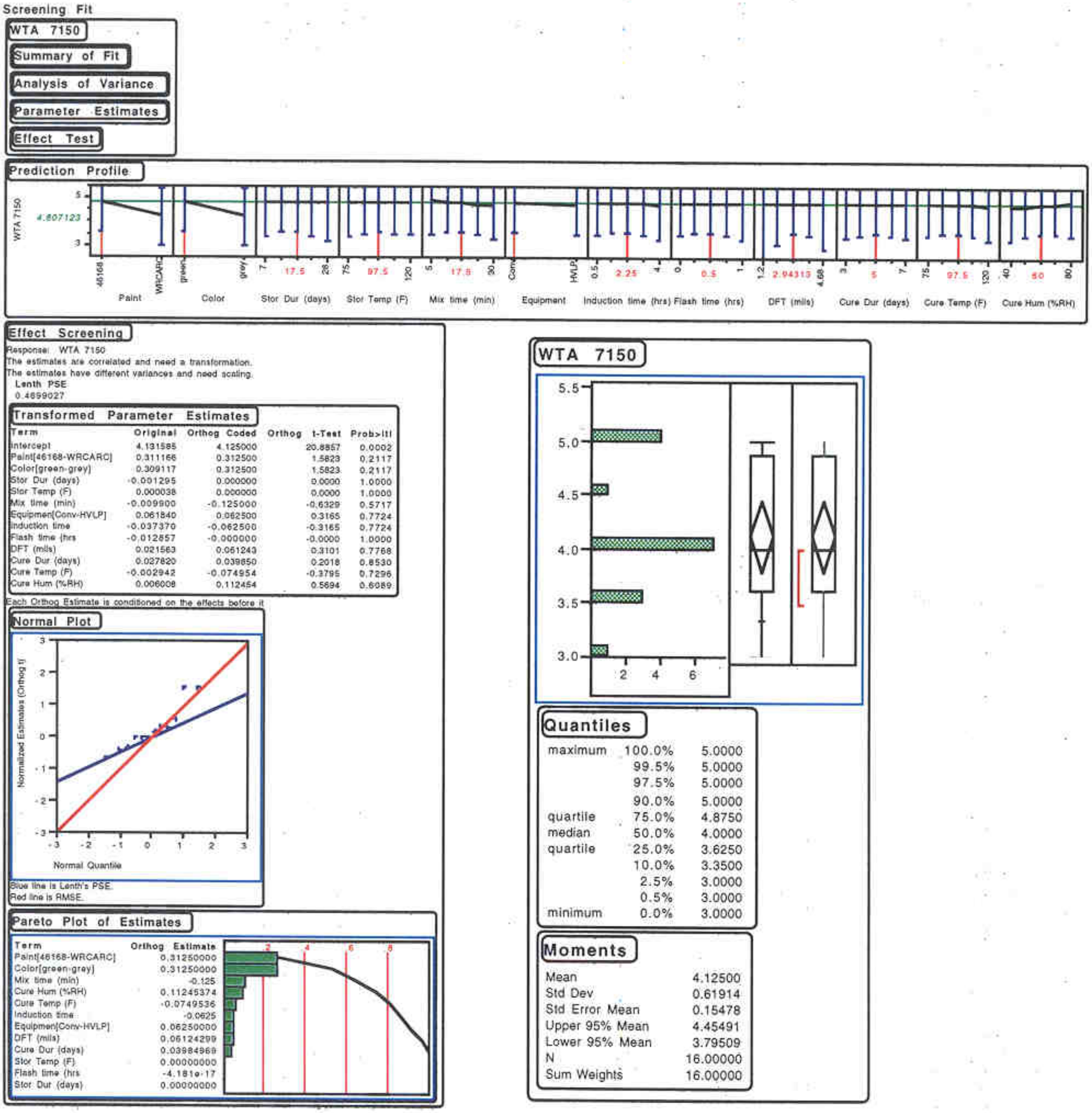
Quantiles

maximum	100.0%	5.0000
	99.5%	5.0000
	97.5%	5.0000
	90.0%	5.0000
quartile	75.0%	4.7500
median	50.0%	4.0000
quartile	25.0%	4.0000
	10.0%	3.7000
	2.5%	3.0000
	0.5%	3.0000
minimum	0.0%	3.0000

Moments

Mean	4.18750
Std Dev	0.54391
Std Error Mean	0.13598
Upper 95% Mean	4.47733
Lower 95% Mean	3.89767
N	16.00000
Sum Weights	16.00000

Figure 17 Distribution of data and DOE analysis for Wet Tape Adhesion (7 days @ 150°F)



Response: WTA 7150
The estimates are correlated and need a transformation.
The estimates have different variances and need scaling.
Lenth PSE
0.4699027

Transformed Parameter Estimates

Term	Original	Orthog Coded	Orthog t-Test	Prob>|t|
Intercept	4.131585	4.125000	20.8857	0.0002
Paint[46168-WRCARC]	0.311166	0.312500	1.5823	0.2117
Color[green-grey]	0.309117	0.312500	1.5823	0.2117
Stor Dur (days)	-0.001295	0.000000	0.0000	1.0000
Stor Temp (F)	0.000038	0.000000	0.0000	1.0000
Mix time (min)	-0.009900	-0.125000	-0.6329	0.5717
Equipmen[Conv-HVLP]	0.061840	0.062500	0.3165	0.7724
Induction time	-0.037370	-0.062500	-0.3165	0.7724
Flash time (hrs	-0.012857	-0.000000	-0.0000	1.0000
DFT (mils)	0.021563	0.061243	0.3101	0.7768
Cure Dur (days)	0.027820	0.039850	0.2018	0.8530
Cure Temp (F)	-0.002942	-0.074954	-0.3795	0.7296
Cure Hum (%RH)	0.006008	0.112454	0.5694	0.6089

Each Orthog Estimate is conditioned on the effects before it

Blue line is Lenth's PSE.
Red line is RMSE.

Term	Orthog Estimate
Paint[46168-WRCARC]	0.31250000
Color[green-grey]	0.31250000
Mix time (min)	-0.125
Cure Hum (%RH)	0.11245374
Cure Temp (F)	-0.0749536
Induction time	-0.0625
Equipmen[Conv-HVLP]	0.06250000
DFT (mils)	0.06124299
Cure Dur (days)	0.03984969
Stor Temp (F)	0.00000000
Flash time (hrs	-4.181e-17
Stor Dur (days)	0.00000000

maximum	100.0%	5.0000
	99.5%	5.0000
	97.5%	5.0000
	90.0%	5.0000
quartile	75.0%	4.8750
median	50.0%	4.0000
quartile	25.0%	3.6250
	10.0%	3.3500
	2.5%	3.0000
	0.5%	3.0000
minimum	0.0%	3.0000

Mean	4.12500
Std Dev	0.61914
Std Error Mean	0.15478
Upper 95% Mean	4.45491
Lower 95% Mean	3.79509
N	16.00000
Sum Weights	16.00000

Figure 18 Cumulative Variable Influence Contribution (VIC) on Adhesion

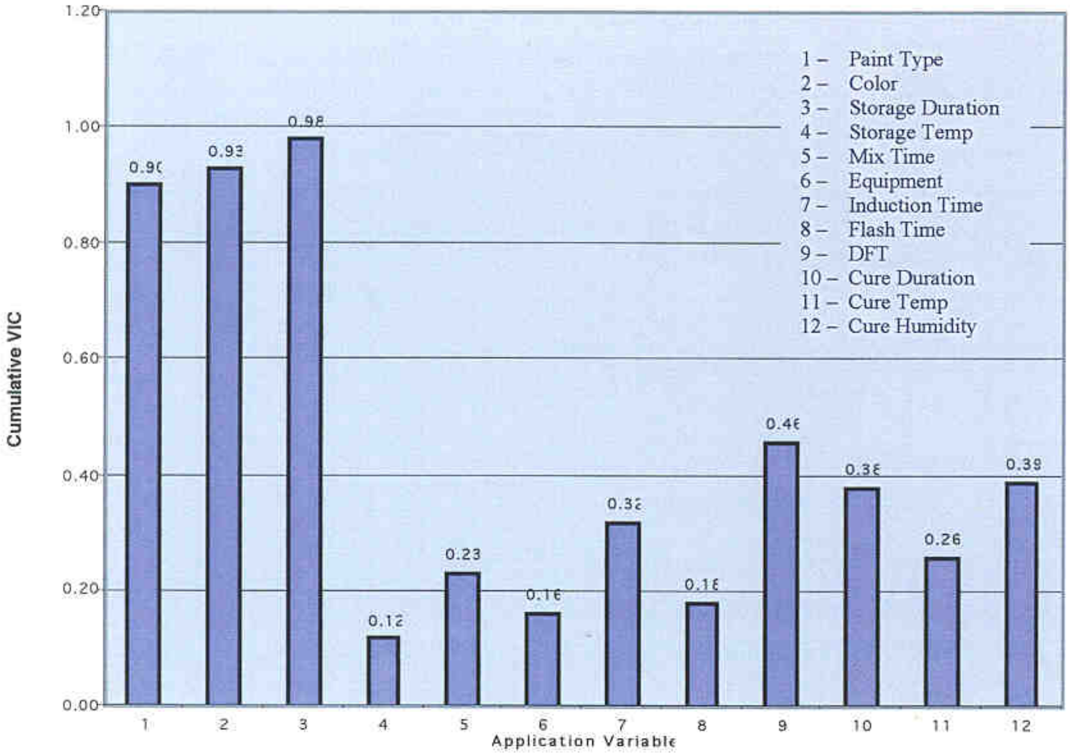
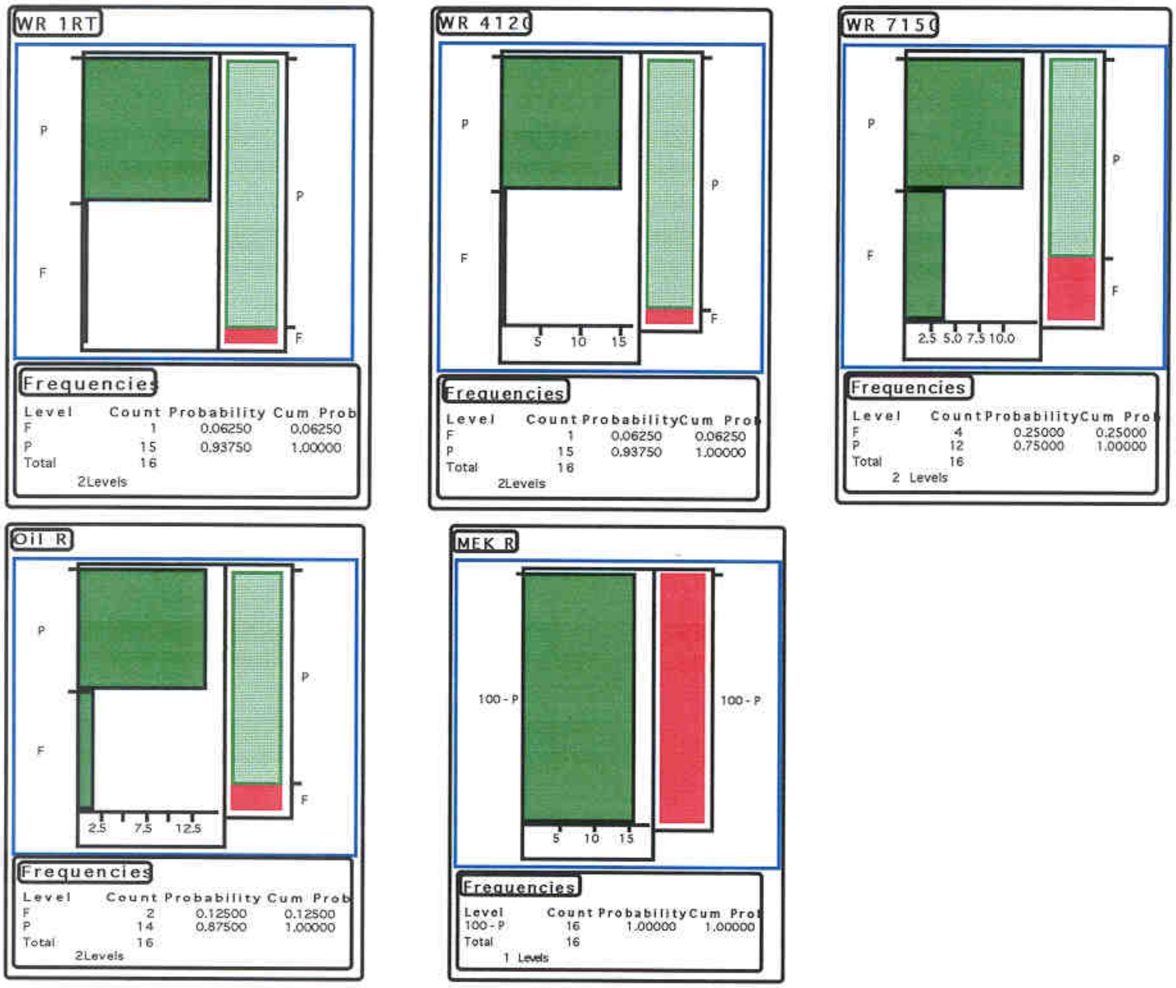


Figure 19 Distribution of data and DOE analysis for Fluid Resistance



WR 1RT

Frequencies

Level	Count	Probability	Cum Prob
F	1	0.06250	0.06250
P	15	0.93750	1.00000
Total	16		

2Levels

WR 412C

Frequencies

Level	Count	Probability	Cum Pro
F	1	0.06250	0.06250
P	15	0.93750	1.00000
Total	16		

2Levels

WR 715C

Frequencies

Level	Count	Probability	Cum Pro
F	4	0.25000	0.25000
P	12	0.75000	1.00000
Total	16		

2 Levels

Oil R

Frequencies

Level	Count	Probability	Cum Prob
F	2	0.12500	0.12500
P	14	0.87500	1.00000
Total	16		

2Levels

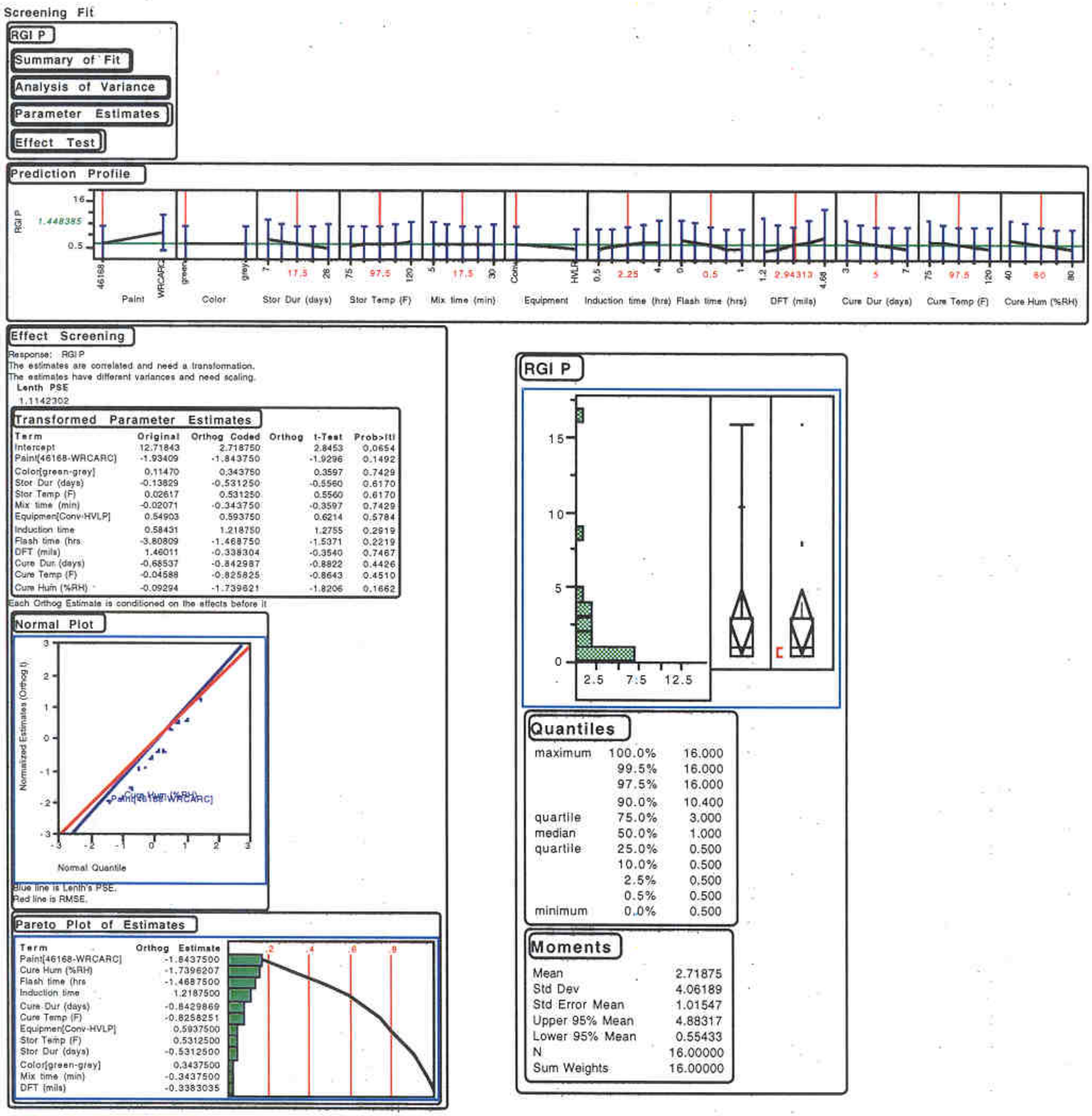
MEK R

Frequencies

Level	Count	Probability	Cum Pro
100 - P	16	1.00000	1.00000
Total	16		

1 Levels

Figure 20 Distribution of data and DOE analysis for Reverse Gardner Impact with primer



Response: RGI P

The estimates are correlated and need a transformation.

The estimates have different variances and need scaling.

Lenth PSE

1.1142302

Transformed Parameter Estimates

Term	Original	Orthog Coded	Orthog	t-Test	Prob>|t|
Intercept	12.71843	2.718750		2.8453	0.0654
Paint[46168-WRCARC]	-1.93409	-1.843750		-1.9296	0.1492
Color[green-grey]	0.11470	0.343750		0.3597	0.7429
Stor Dur (days)	-0.13829	-0.531250		-0.5560	0.6170
Stor Temp (F)	0.02617	0.531250		0.5560	0.6170
Mix time (min)	-0.02071	-0.343750		-0.3597	0.7429
Equipmen[Conv-HVLP]	0.54903	0.593750		0.6214	0.5784
Induction time	0.58431	1.218750		1.2755	0.2919
Flash time (hrs	-3.80809	-1.468750		-1.5371	0.2219
DFT (mils)	1.46011	-0.338304		-0.3540	0.7467
Cure Dur (days)	-0.68537	-0.842987		-0.8822	0.4426
Cure Temp (F)	-0.04588	-0.825825		-0.8643	0.4510
Cure Hum (%RH)	-0.09294	-1.739621		-1.8206	0.1662

Each Orthog Estimate is conditioned on the effects before it

Blue line is Lenth's PSE.

Red line is RMSE.

Term	Orthog Estimate
Paint[46168-WRCARC]	-1.8437500
Cure Hum (%RH)	-1.7396207
Flash time (hrs	-1.4687500
Induction time	1.2187500
Cure Dur (days)	-0.8429869
Cure Temp (F)	-0.8258251
Equipmen[Conv-HVLP]	0.5937500
Stor Temp (F)	0.5312500
Stor Dur (days)	-0.5312500
Color[green-grey]	0.3437500
Mix time (min)	-0.3437500
DFT (mils)	-0.3383035

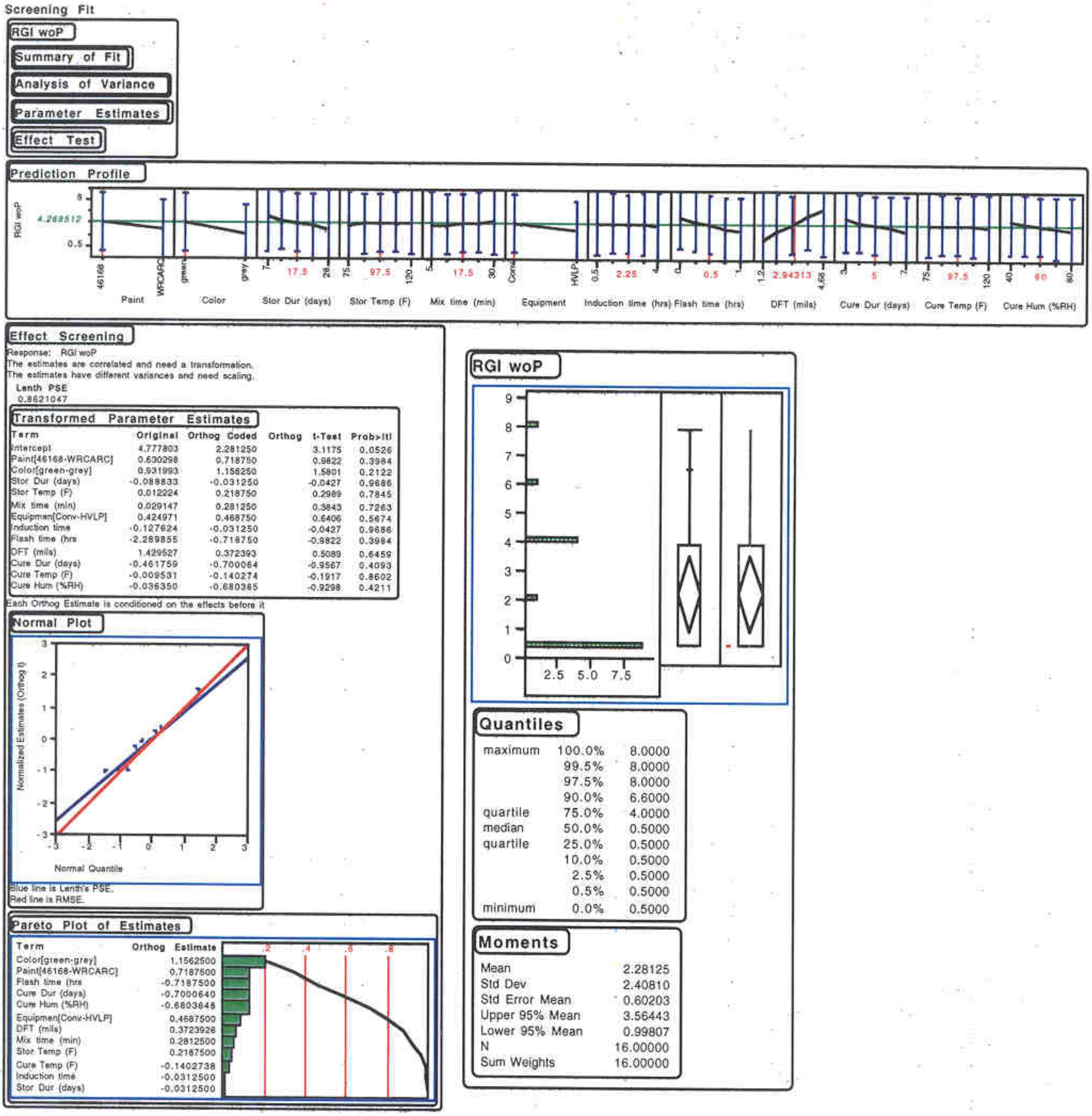
Quantiles

maximum	100.0%	16.000
	99.5%	16.000
	97.5%	16.000
	90.0%	10.400
quartile	75.0%	3.000
median	50.0%	1.000
quartile	25.0%	0.500
	10.0%	0.500
	2.5%	0.500
	0.5%	0.500
minimum	0.0%	0.500

Moments

Mean	2.71875
Std Dev	4.06189
Std Error Mean	1.01547
Upper 95% Mean	4.88317
Lower 95% Mean	0.55433
N	16.00000
Sum Weights	16.00000

Figure 21 Distribution of data and DOE analysis for Reverse Gardner Impact without primer



Screening Fit

RGI woP

Summary of Fit

Analysis of Variance

Parameter Estimates

Effect Test

Prediction Profile

Effect Screening

Response: RGI woP

The estimates are correlated and need a transformation.

The estimates have different variances and need scaling.

Lenth PSE

0.8621047

Transformed Parameter Estimates

Term	Original	Orthog Coded	Orthog	t-Test	Prob>|t|
Intercept	4.777803	2.281250		3.1175	0.0526
Paint[46168-WRCARC]	0.630298	0.718750		0.9822	0.3984
Color[green-grey]	0.931993	1.156250		1.5801	0.2122
Stor Dur (days)	-0.088833	-0.031250		-0.0427	0.9686
Stor Temp (F)	0.012224	0.218750		0.2989	0.7845
Mix time (min)	0.029147	0.281250		0.3843	0.7263
Equipmen[Conv-HVLP]	0.424971	0.468750		0.6406	0.5674
Induction time	-0.127624	-0.031250		-0.0427	0.9686
Flash time (hrs	-2.289855	-0.718750		-0.9822	0.3984
DFT (mils)	1.429527	0.372393		0.5089	0.6459
Cure Dur (days)	-0.461759	-0.700064		-0.9567	0.4093
Cure Temp (F)	-0.009531	-0.140274		-0.1917	0.8602
Cure Hum (%RH)	-0.036350	-0.680365		-0.9298	0.4211

Each Orthog Estimate is conditioned on the effects before it

Normal Plot

Blue line is Lenth's PSE.

Red line is RMSE.

Pareto Plot of Estimates

Term	Orthog Estimate
Color[green-grey]	1.1562500
Paint[46168-WRCARC]	0.7187500
Flash time (hrs	-0.7187500
Cure Dur (days)	-0.7000640
Cure Hum (%RH)	-0.6803648
Equipmen[Conv-HVLP]	0.4687500
DFT (mils)	0.3723928
Mix time (min)	0.2812500
Stor Temp (F)	0.2187500
Cure Temp (F)	-0.1402738
Induction time	-0.0312500
Stor Dur (days)	-0.0312500

RGI woP

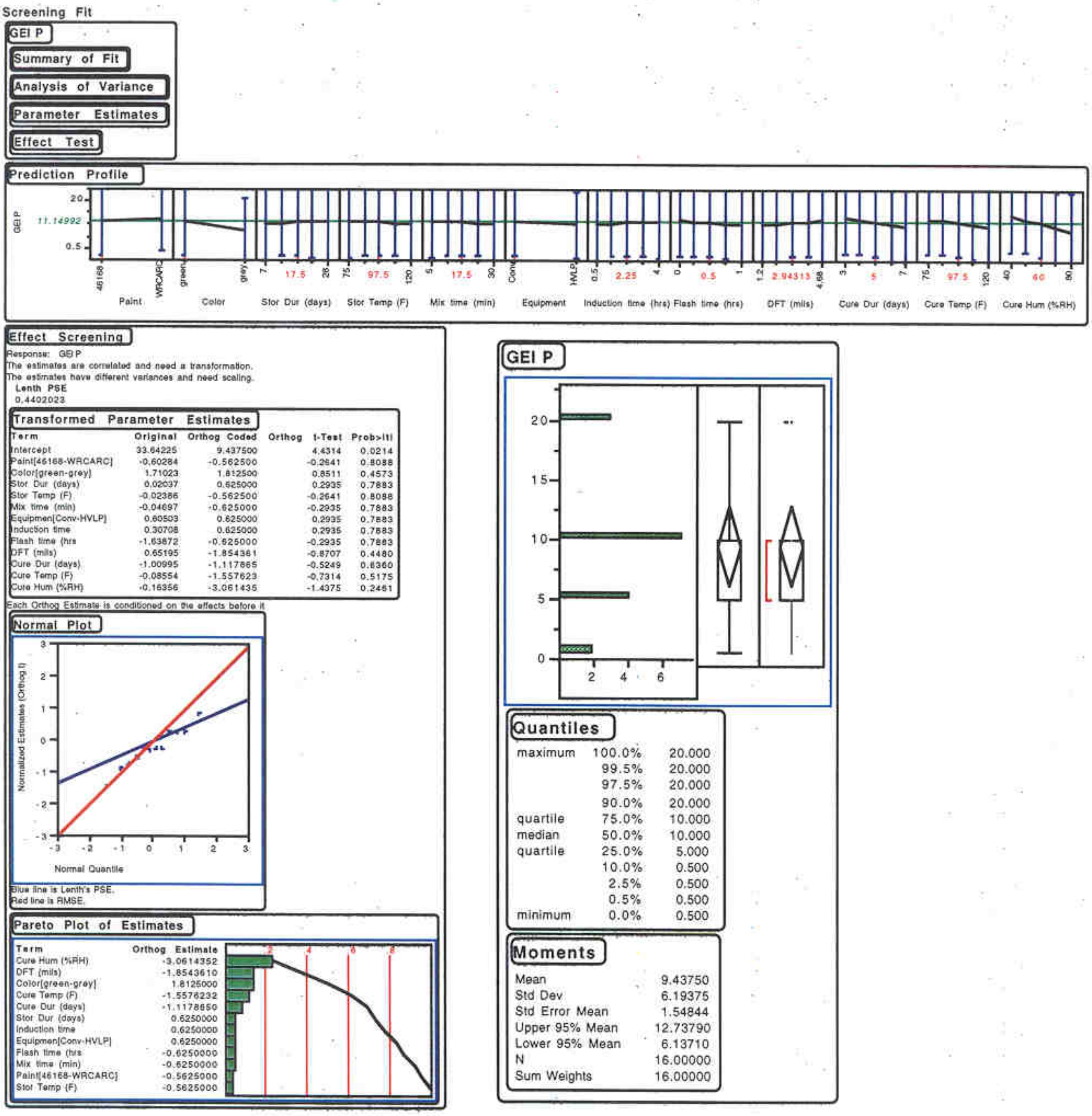
Quantiles

maximum	100.0%	8.0000
	99.5%	8.0000
	97.5%	8.0000
	90.0%	6.6000
quartile	75.0%	4.0000
median	50.0%	0.5000
quartile	25.0%	0.5000
	10.0%	0.5000
	2.5%	0.5000
	0.5%	0.5000
minimum	0.0%	0.5000

Moments

Mean	2.28125
Std Dev	2.40810
Std Error Mean	0.60203
Upper 95% Mean	3.56443
Lower 95% Mean	0.99807
N	16.00000
Sum Weights	16.00000

Figure 22 Distribution of data and DOE analysis for GE Impact with primer



Response: GEI P
The estimates are correlated and need a transformation.
The estimates have different variances and need scaling.

Lenth PSE
0.4402023

Transformed Parameter Estimates

Term	Original	Orthog Coded	Orthog	t-Test	Prob>|t|
Intercept	33.64225	9.437500		4.4314	0.0214
Paint[46168-WRCARC]	-0.60284	-0.562500		-0.2641	0.8088
Color[green-grey]	1.71023	1.812500		0.8511	0.4573
Stor Dur (days)	0.02037	0.625000		0.2935	0.7883
Stor Temp (F)	-0.02386	-0.562500		-0.2641	0.8088
Mix time (min)	-0.04697	-0.625000		-0.2935	0.7883
Equipmen[Conv-HVLP]	0.60503	0.625000		0.2935	0.7883
Induction time	0.30708	0.625000		0.2935	0.7883
Flash time (hrs	-1.63872	-0.625000		-0.2935	0.7883
DFT (mils)	0.65195	-1.854361		-0.8707	0.4480
Cure Dur (days)	-1.00995	-1.117865		-0.5249	0.6360
Cure Temp (F)	-0.08554	-1.557623		-0.7314	0.5175
Cure Hum (%RH)	-0.16356	-3.061435		-1.4375	0.2461

Each Orthog Estimate is conditioned on the effects before it

Blue line is Lenth's PSE.
Red line is RMSE.

Pareto Plot of Estimates

Term	Orthog Estimate
Cure Hum (%RH)	-3.0614352
DFT (mils)	-1.8543610
Color[green-grey]	1.8125000
Cure Temp (F)	-1.5576232
Cure Dur (days)	-1.1178650
Stor Dur (days)	0.6250000
Induction time	0.6250000
Equipmen[Conv-HVLP]	0.6250000
Flash time (hrs	-0.6250000
Mix time (min)	-0.6250000
Paint[46168-WRCARC]	-0.5625000
Stor Temp (F)	-0.5625000

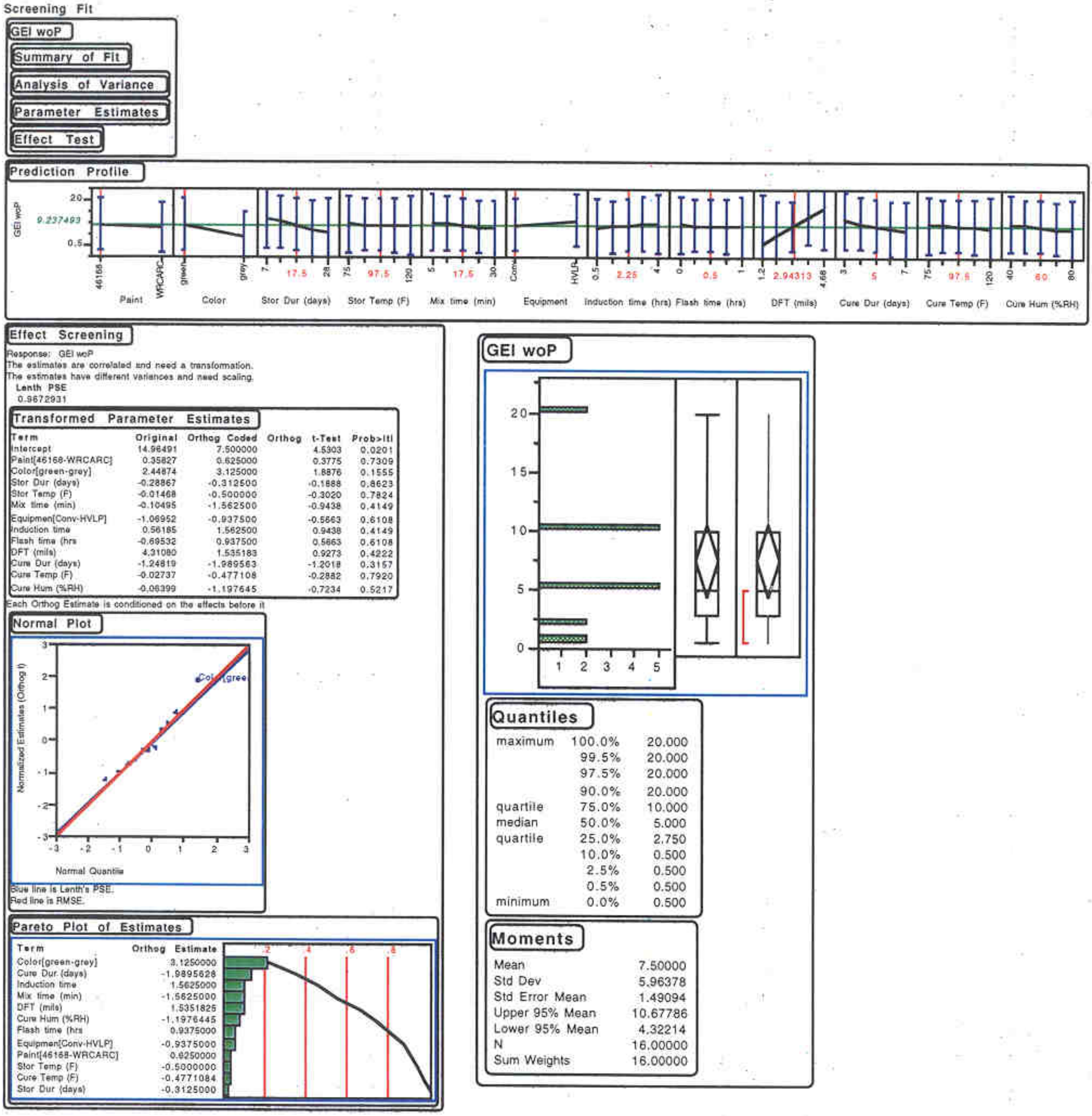
Quantiles

maximum	100.0%	20.000
	99.5%	20.000
	97.5%	20.000
	90.0%	20.000
quartile	75.0%	10.000
median	50.0%	10.000
quartile	25.0%	5.000
	10.0%	0.500
	2.5%	0.500
	0.5%	0.500
minimum	0.0%	0.500

Moments

Mean	9.43750
Std Dev	6.19375
Std Error Mean	1.54844
Upper 95% Mean	12.73790
Lower 95% Mean	6.13710
N	16.00000
Sum Weights	16.00000

Figure 23 Distribution of data and DOE analysis for GE Impact without primer



Response: GEI woP
The estimates are correlated and need a transformation.
The estimates have different variances and need scaling.

Lenth PSE
0.9672931

Transformed Parameter Estimates

Term	Original	Orthog Coded	Orthog	t-Test	Prob>|t|
Intercept	14.96491	7.500000		4.5303	0.0201
Paint[46168-WRCARC]	0.35827	0.625000		0.3775	0.7309
Color[green-grey]	2.44874	3.125000		1.8876	0.1555
Stor Dur (days)	-0.28867	-0.312500		-0.1888	0.8623
Stor Temp (F)	-0.01468	-0.500000		-0.3020	0.7824
Mix time (min)	-0.10495	-1.562500		-0.9438	0.4149
Equipmen[Conv-HVLP]	-1.06952	-0.937500		-0.5663	0.6108
Induction time	0.56185	1.562500		0.9438	0.4149
Flash time (hrs	-0.69532	0.937500		0.5663	0.6108
DFT (mils)	4.31080	1.535183		0.9273	0.4222
Cure Dur (days)	-1.24819	-1.989563		-1.2018	0.3157
Cure Temp (F)	-0.02737	-0.477108		-0.2882	0.7920
Cure Hum (%RH)	-0.06399	-1.197645		-0.7234	0.5217

Each Orthog Estimate is conditioned on the effects before it

Blue line is Lenth's PSE.
Red line is RMSE.

Pareto Plot of Estimates

Term	Orthog Estimate
Color[green-grey]	3.1250000
Cure Dur (days)	-1.9895628
Induction time	1.5625000
Mix time (min)	-1.5625000
DFT (mils)	1.5351825
Cure Hum (%RH)	-1.1976445
Flash time (hrs	0.9375000
Equipmen[Conv-HVLP]	-0.9375000
Paint[46168-WRCARC]	0.6250000
Stor Temp (F)	-0.5000000
Cure Temp (F)	-0.4771084
Stor Dur (days)	-0.3125000

Quantiles

maximum	100.0%	20.000
	99.5%	20.000
	97.5%	20.000
	90.0%	20.000
quartile	75.0%	10.000
median	50.0%	5.000
quartile	25.0%	2.750
	10.0%	0.500
	2.5%	0.500
	0.5%	0.500
minimum	0.0%	0.500

Moments

Mean	7.50000
Std Dev	5.96378
Std Error Mean	1.49094
Upper 95% Mean	10.67786
Lower 95% Mean	4.32214
N	16.00000
Sum Weights	16.00000

Figure 24 Cumulative Variable Influence Contribution (VIC) Impact Resistance

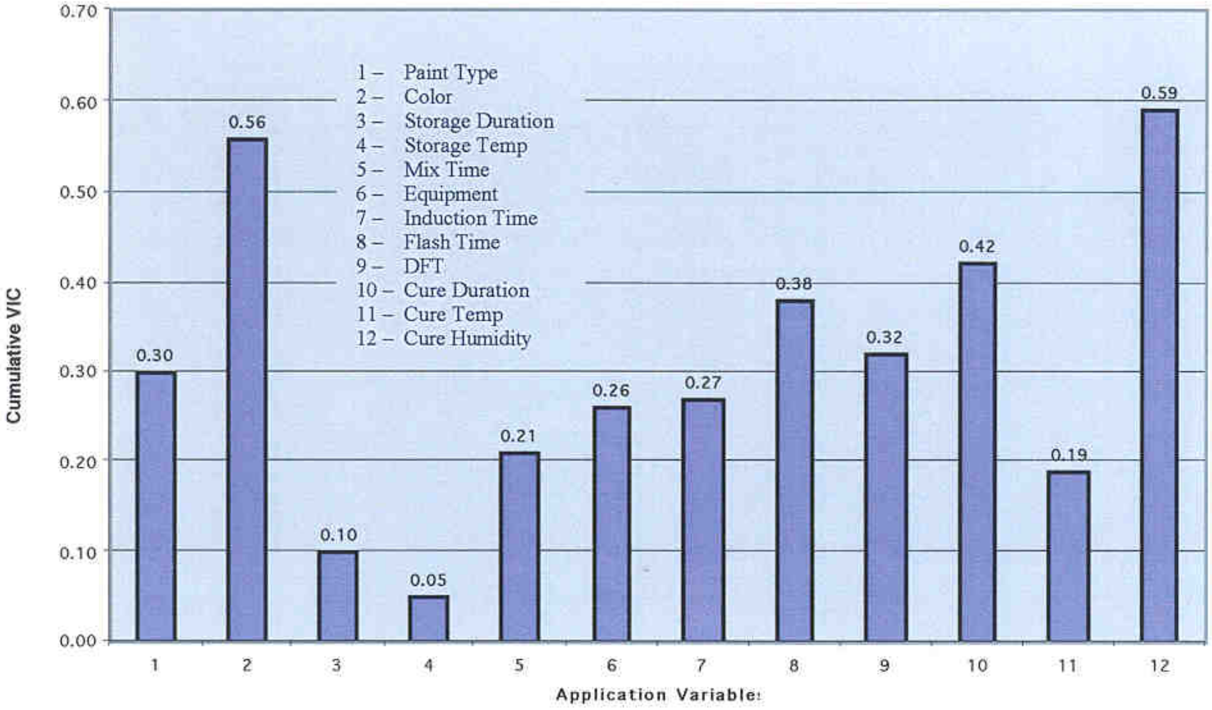
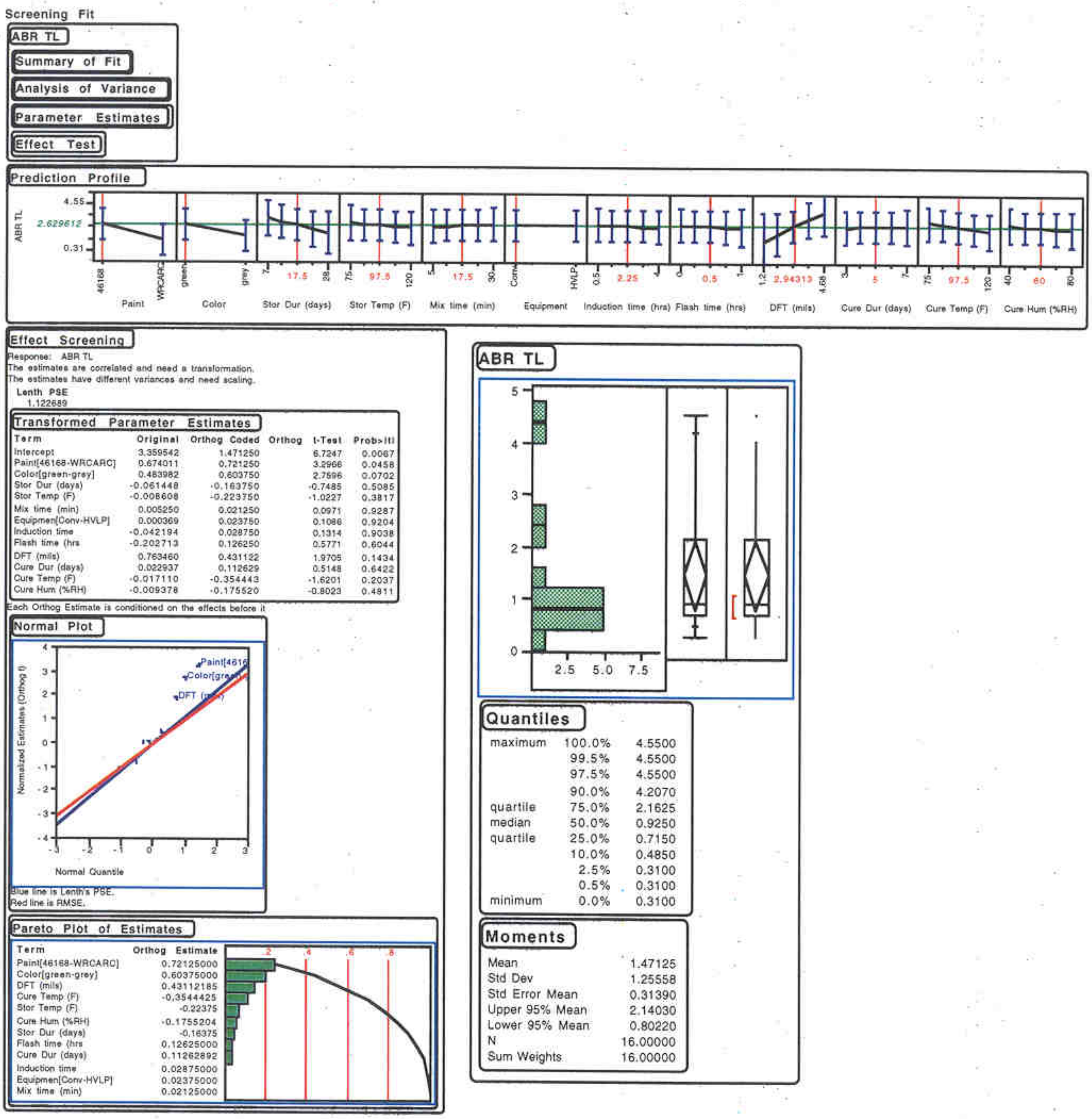


Figure 25 Distribution of data and DOE analysis for Abrasion Resistance Thickness Loss



Response: ABR TL
The estimates are correlated and need a transformation.
The estimates have different variances and need scaling.

Lenth PSE
1.122689

Transformed Parameter Estimates

Term	Original	Orthog Coded	Orthog	t-Test	Prob>|t|
Intercept	3.359542	1.471250		6.7247	0.0067
Paint[46168-WRCARC]	0.674011	0.721250		3.2966	0.0458
Color[green-grey]	0.483982	0.603750		2.7596	0.0702
Stor Dur (days)	-0.061448	-0.163750		-0.7485	0.5085
Stor Temp (F)	-0.008608	-0.223750		-1.0227	0.3817
Mix time (min)	0.005250	0.021250		0.0971	0.9287
Equipmen[Conv-HVLP]	0.000369	0.023750		0.1086	0.9204
Induction time	-0.042194	0.028750		0.1314	0.9038
Flash time (hrs	-0.202713	0.126250		0.5771	0.6044
DFT (mils)	0.763460	0.431122		1.9705	0.1434
Cure Dur (days)	0.022937	0.112629		0.5148	0.6422
Cure Temp (F)	-0.017110	-0.354443		-1.6201	0.2037
Cure Hum (%RH)	-0.009378	-0.175520		-0.8023	0.4811

Each Orthog Estimate is conditioned on the effects before it

Blue line is Lenth's PSE.
Red line is RMSE.

Pareto Plot of Estimates

Term	Orthog Estimate
Paint[46168-WRCARC]	0.72125000
Color[green-grey]	0.60375000
DFT (mils)	0.43112185
Cure Temp (F)	-0.3544425
Stor Temp (F)	-0.22375
Cure Hum (%RH)	-0.1755204
Stor Dur (days)	-0.16375
Flash time (hrs	0.12625000
Cure Dur (days)	0.11262892
Induction time	0.02875000
Equipmen[Conv-HVLP]	0.02375000
Mix time (min)	0.02125000

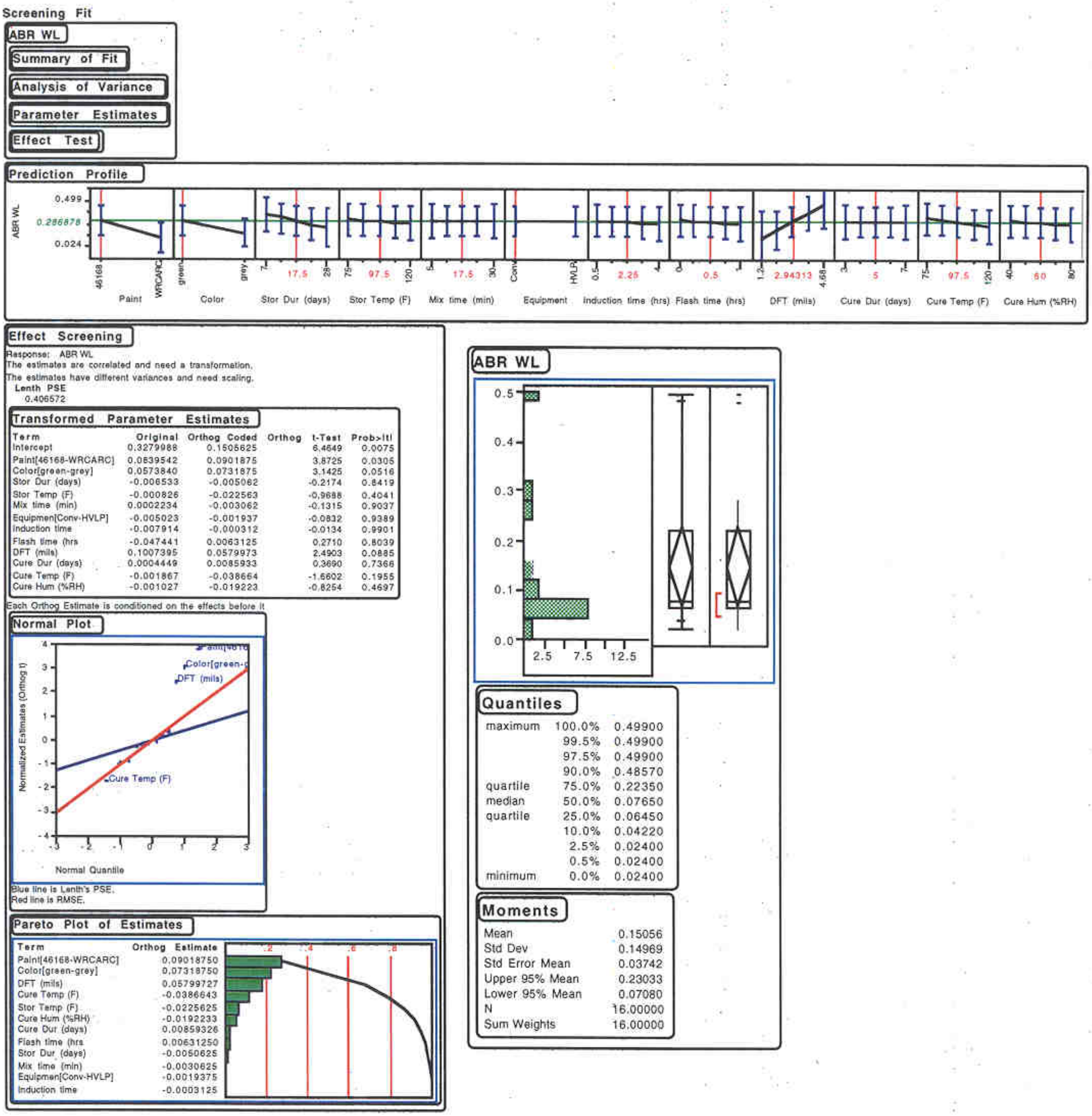
Quantiles

maximum	100.0%	4.5500
	99.5%	4.5500
	97.5%	4.5500
	90.0%	4.2070
quartile	75.0%	2.1625
median	50.0%	0.9250
quartile	25.0%	0.7150
	10.0%	0.4850
	2.5%	0.3100
	0.5%	0.3100
minimum	0.0%	0.3100

Moments

Mean	1.47125
Std Dev	1.25558
Std Error Mean	0.31390
Upper 95% Mean	2.14030
Lower 95% Mean	0.80220
N	16.00000
Sum Weights	16.00000

Figure 26 Distribution of data and DOE analysis for Abrasion Resistance Weight Loss



Response: ABR WL
The estimates are correlated and need a transformation.
The estimates have different variances and need scaling.

Lenth PSE
0.406572

Transformed Parameter Estimates

Term	Original	Orthog Coded	Orthog	t-Test	Prob>|t|
Intercept	0.3279988	0.1505625		6.4649	0.0075
Paint[46168-WRCARC]	0.0839542	0.0901875		3.8725	0.0305
Color[green-grey]	0.0573840	0.0731875		3.1425	0.0516
Stor Dur (days)	-0.006533	-0.005062		-0.2174	0.8419
Stor Temp (F)	-0.000826	-0.022563		-0.9688	0.4041
Mix time (min)	0.0002234	-0.003062		-0.1315	0.9037
Equipmen[Conv-HVLP]	-0.005023	-0.001937		-0.0832	0.9389
Induction time	-0.007914	-0.000312		-0.0134	0.9901
Flash time (hrs	-0.047441	0.0063125		0.2710	0.8039
DFT (mils)	0.1007395	0.0579973		2.4903	0.0885
Cure Dur (days)	0.0004449	0.0085933		0.3690	0.7366
Cure Temp (F)	-0.001867	-0.038664		-1.6602	0.1955
Cure Hum (%RH)	-0.001027	-0.019223		-0.8254	0.4697

Each Orthog Estimate is conditioned on the effects before it

Blue line is Lenth's PSE.
Red line is RMSE.

Pareto Plot of Estimates

Term	Orthog Estimate
Paint[46168-WRCARC]	0.09018750
Color[green-grey]	0.07318750
DFT (mils)	0.05799727
Cure Temp (F)	-0.0386643
Stor Temp (F)	-0.0225625
Cure Hum (%RH)	-0.0192233
Cure Dur (days)	0.00859326
Flash time (hrs	0.00631250
Stor Dur (days)	-0.0050625
Mix time (min)	-0.0030625
Equipmen[Conv-HVLP]	-0.0019375
Induction time	-0.0003125

Quantiles

maximum	100.0%	0.49900
	99.5%	0.49900
	97.5%	0.49900
	90.0%	0.48570
quartile	75.0%	0.22350
median	50.0%	0.07650
quartile	25.0%	0.06450
	10.0%	0.04220
	2.5%	0.02400
	0.5%	0.02400
minimum	0.0%	0.02400

Moments

Mean	0.15056
Std Dev	0.14969
Std Error Mean	0.03742
Upper 95% Mean	0.23033
Lower 95% Mean	0.07080
N	16.00000
Sum Weights	16.00000

Figure 27 Cumulative Variable Influence Contribution (VIC) on Abrasion Resistance

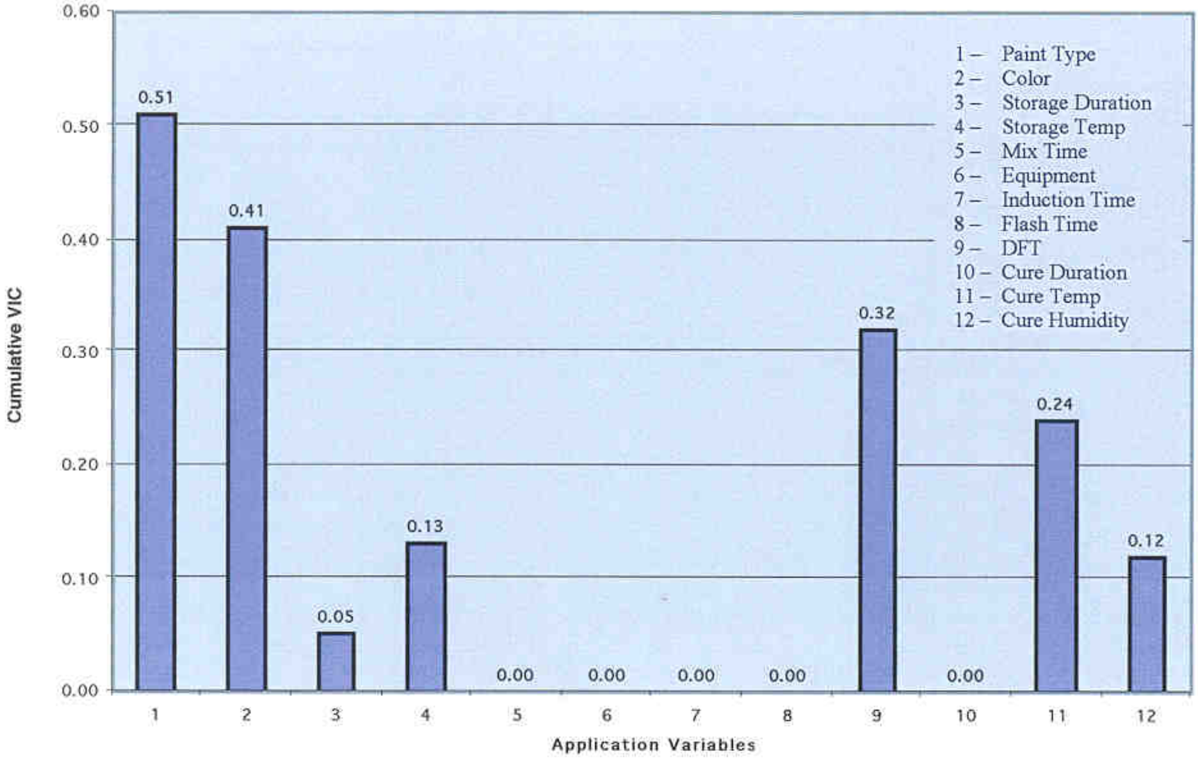
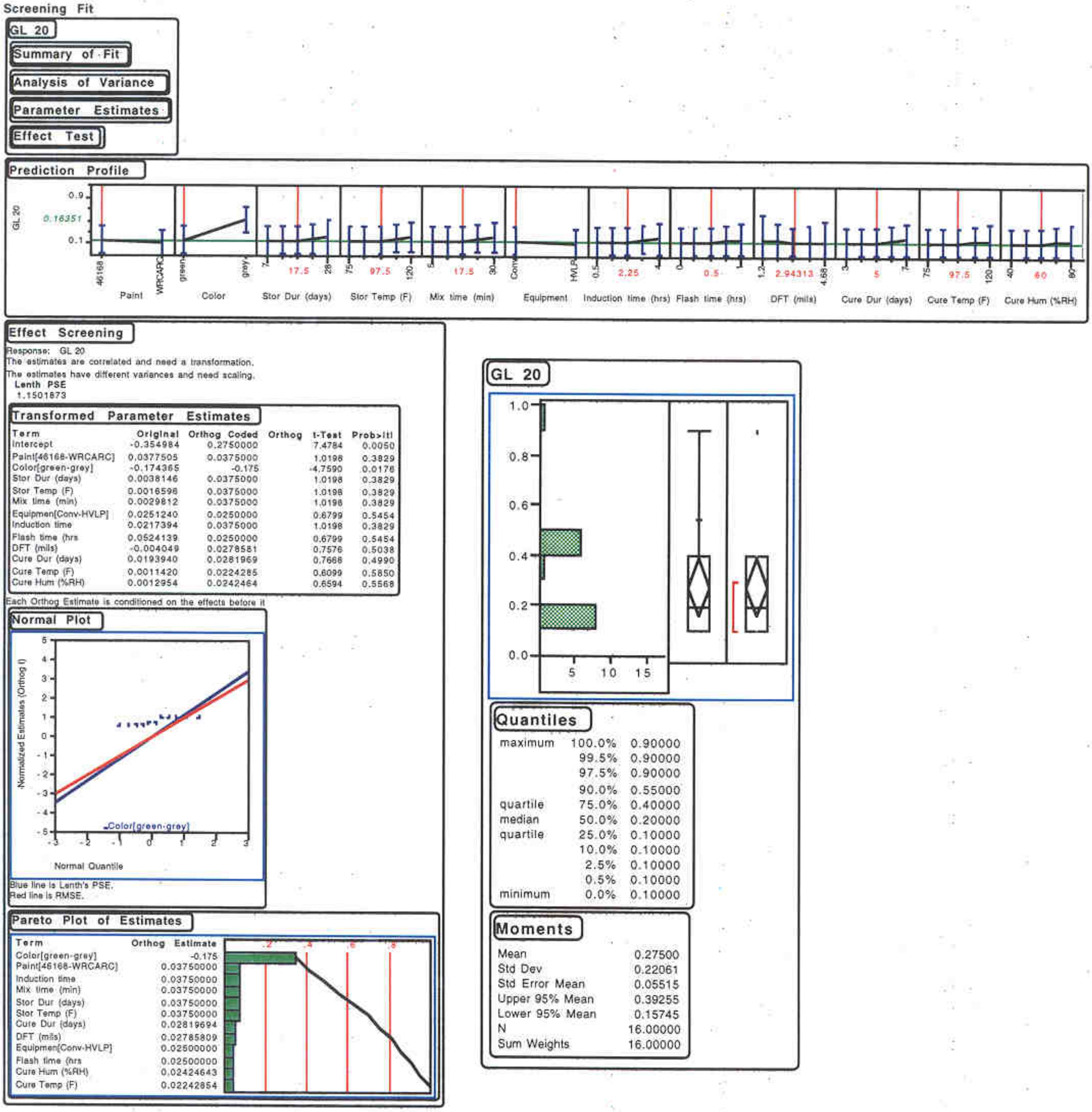


Figure 28 Distribution of data and DOE analysis for Gloss 20°



Screening Fit

GL 20

Summary of Fit

Analysis of Variance

Parameter Estimates

Effect Test

Prediction Profile

Effect Screening

Response: GL 20
The estimates are correlated and need a transformation.
The estimates have different variances and need scaling.

Lenth PSE
1.1501873

Transformed Parameter Estimates

Term	Original	Orthog Coded	Orthog	t-Test	Prob>|t|
Intercept	-0.354984	0.2750000		7.4784	0.0050
Paint[46168-WRCARC]	0.0377505	0.0375000		1.0198	0.3829
Color[green-grey]	-0.174365	-0.175		-4.7590	0.0176
Stor Dur (days)	0.0038146	0.0375000		1.0198	0.3829
Stor Temp (F)	0.0016598	0.0375000		1.0198	0.3829
Mix time (min)	0.0029812	0.0375000		1.0198	0.3829
Equipmen[Conv-HVLP]	0.0251240	0.0250000		0.6799	0.5454
Induction time	0.0217394	0.0375000		1.0198	0.3829
Flash time (hrs	0.0524139	0.0250000		0.6799	0.5454
DFT (mils)	-0.004049	0.0278581		0.7576	0.5038
Cure Dur (days)	0.0193940	0.0281969		0.7666	0.4990
Cure Temp (F)	0.0011420	0.0224285		0.6099	0.5850
Cure Hum (%RH)	0.0012954	0.0242464		0.6594	0.5568

Each Orthog Estimate is conditioned on the effects before it

Normal Plot

Blue line is Lenth's PSE.
Red line is RMSE.

Pareto Plot of Estimates

Term	Orthog Estimate
Color[green-grey]	-0.175
Paint[46168-WRCARC]	0.03750000
Induction time	0.03750000
Mix time (min)	0.03750000
Stor Dur (days)	0.03750000
Stor Temp (F)	0.03750000
Cure Dur (days)	0.02819694
DFT (mils)	0.02785809
Equipmen[Conv-HVLP]	0.02500000
Flash time (hrs	0.02500000
Cure Hum (%RH)	0.02424643
Cure Temp (F)	0.02242854

GL 20

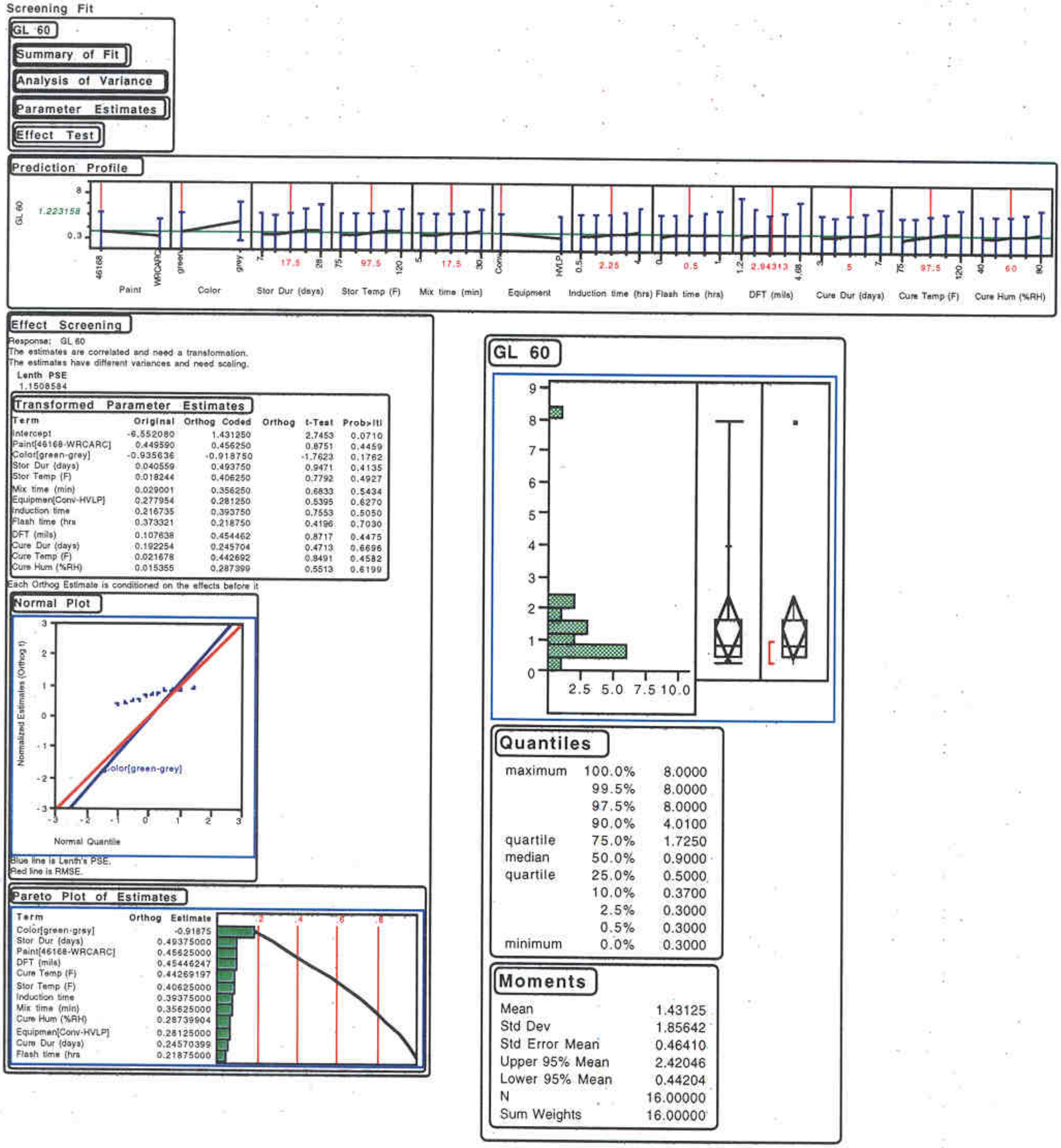
Quantiles

maximum	100.0%	0.90000
	99.5%	0.90000
	97.5%	0.90000
	90.0%	0.55000
quartile	75.0%	0.40000
median	50.0%	0.20000
quartile	25.0%	0.10000
	10.0%	0.10000
	2.5%	0.10000
	0.5%	0.10000
minimum	0.0%	0.10000

Moments

Mean	0.27500
Std Dev	0.22061
Std Error Mean	0.05515
Upper 95% Mean	0.39255
Lower 95% Mean	0.15745
N	16.00000
Sum Weights	16.00000

Figure 29 Distribution of data and DOE analysis for Gloss 60°



Effect Screening

Response: GL 60
The estimates are correlated and need a transformation.
The estimates have different variances and need scaling.

Lenth PSE
1.1508584

Transformed Parameter Estimates

Term	Original	Orthog Coded	Orthog	t-Test	Prob>|t|
Intercept	-6.552080	1.431250		2.7453	0.0710
Paint[46168-WRCARC]	0.449590	0.456250		0.8751	0.4459
Color[green-grey]	-0.935636	-0.918750		-1.7623	0.1762
Stor Dur (days)	0.040559	0.493750		0.9471	0.4135
Stor Temp (F)	0.018244	0.406250		0.7792	0.4927
Mix time (min)	0.029001	0.356250		0.6833	0.5434
Equipmen[Conv-HVLP]	0.277954	0.281250		0.5395	0.6270
Induction time	0.216735	0.393750		0.7553	0.5050
Flash time (hrs	0.373321	0.218750		0.4196	0.7030
DFT (mils)	0.107638	0.454462		0.8717	0.4475
Cure Dur (days)	0.192254	0.245704		0.4713	0.6696
Cure Temp (F)	0.021678	0.442692		0.8491	0.4582
Cure Hum (%RH)	0.015355	0.287399		0.5513	0.6199

Each Orthog Estimate is conditioned on the effects before it

Blue line is Lenth's PSE.
Red line is RMSE.

Pareto Plot of Estimates

Term	Orthog Estimate
Color[green-grey]	-0.91875
Stor Dur (days)	0.49375000
Paint[46168-WRCARC]	0.45625000
DFT (mils)	0.45446247
Cure Temp (F)	0.44269197
Stor Temp (F)	0.40625000
Induction time	0.39375000
Mix time (min)	0.35625000
Cure Hum (%RH)	0.28739904
Equipmen[Conv-HVLP]	0.28125000
Cure Dur (days)	0.24570399
Flash time (hrs	0.21875000

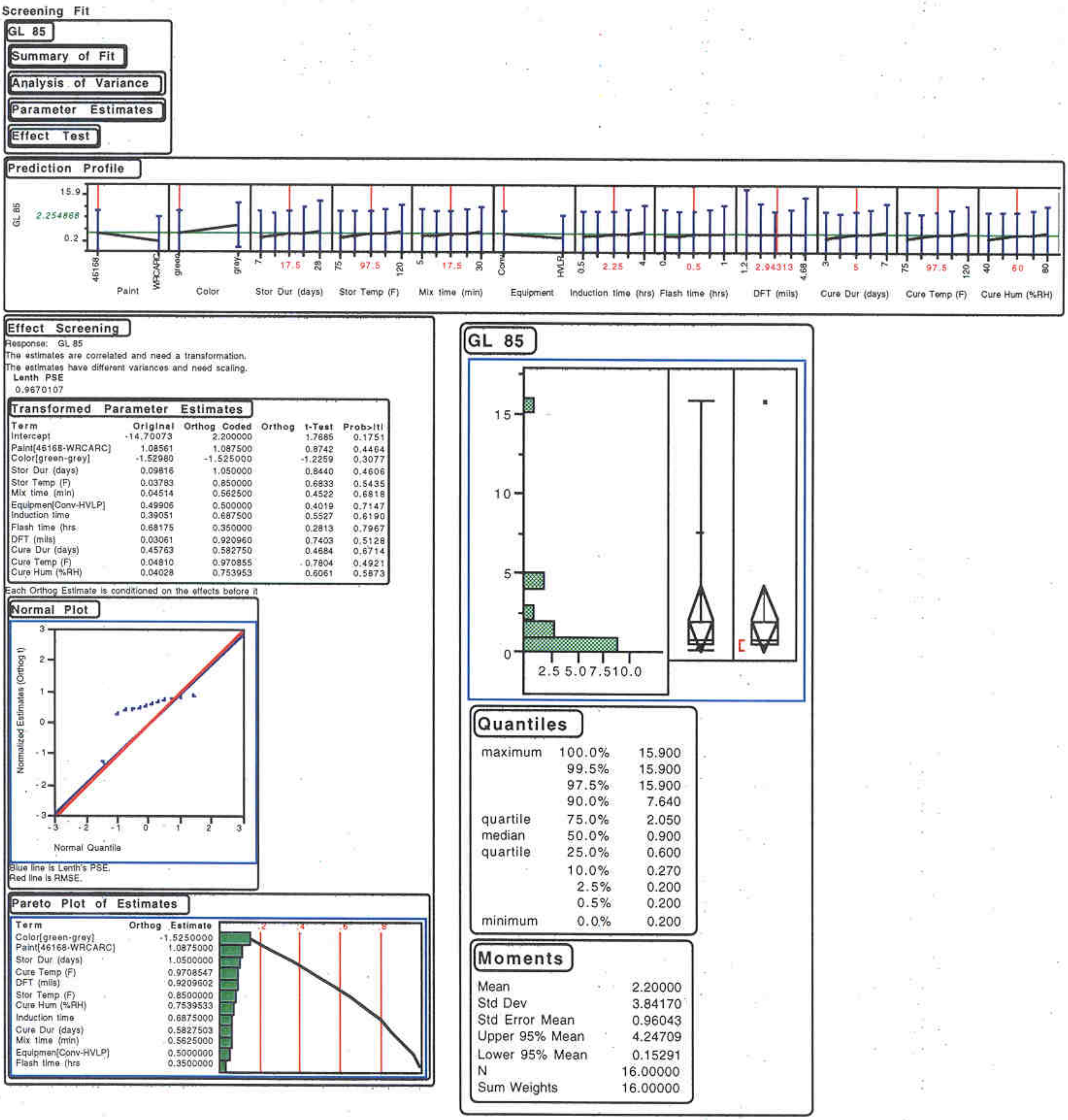
Quantiles

maximum	100.0%	8.0000
	99.5%	8.0000
	97.5%	8.0000
	90.0%	4.0100
quartile	75.0%	1.7250
median	50.0%	0.9000
quartile	25.0%	0.5000
	10.0%	0.3700
	2.5%	0.3000
	0.5%	0.3000
minimum	0.0%	0.3000

Moments

Mean	1.43125
Std Dev	1.85642
Std Error Mean	0.46410
Upper 95% Mean	2.42046
Lower 95% Mean	0.44204
N	16.00000
Sum Weights	16.00000

Figure 30 Distribution of data and DOE analysis for Gloss 80°



Response: GL 85
The estimates are correlated and need a transformation.
The estimates have different variances and need scaling.
Lenth PSE
0.9670107

Transformed Parameter Estimates

Term	Original	Orthog Coded	Orthog	t-Test	Prob>|t|
Intercept	-14.70073	2.200000		1.7685	0.1751
Paint[46168-WRCARC]	1.08561	1.087500		0.8742	0.4464
Color[green-grey]	-1.52980	-1.525000		-1.2259	0.3077
Stor Dur (days)	0.09816	1.050000		0.8440	0.4606
Stor Temp (F)	0.03783	0.850000		0.6833	0.5435
Mix time (min)	0.04514	0.562500		0.4522	0.6818
Equipmen[Conv-HVLP]	0.49906	0.500000		0.4019	0.7147
Induction time	0.39051	0.687500		0.5527	0.6190
Flash time (hrs	0.68175	0.350000		0.2813	0.7967
DFT (mils)	0.03061	0.920960		0.7403	0.5128
Cure Dur (days)	0.45763	0.582750		0.4684	0.6714
Cure Temp (F)	0.04810	0.970855		0.7804	0.4921
Cure Hum (%RH)	0.04028	0.753953		0.6061	0.5873

Each Orthog Estimate is conditioned on the effects before it

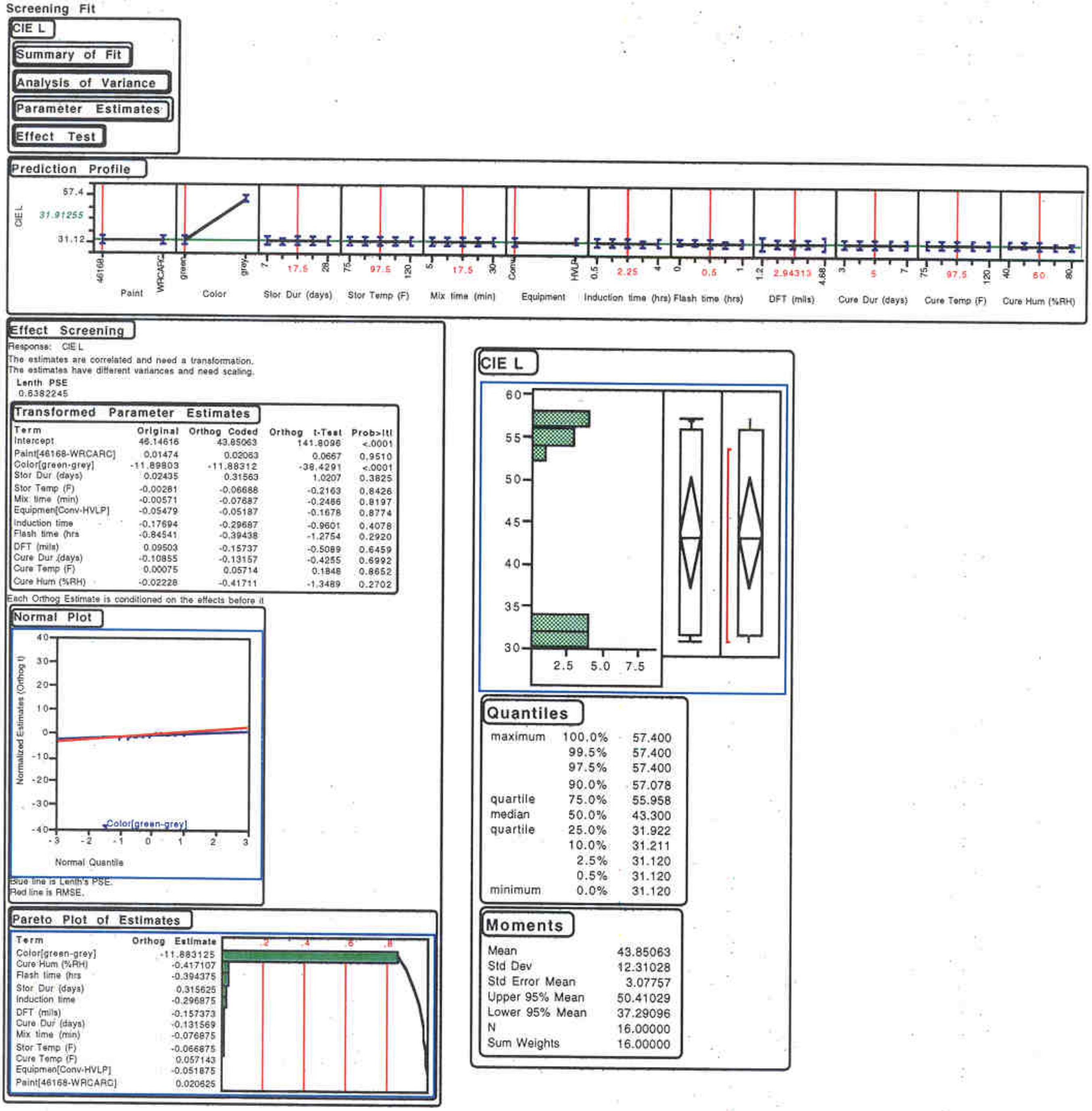
Blue line is Lenth's PSE.
Red line is RMSE.

Term	Orthog Estimate
Color[green-grey]	-1.5250000
Paint[46168-WRCARC]	1.0875000
Stor Dur (days)	1.0500000
Cure Temp (F)	0.9708547
DFT (mils)	0.9209602
Stor Temp (F)	0.8500000
Cure Hum (%RH)	0.7539533
Induction time	0.6875000
Cure Dur (days)	0.5827503
Mix time (min)	0.5625000
Equipmen[Conv-HVLP]	0.5000000
Flash time (hrs	0.3500000

maximum	100.0%	15.900
	99.5%	15.900
	97.5%	15.900
	90.0%	7.640
quartile	75.0%	2.050
median	50.0%	0.900
quartile	25.0%	0.600
	10.0%	0.270
	2.5%	0.200
	0.5%	0.200
minimum	0.0%	0.200

Mean	2.20000
Std Dev	3.84170
Std Error Mean	0.96043
Upper 95% Mean	4.24709
Lower 95% Mean	0.15291
N	16.00000
Sum Weights	16.00000

Figure 31 Distribution of data and DOE analysis for CIE-L



Effect Screening

Response: CIE L

The estimates are correlated and need a transformation.
The estimates have different variances and need scaling.

Lenth PSE
0.6382245

Transformed Parameter Estimates

Term	Original	Orthog Coded	Orthog t-Test	Prob>|t|
Intercept	46.14616	43.85063	141.8096	<.0001
Paint[46168-WRCARC]	0.01474	0.02063	0.0667	0.9510
Color[green-grey]	-11.89803	-11.88312	-38.4291	<.0001
Stor Dur (days)	0.02435	0.31563	1.0207	0.3825
Stor Temp (F)	-0.00281	-0.06688	-0.2163	0.8426
Mix time (min)	-0.00571	-0.07687	-0.2486	0.8197
Equipmen[Conv-HVLP]	-0.05479	-0.05187	-0.1678	0.8774
Induction time	-0.17694	-0.29687	-0.9601	0.4078
Flash time (hrs	-0.84541	-0.39438	-1.2754	0.2920
DFT (mils)	0.09503	-0.15737	-0.5089	0.6459
Cure Dur (days)	-0.10855	-0.13157	-0.4255	0.6992
Cure Temp (F)	0.00075	0.05714	0.1848	0.8652
Cure Hum (%RH)	-0.02228	-0.41711	-1.3489	0.2702

Each Orthog Estimate is conditioned on the effects before it

Blue line is Lenth's PSE.
Red line is RMSE.

Pareto Plot of Estimates

Term	Orthog Estimate
Color[green-grey]	-11.883125
Cure Hum (%RH)	-0.417107
Flash time (hrs	-0.394375
Stor Dur (days)	0.315625
Induction time	-0.296875
DFT (mils)	-0.157373
Cure Dur (days)	-0.131569
Mix time (min)	-0.076875
Stor Temp (F)	-0.066875
Cure Temp (F)	0.057143
Equipmen[Conv-HVLP]	-0.051875
Paint[46168-WRCARC]	0.020625

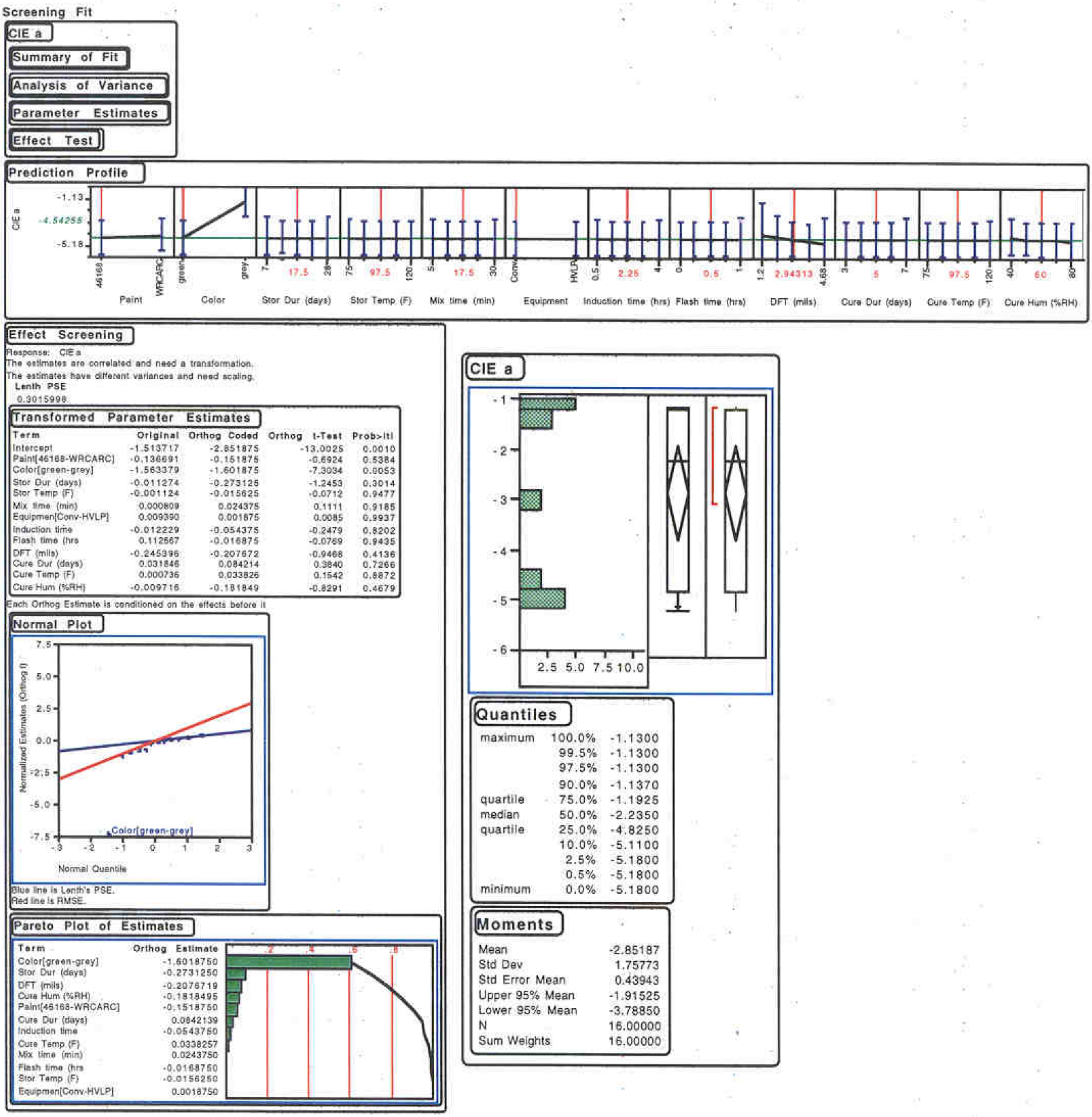
Quantiles

maximum	100.0%	57.400
	99.5%	57.400
	97.5%	57.400
	90.0%	57.078
quartile	75.0%	55.958
median	50.0%	43.300
quartile	25.0%	31.922
	10.0%	31.211
	2.5%	31.120
	0.5%	31.120
minimum	0.0%	31.120

Moments

Mean	43.85063
Std Dev	12.31028
Std Error Mean	3.07757
Upper 95% Mean	50.41029
Lower 95% Mean	37.29096
N	16.00000
Sum Weights	16.00000

Figure 32 Distribution of data and DOE analysis for CIE-a



Effect Screening

Response: CIE a

The estimates are correlated and need a transformation.

The estimates have different variances and need scaling.

Lenth PSE

0.3015998

Transformed Parameter Estimates

Term	Original	Orthog Coded	Orthog t-Test	Prob>|t|
Intercept	-1.513717	-2.851875	-13.0025	0.0010
Paint[46168-WRCARC]	-0.136691	-0.151875	-0.6924	0.5384
Color[green-grey]	-1.563379	-1.601875	-7.3034	0.0053
Stor Dur (days)	-0.011274	-0.273125	-1.2453	0.3014
Stor Temp (F)	-0.001124	-0.015625	-0.0712	0.9477
Mix time (min)	0.000809	0.024375	0.1111	0.9185
Equipmen[Conv-HVLP]	0.009390	0.001875	0.0085	0.9937
Induction time	-0.012229	-0.054375	-0.2479	0.8202
Flash time (hrs	0.112567	-0.016875	-0.0769	0.9435
DFT (mils)	-0.245396	-0.207672	-0.9468	0.4136
Cure Dur (days)	0.031846	0.084214	0.3840	0.7266
Cure Temp (F)	0.000736	0.033826	0.1542	0.8872
Cure Hum (%RH)	-0.009716	-0.181849	-0.8291	0.4679

Each Orthog Estimate is conditioned on the effects before it

Blue line is Lenth's PSE.

Red line is RMSE.

Pareto Plot of Estimates

Term	Orthog Estimate
Color[green-grey]	-1.6018750
Stor Dur (days)	-0.2731250
DFT (mils)	-0.2076719
Cure Hum (%RH)	-0.1818495
Paint[46168-WRCARC]	-0.1518750
Cure Dur (days)	0.0842139
Induction time	-0.0543750
Cure Temp (F)	0.0338257
Mix time (min)	0.0243750
Flash time (hrs	-0.0168750
Stor Temp (F)	-0.0156250
Equipmen[Conv-HVLP]	0.0018750

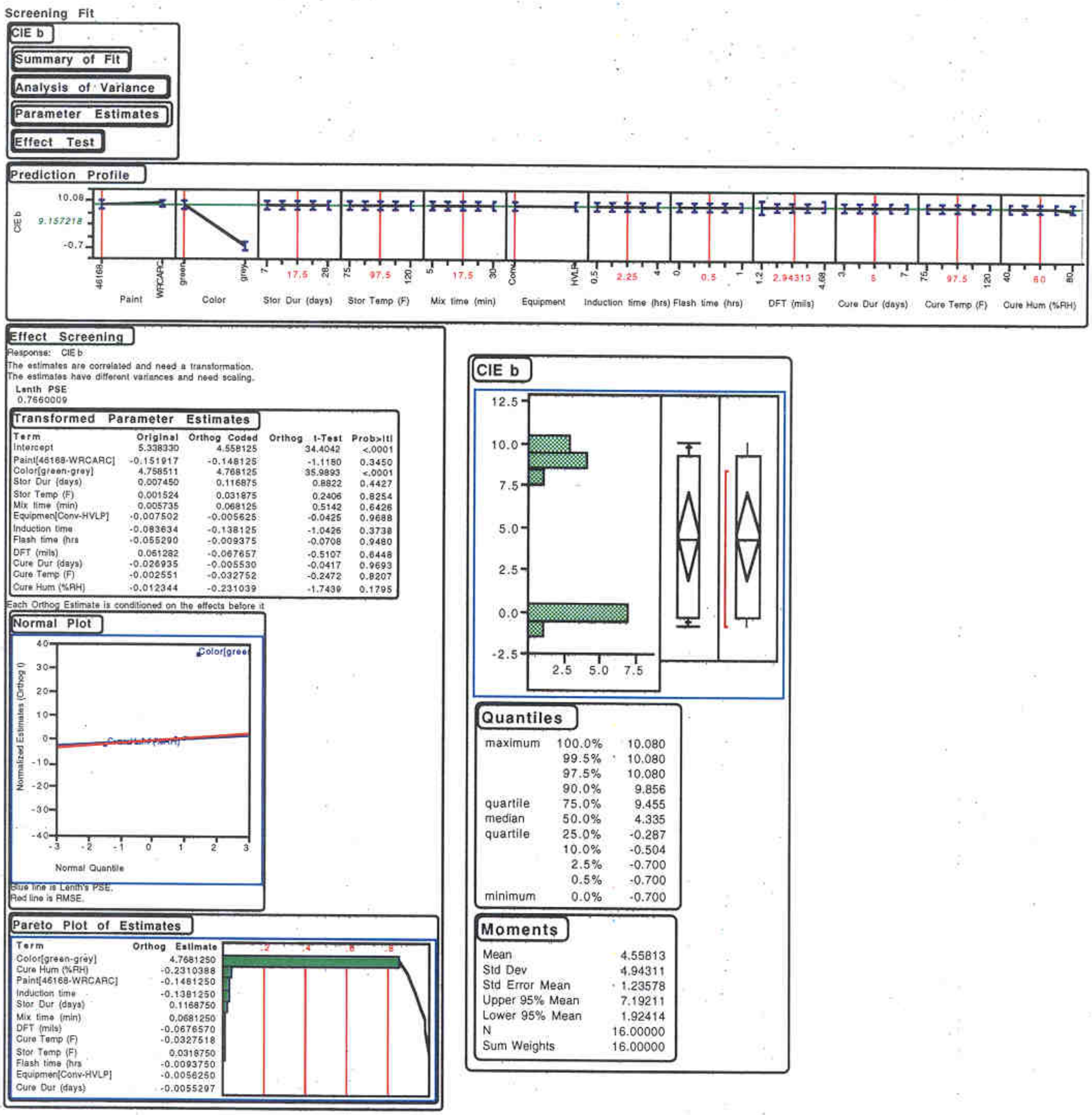
Quantiles

maximum	100.0%	-1.1300
	99.5%	-1.1300
	97.5%	-1.1300
	90.0%	-1.1370
quartile	75.0%	-1.1925
median	50.0%	-2.2350
quartile	25.0%	-4.8250
	10.0%	-5.1100
	2.5%	-5.1800
	0.5%	-5.1800
minimum	0.0%	-5.1800

Moments

Mean	-2.85187
Std Dev	1.75773
Std Error Mean	0.43943
Upper 95% Mean	-1.91525
Lower 95% Mean	-3.78850
N	16.00000
Sum Weights	16.00000

Figure 33 Distribution of data and DOE analysis for CIE-b



Response: CIE b

The estimates are correlated and need a transformation.
The estimates have different variances and need scaling.

Lenth PSE
0.7660009

Transformed Parameter Estimates

Term	Original	Orthog Coded	Orthog t-Test	Prob>|t|
Intercept	5.338330	4.558125	34.4042	<.0001
Paint[46168-WRCARC]	-0.151917	-0.148125	-1.1180	0.3450
Color[green-grey]	4.758511	4.768125	35.9893	<.0001
Stor Dur (days)	0.007450	0.116875	0.8822	0.4427
Stor Temp (F)	0.001524	0.031875	0.2406	0.8254
Mix time (min)	0.005735	0.068125	0.5142	0.6426
Equipmen[Conv-HVLP]	-0.007502	-0.005625	-0.0425	0.9688
Induction time	-0.083634	-0.138125	-1.0426	0.3738
Flash time (hrs	-0.055290	-0.009375	-0.0708	0.9480
DFT (mils)	0.061282	-0.067657	-0.5107	0.6448
Cure Dur (days)	-0.026935	-0.005530	-0.0417	0.9693
Cure Temp (F)	-0.002551	-0.032752	-0.2472	0.8207
Cure Hum (%RH)	-0.012344	-0.231039	-1.7439	0.1795

Each Orthog Estimate is conditioned on the effects before it

Blue line is Lenth's PSE.
Red line is RMSE.

Term	Orthog Estimate
Color[green-grey]	4.7681250
Cure Hum (%RH)	-0.2310388
Paint[46168-WRCARC]	-0.1481250
Induction time	-0.1381250
Stor Dur (days)	0.1168750
Mix time (min)	0.0681250
DFT (mils)	-0.0676570
Cure Temp (F)	-0.0327518
Stor Temp (F)	0.0318750
Flash time (hrs	-0.0093750
Equipmen[Conv-HVLP]	-0.0056250
Cure Dur (days)	-0.0055297

maximum	100.0%	10.080
	99.5%	10.080
	97.5%	10.080
	90.0%	9.856
quartile	75.0%	9.455
median	50.0%	4.335
quartile	25.0%	-0.287
	10.0%	-0.504
	2.5%	-0.700
	0.5%	-0.700
minimum	0.0%	-0.700

Mean	4.55813
Std Dev	4.94311
Std Error Mean	1.23578
Upper 95% Mean	7.19211
Lower 95% Mean	1.92414
N	16.00000
Sum Weights	16.00000

Figure 34 Cumulative Variable Influence Contribution (VIC) on Color

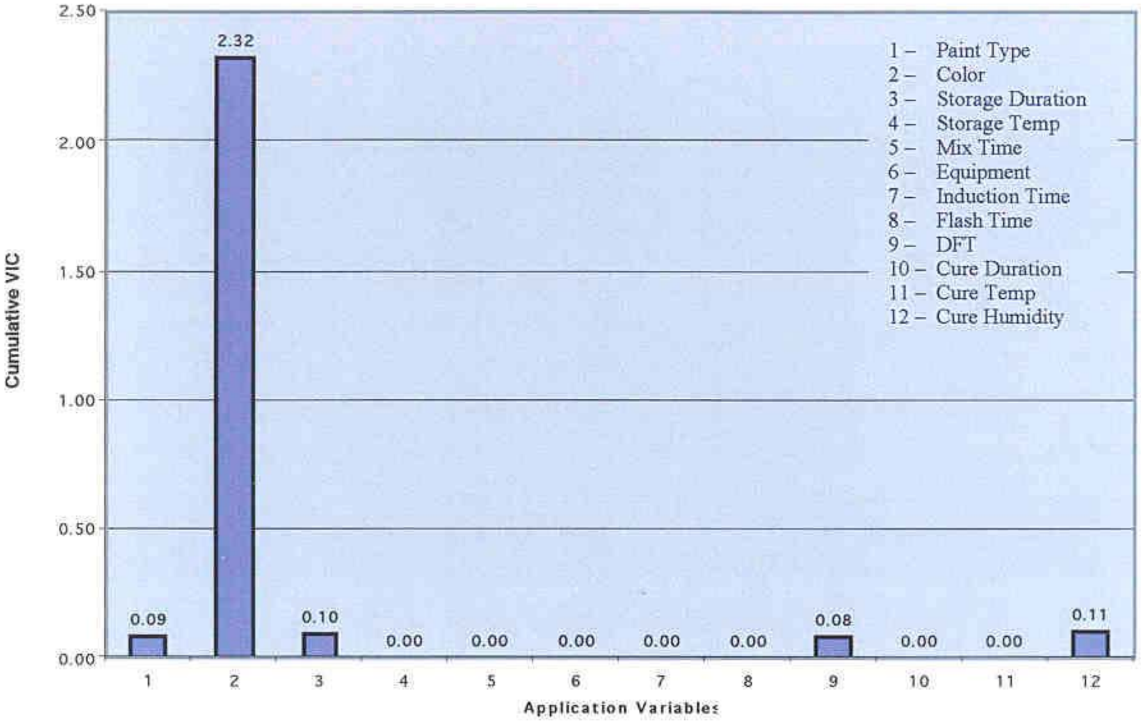


Figure 35 Cumulative Variable Influence Contribution (VIC) on Gloss

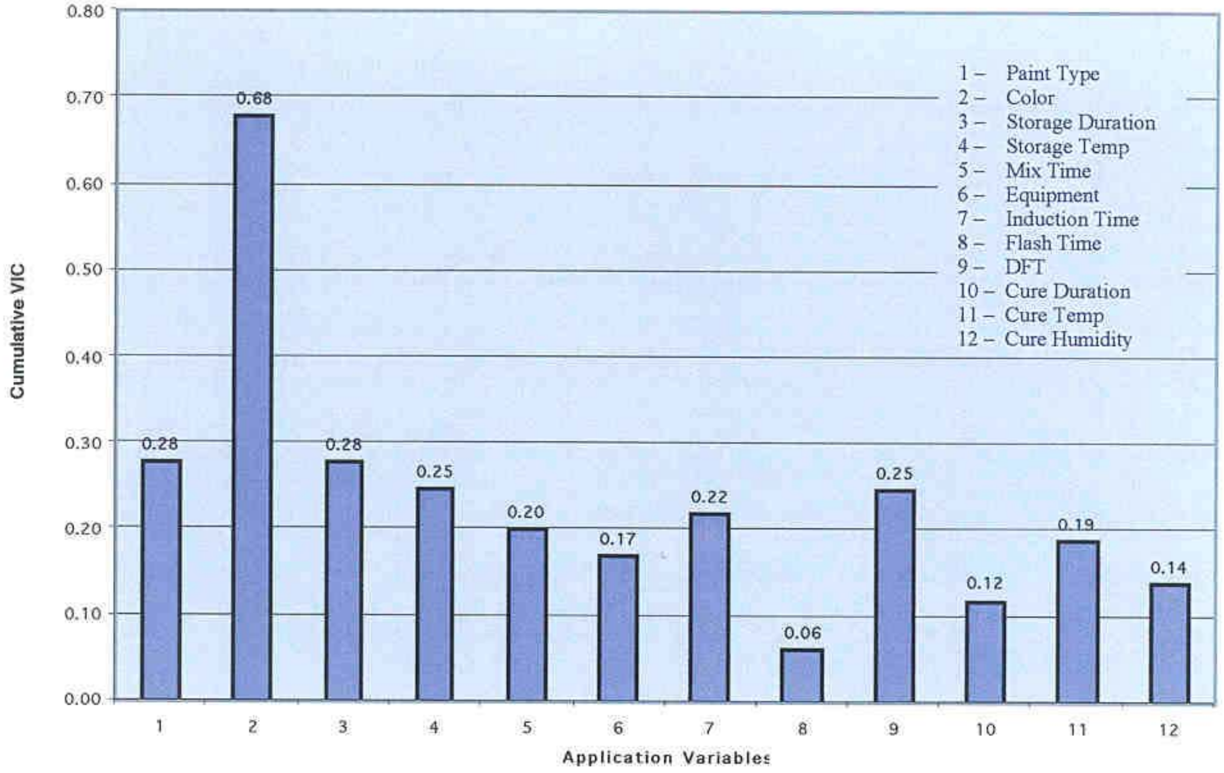


Figure 36 Cumulative Variable Influence Contribution (VIC) on Overall Performance

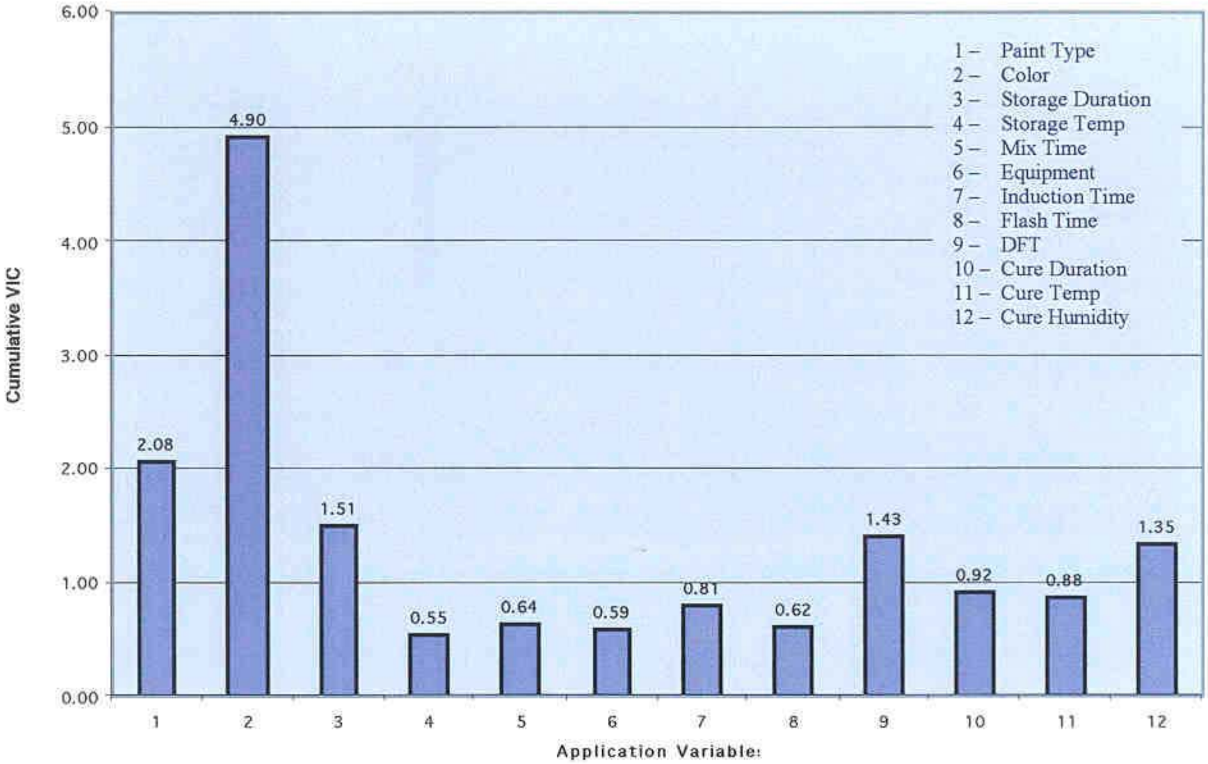


Table 1 Independent Variables with Evaluation Levels and Dependent Variables for DOE Test Matrix

Number	Independent Variable	(+) Level	(-) Level
1	CARC Color	gray (36251)	green (34094)
2	Storage Duration (days)	28	7
3	Storage Temperature (°F)	120	75
4	Paint Shaker Mix Time (min for Component A)	30	5
5	Application Equipment	Conventional	HVLP
6	Induction Time (hrs)	4	0.5
7	Flash Off - Time Between Coats (hrs)	1	0
8	DFT (mils)	4	2
9	Cure Duration (days)	7	3
10	Cure Temperature (°F)	120	75
11	Cure Humidity (% RH)	80	40
12	Paint Type	MIL-C-46168	WRCARC
	Dependent Variable		
1	Dry Tensile Adhesion		
2	Tape Adhesion/Water Resistance		
3	Reverse Impact Resistance		
4	MEK Resistance		
5	Hydraulic Fluid Resistance		
6	Humidity Resistance (100% RH)		
7	Taber Abrasion Resistance		
8	Gloss (20°, 60° and 85°)		
9	GE Impact Flexibility		
10	ΔE Color Match		

Table 2 SERDP Low VOC CARC DOE Experimental Matrix

Row	Pattern	Paint Type	Color	Storage Duration (days)	Storage Temp. (°F)	Mix Time (min)	Eqpt.	Ind Time (min)	Flash Time (hrs)	DFT	Cure Duration (days)	Cure Temp (°F)	Cure Humidity (% Rel)
B1	----+--+-++-	WRCARC	34094	7	75	30	hvlp	30	1	2	7	120	40
B2	---+-++-+---	WRCARC	34094	7	120	5	conv	240	0	4	3	75	40
B3	--+--++--+++	WRCARC	34094	28	75	5	conv	240	0	2	7	120	80
B4	--+++--++--+	WRCARC	34094	28	120	30	hvlp	30	1	4	3	75	80
B5	-+---+-++-++	WRCARC	36521	7	75	5	conv	30	1	4	3	120	80
B6	-+-++-+--+-+	WRCARC	36521	7	120	30	hvlp	240	0	2	7	75	80
B7	-++-+-+-+-+-	WRCARC	36521	28	75	30	hvlp	240	0	4	3	120	40
B8	-+++-+-+-+--	WRCARC	36521	28	120	5	conv	30	1	2	7	75	40
B9	+-----++++-+	46168	34094	7	75	5	hvlp	240	1	4	7	75	80
B10	+--+++----++	46168	34094	7	120	30	conv	30	0	2	3	120	80
B11	+-+-++--++--	46168	34094	28	75	30	conv	30	0	4	7	75	40
B12	+-++--++--+-	46168	34094	28	120	5	hvlp	240	1	2	3	120	40
B13	++--++++----	46168	36521	7	75	30	conv	240	1	2	3	75	40
B14	++-+----+++-	46168	36521	7	120	5	hvlp	30	0	4	7	120	40
B15	+++--------+	46168	36521	28	75	5	hvlp	30	0	2	3	75	80
B16	++++++++++++	46168	36521	28	120	30	conv	240	1	4	7	120	80

Table 3 DOE Total Performance Evaluation of Low VOC CARC

Performance Property	Test	Primed (P) or Unprimed (U)	Range
Adhesion	Tensile (ASTM D4541)	P	0 - 1000 psi
	Dry Tape "A" Method (ASTM D3359/Fed Std 141-6301)	P	0 - 5
	Wet Tape (2 hr/RT) (ASTM D3359/Fed Std 141-6301)	P	0 - 5
	Wet Tape (4d/120°F) (ASTM D3359/Fed Std 141-6301)	P	0 - 5
	Wet Tape (7d/150°F) (ASTM D3359/Fed Std 141-6301)	P	0 - 5
Fluid/Corrosion Resistance	H2O Resistance (24hr/RT) (TTP-2756)	P	0 - 100% blister
	H2O Resistance (4d/120°F) (TTP-2756)	P	0 - 100% blister
	H2O Resistance (7d/150°F) (TTP-2756)	P	0 - 100% blister
	Humidity Resistance (28d/100%RH/120°F) (ASTM D2247)	P	0 - 100% blister
	23699 Oil Resistance (24hr/250°F) (MIL-C-85285)	P	0 - 100% blister
	MEK Resistance (25 double rubs) (MIL-C-85285)	P	0 - 25 double rubs
Flexibility or Mechanical	Gardner Reverse Impact Test (ASTM D2794)	U	0 - 80 inch-lbs.
	Gardner Reverse Impact Test (ASTM D2794)	P	0 - 80 inch-lbs.
	GE Impact Test (Fed Std 141-6226)	U	0 - 60%
	GE Impact Test (Fed Std 141-6226)	P	0 - 60%
	Taber Abrasion (ASTM D6037)	P	0 - 750 mg
Optical	20° Gloss (ASTM D523)	N/A	unitless
	60° Gloss (ASTM D523)	N/A	unitless
	85° Gloss (ASTM D523)	N/A	unitless
	Color Match (ΔE) (ASTM D2244)	N/A	unitless

Table 4 Non-Film Properties

	WRCARC (GREEN)			WRCARC (GRAY)		
	PART A	**PART B**	**ADMIXED**	**PART A**	**PART B**	**ADMIXED**
Wt% Solids (1 hr @ 110°C)	47	75.41	42.88	44.45	75.41	41.02
Vol% Solids (Manuf Data on Components)	34.6	69.3	34.63	34.4	69.3	34.53
Wet Density (lb/gal cup)	10.21	9.02	9.46	9.74	9.02	9.27
Fineness of Dispersion (Hegman Scale, 0-8)	2.5	n/a	n/a	2.5	n/a	n/a
Flash Point (via Pensky-Martens Closed Cup)	>212	144	n/a	>212	144	n/a
Viscosity (Admix), Ford #4 (sec)	n/a	n/a	27	n/a	n/a	24
Pot Life (1 hr), Ford #4 (sec)	n/a	n/a	30.5	n/a	n/a	25.5
Pot Life (2 hr), Ford #4 (sec)	n/a	n/a	31.5	n/a	n/a	26
Pot Life (3 hr), Ford #4 (sec)	n/a	n/a	34.5	n/a	n/a	n/a
Pot Life (4 hr), Ford #4 (sec)	n/a	n/a	45	n/a	n/a	25
Pot Life (5 hr), Ford #4 (sec)	n/a	n/a	n/a	n/a	n/a	n/a
Pot Life (6 hr), Ford #4 (sec)	n/a	n/a	84	n/a	n/a	24.5
Accelerated Storage (30d@140°F)	Pass	Pass	n/a	Pass	Pass	n/a
Accelerated Storage (Ford#4 @ 0, 1, 2 hr)	n/a	n/a	29, 41.5, 57	n/a	n/a	27, 33.5, 36
Freeze Thaw (4 cycle / 16hr@10°F+8hr@72°F)	Pass	Pass	n/a	Pass	Pass	n/a
Freeze Thaw (Ford#4@0,1,2hr)	n/a	n/a	28.5, 33, 35	n/a	n/a	31.5, 40, 44

Table 5 Application Evaluation of WRCARC (34094)

Test Designation	Substrate	No. of Passes	TC WFT (mils)*	TC DFT (mils)*	Film Formation
A7 - 1	1010 CRS	1	2	0.67 ± 0.11	Uniform
A7 - 2	1010 CRS	2	4	1.04 ± 0.20	Uniform
A7 - 3	1010 CRS	3	5	1.59 ± 0.34	Uniform
A7 - 4	1010 CRS	4	7	2.03 ± 0.25	Sag**
A7 - 5	1010 CRS	5	9	2.40 ± 0.36	Sag**
A7 - 6	1010 CRS	6	11	2.36 ± 0.44	Gross Sag***
A11 - 1	1010 CRS w/MIL-P-53022	1	2	0.77 ± 0.15	Uniform
A11 - 2	1010 CRS w/MIL-P-53022	2	4	1.31 ± 0.30	Sag**
A11 - 3	1010 CRS w/MIL-P-53022	3	6	1.43± 0.31	Gross Sag***

*Note: TC WFT = estimated topcoat wet film thickness; TC DFT = topcoat dry film thickness
**Note: Sag noticed during drying but unnoticeable in cured film
***Note: Gross sag noticed during drying and after cure

Table 6 Property Effects of Mix Procedure/Induction Time

	I	II	III	IV
Topcoat	WRCARC(34094)	WRCARC(34094)	WRCARC(34094)	WRCARC(34094)
Mix Procedure (A : B : H_2O)	2:1(mix):1(mix)	2:1(mix):1(mix)	2:1:1(mix)	2:1:1(mix)
Induction Time (hr)	0	2 hr	0	2 hr
Primer	None	None	None	None
Pretreatment	None	None	None	None
Substrate	1010 CRS	1010 CRS	1010 CRS	1010 CRS
Application Characteristics				
(Flow from gun, film formation)	wet, uniform	wet, uniform	sputtered, mottled	sputtered, mottled
Cured Film Appearance	smooth	smooth	textured, porous	textured, porous
Color (CIELAB, D65 Illum, 10° Obs)				
L*	31.1	31.32	30.3	30.27
a*	-2.82	-2.9	-1.46	-2.02
b*	9.95	9.68	10.46	9.96
Color Change (ΔE)				
Mix Procedure (I vs. III)	n/a	n/a	1.66	n/a
Mix Procedure (II vs. IV)	n/a	n/a	n/a	1.4
Induction Time (I vs. II)	n/a	0.36	n/a	n/a
Induction Time (III vs. IV)	n/a	n/a	n/a	0.75
Gloss				
20°	0.1	0.1	0.2	0.1
60°	0.5	0.5	0.5	0.6
85°	1	1	0.7	0.9
Taber Abrsn (H-10, 750 rev, 500g)				
wt. loss (mg)	106 ± 45	134 ± 33	107 ± 18	142 ± 14
DFT loss (mils)	1.05 ± 0.49	1.35 ± 0.07	1.75 ± 0.21	2.05 ± 0.21

Table 7 Post Application Paint Properties

	WRCARC		MIL-C-46168		MIL-C-29475 (note 1)
	34094	36251	34094	36251	34094
Sag Resistance (Horizontal Anti-Sag Index)	1.77	1.35	8.8	2.9	4.65
Vol% Solids (Manuf Data on Components)	34.63	34.53	52.6	51	41.9
HASI Estimated Single Application DFT (mils)	0.61	0.47	4.63	1.48	1.95
Set To Touch (hr)	0.5	n/a	n/a	n/a	n/a
Dry To Touch (hr)	2.5	n/a	n/a	n/a	n/a
Dry Hard (hr)	4.5	n/a	n/a	n/a	n/a
Dry Through / Dry To Handle (hr)	> 7	n/a	n/a	n/a	n/a
Color (CIELAB, D65 Illum, 10° Obs)					
L*	31.67	54.4	33.43	55.53	32.75
a*	-2.94	-1.47	-5.06	-1.16	-5.23
b*	9.25	0.05	9.83	-0.14	10.27
ΔE (note 2,3)	4.32	0.23	2.14	1.48	2.94
Gloss					
20°	0.1	0.4	0.1	0.2	0.1
60°	0.5	1.1	0.6	1.4	0.6
85°	1.1	1.1	0.5	1.6	1.9
Holiday Presence (2, 3 mils without primer)	positive	n/a	positive	n/a	positive

note 1: dry film thickness was 1.2 mils for optical tests
note 2: FED-STD-595 (34094): L* = 35.22, a* = -5.33, b* = 8.68
note 3: FED-STD-595 (36251): L* = 54.19, a* = -1.47, b* = 0.15

Table 8 Cured Film Paint Properties

Topcoat	WRCARC (34094)	WRCARC (34094)	WRCARC (34094)	WRCARC (34094)	WRCARC (34094)	WRCARC (34094)
Primer	none	MIL-P-53022	MIL-P-53022	MIL-P-53022	none	MIL-P-53022
Pretreatment	none	none	TT-C-490	MIL-C-5541	MIL-A-8625	MIL-A-8625
Substrate	1010 CRS	1010 CRS	1010 CRS	2024 T3 Alclad	2024 T0	2024 T0
Adhesion						
Tensile (psi)	467 ± 14	609 ± 10	500 ± 33	709 ± 122	n/a	n/a
Dry Tape "A" method (0A-5A)	4A (Pass)	4A (Pass)	4A (Pass)	4A (Pass)	n/a	n/a
Wet Tape (24 hr/ RT) (0A-5A)	0A (Fail)	4A (Pass)	4.5A (Pass)	4A (Pass)	n/a	n/a
Wet Tape (4d/ 120°F) (0A-5A)	n/a	0A (Fail)	4.5A (Pass)	2.5A (Fail)	n/a	n/a
Wet Tape (7d/ 150°F) (0A-5A)	n/a	0A (Fail)	4.5A (Pass)	3.5A (Fail)	n/a	n/a
Permeation Resistance						
H2O Resistance (24 hr/ RT) (defect free)	Fail	Pass	Pass	Pass	n/a	n/a
H2O Resistance (4 d/ 120°F) (defect free)	n/a	Fail	Pass	Pass	n/a	n/a
H2O Resistance (7 d/ 150°F) (defect free)	n/a	Fail	Pass	Pass	n/a	n/a
Mechanical Properties						
Gardner Direct Impact (0-160 in-lb)	n/a	n/a	n/a	n/a	24	24
Gardner Reverse Impact (0-160 in-lb)	n/a	n/a	n/a	n/a	8	4
GE Impact Flexibility (0-60%)	n/a	n/a	n/a	n/a	10	10
Mandrel Bend (75°F) (no cracks)	n/a	n/a	n/a	n/a	Pass @ 0.25"	Fail @ 0.25"
Mandrel Bend (-60°F) (no cracks)	n/a	n/a	n/a	n/a	Pass @ 1"	Fail @ 1"
Taber Abrsn (H-10, 750 rev, 500g) (wt. loss mg)	96 ± 25	n/a	n/a	n/a	n/a	n/a
Taber Abrsn (H-10, 750 rev, 500g) (DFT loss, mils)	1.3 ± 0.35	n/a	n/a	n/a	n/a	n/a

Note: tensile adhesion data generated on painted metal substrate without being bonded to backing plate

Table 9 Taber Abrasion of WRCARC (34094)

No . of Cycles	Weight Loss (mg)	Cumulative Weight Loss (mg)	Total Thickness Loss (mils)
100	-23	-23	n/a
200	5	-18	n/a
300	3	-15	n/a
400	20	5	n/a
500	10	15	n/a
600	3	18	n/a
700	7	25	n/a
800	9	34	n/a
900	-14	20	n/a
1000	14	34	n/a
1100	-9	25	n/a
1200	13	38	n/a
1300	5	43	n/a
1400	-23	20	n/a
1500	21	41	0.67

Note: CS-17 wheel, 1000-gram weight
Note: final appearance of test area = dulled wear rack

Table 10 Topcoat recoatability data

							Pull-off Adhesion (psi)		**Pull-off adhesion (psi) w.r.t. recoat duration**	
Recoat Duration (hr)	**Primer**	**Topcoat**	**Color**	**DFT (mils) Primer**	**Topcoat**	**Film Defects**	*avgerage*	*Standard deviation*	*avgerage*	*Standard deviation*
2	none	scarc	34094	---	2.4	none	517	101	1155.5	604.6567
2	53022	scarc	34094	1.1	2.5	none	741	414		
2	none	scarc	36251	---	2.6	none	451	137		
2	53022	scarc	36251	1.2	2.5	none	1946	32		
2	none	46168	34094	---	2.7	none	1179	673		
2	53022	46168	34094	1.3	2.7	none	2009	332		
2	none	46168	36251	---	2.5	none	1451	43		
2	53022	46168	36251	1.4	2.3	none	950	112		
24	none	scarc	34094	---	3.8	none	587	36	1063.75	365.0369
24	53022	scarc	34094	1.2	4.3	none	446	54		
24	none	scarc	36251	---	3.5	none	1444	573		
24	53022	scarc	36251	1.2	3.4	none	1240	666		
24	none	46168	34094	---	4.3	none	1271	604		
24	53022	46168	34094	1.5	4.1	none	975	580		
24	none	46168	36251	---	3.6	none	1205	386		
24	53022	46168	36251	1.3	3.4	none	1342	377		
72	none	scarc	34094	---	4	none	497	107	1196.75	479.5783
72	53022	scarc	34094	1.1	4.1	none	785	278		
72	none	scarc	36251	---	3.8	none	1790	94		
72	53022	scarc	36251	1.4	3.4	none	1123	527		
72	none	46168	34094	---	4.2	none	1108	494		
72	53022	46168	34094	1.2	4	none	1872	108		
72	none	46168	36251	---	3.9	none	1454	64		
72	53022	46168	36251	1.4	3.8	none	945	127		
168	none	scarc	34094	---	4.2	none	843	560	1216.25	386.6596
168	53022	scarc	34094	1.2	4.2	none	1274	47		
168	none	scarc	36251	---	3.5	none	1148	478		
168	53022	scarc	36251	1.2	3.6	none	1887	30		
168	none	46168	34094	---	4.3	none	802	484		
168	53022	46168	34094	1.4	4.4	none	1627	402		
168	none	46168	36251	---	5.5	none	1260	210		
168	53022	46168	36251	1.3	4.7	none	889	466		
						average	1158.063			

Note: backing plate used for all tests

Table 11 Primer Compatibility

				DFT (mils)		**3-Day Cure Tensile Adhesion (psi)**		**7-Day Cure Tensile Adhesion (psi)**		
Catalog Number	*Primer*	*Topcoat*	*Color*	*Primer*	*Topcoat*	*Average*	*Standard Deviation*	*Average*	*Standard Deviation*	*Average*
E-1-2A	53022	46168	34094	1	2	2060	124	2665	263	1991.1
E-1-2B	53022	46168	36251	1	1.4	1768	1080	2909	366	
E-2-2A	53030	46168	34094	1.3	2	1992	528	2767	272	
E-3-2A	23377C	46168	34094	1	2	2329	265	2919	333	
E-4-2A	85582N	46168	34094	1.2	2	2176	416	2400	640	
E-5-2A	BR235	46168	34094	3.6	2	1392	466	1993	330	
E-6-2A	26915	46168	34094	1.8	2	1962	814	3256	212	
E-7-2A	2760	46168	34094	1.5	2	1992	589	3245	117	
E-8-2A	2756	46168	34094	1.5	2	2074	483	2746	749	
E-9-2A	bms1011	46168	34094	0.9	2	2166	387	2481	694	
E-1-1A	53022	scarc	34094	1	1.7	2125	626	3041	328	2034.2
E-1-1B	53022	scarc	36251	1	1.9	1096	108	2512	250	
E-2-1A	53030	scarc	34094	1.3	1.7	2543	575	3894	209	
E-3-1A	23377C	scarc	34094	1	1.7	2875	24	3134	1252	
E-4-1A	85582N	scarc	34094	1.2	1.7	2386	143	3160	124	
E-5-1A	BR235	scarc	34094	3.6	1.7	2033	0	1395	85	
E-6-1A	26915	scarc	34094	1.8	1.7	1830	848	2767	528	
E-7-1A	2760	scarc	34094	1.5	1.7	879	193	2980	893	
E-8-1A	2756	scarc	34094	1.5	1.7	2145	449	2991	453	
E-9-1A	bms1011	scarc	34094	0.9	1.7	2430	586	2492	970	
					Average	2012.65		2787.35		

Note: backing plate used for all tests

Table 12 DOE Panel Set Dry Film Thickness Measurements

Panel Set	Storage Duration (days)	Application Equipment	Primer DFT	Topcoat DFT	Target Topcoat DFT	Total System DFT
B1	7	HVLP	1.5	1.9	2	3.4
B2	7	Conventional	1.6	1.7	4	3.3
B3	28	Conventional				0
B4	28	HVLP				0
B5	7	Conventional	1.4	3.3	4	4.7
B6	7	HVLP	1.1	2	2	3.1
B7	28	HVLP				0
B8	28	Conventional				0
B9	7	HVLP	1.2	4.2	4	5.4
B10	7	Conventional	1.3	1.9	2	3.2
B11	28	Conventional				0
B12	28	HVLP				0
B13	7	Conventional	1.4	1.2	2	2.6
B14	7	HVLP	1.1	2.3	4	3.4
B15	28	HVLP				0
B16	28	Conventional				0

Notes:

1. Only panel sets coated with material for 7 days storage reported in this interim report
2. Each reported value is representative of all panels within that set (i.e., all panels within panel set B1 have a primer thickness of 1.5 mil DFT)

Table 13 DOE Performance Test Results

Experimental Set	Tensile Adhesion with Primer	Tensile Adhesion without Primer	Dry Tape Adhesion	Wet Tape Adhesion – 1day/25°C	Wet Tape Adhesion – 4 days/120°C	Wet Tape Adhesion – 7 days/150°C	WR 1 day /RT	WR 4 days /120°C
B1	561	507	4.0	4.0	4.0	4.0	P	P
B2	471	542	4.0	3.5	4.0	4.0	P	P
B3	263	255	4.0	4.0	4.0	4.0	P	P
B4	287	241	4.0	4.0	4.0	3.5	P	P
B5	537	520	4.0	4.0	4.0	4.0	P	P
B6	505	668	4.0	4.0	4.0	4.0	P	P
B7	255	238	4.0	3.0	3.0	3.0	F	F
B8	252	324	3.0	4.0	4.0	4.0	P	P
B9	471	607	5.0	5.0	5.0	5.0	P	P
B10	387	367	5.0	5.0	5.0	5.0	P	P
B11	353	311	4.0	5.0	5.0	5.0	P	P
B12	326	287	4.0	5.0	5.0	5.0	P	P
B13	445	506	3.5	4.0	4.0	3.5	P	P
B14	572	574	3.0	4.0	4.0	3.5	P	P
B15	274	243	4.0	4.0	4.0	4.5	P	P
B16	360	334	4.0	4.0	4.0	4.0	P	P

Experimental Set	WR 7 days /150°C	Oil Resistance	MEK Resistance	RG Impact with Primer (in-lbs)	RG Impact without Primer (in-lbs)	GE Impact with Primer (% flex)	GE Impact without Primer (% flex)	Taber Abrasion – thickness loss (mils)
B1	P	P	100 - P	2	<1	10	5	1.05
B2	P	P	100 - P	16	4	20	10	0.71
B3	P	P	100 - P	1	<1	5	5	0.69
B4	F	P	100 - p	<1	<1	5	5	0.73
B5	P	P	100 - P	2	<1	10	10	0.83
B6	P	P	100 - P	4	<1	10	5	0.90
B7	F	F	100 - P	8	4	10	10	0.31
B8	F	F	100 - P	3	2	10	5	0.78
B9	P	P	100 - P	<1	4	5	20	4.55
B10	P	P	100 - P	<1	8	>=5	10	2.43
B11	P	P	100 - P	3	6	20	10	4.06
B12	P	P	100 - P	1	4	20	20	2.38
B13	P	P	100 - P	<1	<1	10	2	1.51
B14	P	P	100 - P	<1	<1	0.5	0.5	1.10
B15	F	P	100 - P	<1	<1	10	2	0.56
B16	P	P	100 - P	<1	<1	0.5	0.5	0.95

Experimental Set	Taber Abrasion – weight loss (grams)	Gloss 20°	Gloss 60°	Gloss 85°	CIE - L	CIE - a	CIE - b
B1	0.074	0.1	0.5	0.9	31.25	-3.05	9.65
B2	0.061	0.1	0.6	1.1	31.41	-3.15	9.41
B3	0.064	0.1	0.8	1.3	32.17	-5.18	8.90
B4	0.073	0.1	0.5	0.4	31.84	-5.04	9.47
B5	0.071	0.3	1.0	0.9	54.90	-1.41	-0.04
B6	0.066	0.4	1.2	1.1	54.73	-1.42	0.00
B7	0.024	0.4	2.0	2.3	57.40	-1.20	0.00
B8	0.050	0.4	1.2	0.9	56.94	-1.15	0.26
B9	0.499	0.1	0.3	0.2	31.12	-4.72	8.41
B10	0.257	0.1	0.4	0.3	32.81	-4.55	8.93
B11	0.480	0.1	0.5	0.6	32.85	-4.86	10.08
B12	0.282	0.1	0.5	0.6	32.29	-5.08	9.76
B13	0.094	0.4	1.2	0.6	55.56	-1.14	-0.42
B14	0.123	0.4	2.3	4.1	56.50	-1.19	-0.41
B15	0.079	0.4	1.9	4.0	56.09	-1.13	-0.37
B16	0.112	0.9	8.0	15.9	53.75	-1.36	-0.70

Table 14 Summary of VIC for Each Independent Variable on Performance Properties

Performance Property	*Paint Type*	Color	Storage Duration	Storage Temp	Mix Time	Equipment	Induction Time	Flash Time	DFT	Cure Duration	Cure Temp	Cure *Humidity*	Total VIC
Tensile Adhesion with Primer			0.51			0.06		0.05	0.09	0.08	0.05	0.06	**0.90**
Tensile Adhesion without Primer	0.06		0.42				0.07		0.08	0.12	0.08		**0.83**
Dry Tape Adhesion	0.07	0.21		0.07	0.07		0.07		0.10	0.13		0.17	**0.89**
Wet Tape Adhesion 1 day/RT	0.28	0.23					0.08	0.08	0.08	0.05		0.06	**0.86**
Wet Tape Adhesion 4 days/120°	0.26	0.26	0.05	0.05	0.05	0.05	0.05	0.05	0.06		0.07		**0.95**
Wet Tape Adhesion 7 days/150°	0.23	0.23			0.11	0.05	0.05		0.05		0.06	0.10	**0.88**
Cumulative VIC for Adhesion	**0.90**	**0.93**	**0.98**	**0.12**	**0.23**	**0.16**	**0.32**	**0.18**	**0.46**	**0.38**	**0.26**	**0.39**	
WR 1 day /RT	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	**0.00**
WR 4 days/120°	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	**0.00**
WR 7 days/150°	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	**0.00**
Oil Resistance	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	**0.00**
MEK Resistance	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	**0.00**
RG Impact w/Pr	0.17		0.05	0.05		0.06	0.11	0.14		0.08	0.08	0.16	**0.90**
RG Impact w/0 Pr	0.13	0.21			0.05	0.09		0.13	0.07	0.13		0.13	**0.94**
GE Impact w/Pr		0.14	0.05		0.05	0.05	0.05	0.05	0.14	0.08	0.11	0.22	**0.94**
GE Impact w/o Pr		0.21			0.11	0.06	0.11	0.06	0.11	0.13		0.08	**0.87**
Cumulative VIC for Impact Resistance	**0.30**	**0.56**	**0.10**	**0.05**	**0.21**	**0.26**	**0.27**	**0.38**	**0.32**	**0.42**	**0.19**	**0.59**	
Taber Abrasion (*thickness* loss)	0.24	0.20	0.05	0.07					0.14		0.12	0.06	**0.88**
Taber Abrasion (weight loss)	0.27	0.21		0.06					0.18		0.12	0.06	**0.90**
Cumulative VIC for Abrasion Resistance	**0.51**	**0.41**	**0.05**	**0.13**	**0.00**	**0.00**	**0.00**	**0.00**	**0.32**	**0.00**	**0.24**	**0.12**	
	1.71	**1.90**	**1.13**	**0.30**	**0.44**	**0.42**	**0.59**	**0.56**	**1.10**	**0.80**	**0.69**	**1.10**	
Gloss 20°	0.07	0.33	0.07	0.07	0.07	0.06	0.07	0.06	0.06	0.06			**0.92**
Gloss 60°	0.10	0.19	0.10	0.09	0.07	0.06	0.08		0.10		0.09	0.06	**0.94**
Gloss 85°	0.11	0.16	0.11	0.09	0.06	0.05	0.07		0.09	0.06	0.10	0.08	**0.98**
Cumulative VIC for Gloss	**0.28**	**0.68**	**0.28**	**0.25**	**0.20**	**0.17**	**0.22**	**0.06**	**0.25**	**0.12**	**0.19**	**0.14**	
CIE - L		0.86											**0.86**
CIE - a	0.06	0.61	0.10						0.08			0.07	**0.92**
CIE - b	0.03	0.85										0.04	**0.92**
Cumulative VIC for Color	**0.09**	**2.32**	**0.10**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.08**	**0.00**	**0.00**	**0.11**	
Overall Cumulative VIC	**2.08**	**4.90**	**1.51**	**0.55**	**0.64**	**0.59**	**0.81**	**0.62**	**1.43**	**0.92**	**0.88**	**1.35**	

APPENDIX Application Survey of Field Maintenance Units

DOD			**SUBSTRATE**	**APPLICATION EQUIPMENT**		
BR	**SITE**	**TYPE**	**PREPARATION**	**CONVENTIONAL**	**AIRLESS**	**HVLP**
AF	Dover,DE	Al, FG/Ep	SS (no CCC)	n/a	n/a	Airverter
AF	Dyess, TX			n/a	n/a	Airverter
AF	Edwards, CA			n/a	n/a	Bink Mach 1
AF	Eglin, FL	Al, Gr/Ep, B/Ep	SS (all)	(Graco Pro 4500)	Graco	Binks, Kremlin
AF	Fairchild, WA			n/a	n/a	Sharp
AF	Hurlburt, FL	Al, FG/Ep	SS (no CCC)	n/a	n/a	Airverter
AF	Langley, VA			n/a	Graco AA	n/a
AF	Little Rock, AR			n/a	n/a	DeVilbiss
AF	Luke AFB, AZ	Al, Gr/Ep	CCC, n/a	n/a	n/a	SE
AF	McGuire, NJ	Al, Comp	SS (all)	n/a	Graco	Binks
AF	Minot, ND			n/a	n/a	Airverter
AF	Mtn. Home, ID	Al, Gr/Ep, B/Ep	SS (all)	n/a	Graco	Devilbis,Airverter
AF	Nellis, NV			n/a	n/a	Bink Mach 1
AF	OC-ALC, OK	Al, FG/Ep, Gr/Ep	CCC, n/a, n/a	DeVilbiss	n/a	Graco M1265
AF	Offutt, NE			n/a	n/a	Airverter
AF	OO-ALC, UT	Al, Gr/Ep	CCC, n/a	DeVilbiss	n/a	Airverter
AF	Patrick, FL	Al, FG/Ep	SS (all)	n/a	Graco	n/a
AF	SA-ALC, TX	Al, FG/Ep	CCC, n/a	Graco ES Pro 4500sc	n/a	n/a
AF	Seymour Johnson, NC			n/a	n/a	Airverter
AF	SM-ALC, CA	Al, Gr/Ep, B/Ep	CCC, SS, SS	n/a	n/a	Binks
AF	WR-ALC, GA	Al, FG/Ep, Gr/Ep	CCC, n/a, n/a	DeVilbiss	n/a	Airverter
Army	Anniston Depot, AL	Al, St	SS/WHB, SS/abr bl	Binks	n/a	Binks
Army	Corpus Christi Depot, TX	Al,Kvlr/Ep, FG/Ep,steel,Ti,Mg	CCC,n/a,n/a,psvt, anod,dcr	pressure pots/guns	n/a	cup guns
Army	Rock Island Arsnl, IL	Al, St	abr bl(GB)/CF/SAA, abr bl (GB)/ZnP	Binks 2001	n/a	n/a
Army	SDSRR-ME Bldg 0323	Al, St, mixed (shelters)	abr bl/CCC,abr bl/ZnP, SS (all), wpr	DeVilbiss	Graco	n/a
Army	SDSRR-ME Bldg 0333	Al, St	abr bl/CCC, abr bl/ZnP,wpr	DeVilbiss, Graco	Graco	n/a
Army	SDSRR-ME Bldg 0345	Al, St	abr bl/CCC, abr bl/ZnP,wpr	DeVilbiss	n/a	n/a
Army	SDSRR-ME Bldg 0357	Al, St	abr bl/ZnP,wpr	DeVilbiss	Graco	n/a
Army	SDSRR-ME Bldg 0360	Al, St	abr bl/ZnP,wpr	DeVilbiss	Graco	n/a
Army	SDSRR-ME Bldg 0373	Al, St	solvent clean, wpr	DeVilbiss	n/a	n/a

APPENDIX (continued) Application Survey of Field Maintenance Units

DOD			SUBSTRATE		APPLICATION EQUIPMENT	
BR	**SITE**	**TYPE**	**PREPARATION**	**CONVENTIONAL**	**AIRLESS**	**HVLP**
Army	SDSRR-ME Bldg 0407	Al, St	abr bl/CCC,abr bl/ZnP,wpr	DeVilbiss	n/a	n/a
Army	SDSRR-ME Bldg 0591	Al, St	orbital air sand, HS, wire brush	DeVilbiss	n/a	n/a
Army	SDSRR-ME Bldg 0654	Al, St	orbital air sand, HS, abr bl	DeVilbiss	n/a	n/a
Army	SDSRR-ME Bldg 0939	Al, St	orbital air sand, HS, abr bl	DeVilbiss	n/a	n/a
Army	SDSRR-ME Bldg 1116	Al, St	orbital air sand, HS, abr bl	DeVilbiss	n/a	n/a
Army	SDSRR-ME Bldg 1122	Al, St	orbital air sand, HS, abr bl	DeVilbiss	n/a	n/a
Army	SDSRR-ME Bldg 1130	Al, St	orbital air sand, HS, abr bl	DeVilbiss	n/a	n/a
Army	SDSRR-ME Bldg 1163	Al, St	orbital air sand, HS, abr bl	DeVilbiss	n/a	n/a
Army	SDSRR-ME Bldg 1172	Al, St, FG/Ep	orbital air sand, HS, wpr	DeVilbiss	n/a	n/a
Army	Tobyhanna Depot, PA	Al, St, FG/Ep	HS, ZrAlO, abr bl (steel grit)	Graco	n/a	Smith Eastern, Can-Am, DeVilbiss
Army	Watervliet Arsenal, NY	steel, wood, brass		Binks #62	n/a	Binks # Mach I HVLP
MC	Camp Lejeune, NC	Al, St, FG/Ep	orbital air sand, HS, steam cl	n/a	SataModel KL(AAA)	Binks BBR
MC	Camp Pendleton, CA	Al, St, FG/Ep	HS, abr bl	n/a	SataModel KL(AAA)	Binks BBR
MC	Log Base-Albany, GA	Al, St, FG/Ep	orbital air sand, HS, abr bl, steam cl	n/a	SataModel KL(AAA)	Binks BBR
MC	Log Base-Barstow, CA	Al, St, FG/Ep	orbital air sand, HS, abr bl, steam cl	n/a	SataModel KL(AAA)	Binks BBR
MC	Pearl Harbor NSY, HI	Al, St, FG/Ep	HS, abr bl	Binks	Binks, Graco	Binks

APPENDIX (continued) - Application Survey of Field Maintenance Units

DOD BR	SITE	PRIMER	COATING TOPCOAT	MANUFACTURER	PROTECTIVE EQUIPMENT
AF	Dover,DE	Ep (23377?)	PU (85285?)	P&L, Deft	n/a
AF	Dyess, TX				
AF	Edwards, CA				
AF	Eglin, FL	23377	83286	Deft/P&L, Deft	n/a
AF	Fairchild, WA				
AF	Hurlburt, FL	23377	85285	P&L, Deft	n/a
AF	Langley, VA				
AF	Little Rock, AR				
AF	Luke AFB, AZ	Epoxy - 513X423B	85285	Crtd	n/a
AF	McGuire, NJ	Ep (23377?)	PU (85285?)	P&L, Deft	n/a
AF	Minot, ND				
AF	Mtn. Home, ID	23377	85285	n/a	n/a
AF	Nellis, NV				
AF	OC-ALC, OK	23377	85285	Deft; Deft/Crtd	n/a
AF	Offutt, NE				
AF	OO-ALC, UT	2760, BMS-1058, 23377	85285	Crtd,Crtd,Crtd; Deft	n/a
AF	Patrick, FL	23377	85285	Deft, Deft	n/a
AF	SA-ALC, TX	23377, 2760	85285	P&L,Crtd; Deft	n/a
AF	Seymour Johnson, NC				
AF	SM-ALC, CA	23377	85285	Deft; Griggs/Deft	n/a
AF	WR-ALC, GA	23377, 2760	85285, 83286	Deft,Deft; Deft,Deft	n/a
Army	Anniston Depot, AL	53022	22750,46168, TT-P-28, NSN?, dry film?	GSA; GSA,GSA,UNIC,DFI,GSA	ASR,HMR,glove, coverall
Army	Corpus Christi Depot, TX	23377 (T-I)	46168,22750,Ep-phenolic (Synthetesine#200)	Niles, Deft, Devoe	
Army	Rock Island Arsnl, IL	2K epoxy	1K PU (53039?), Ep (22750?)	Sprlt/P&L; Htzn (383); Sprlt/P&L	ASR,glove, coverall
Army	SDSRR-ME Bldg 0323	53022	22750, 46168, 53039	Chemray; Sprlt,Sprlt, Htzn	ASR,glove,coverall, ear plugs
Army	SDSRR-ME Bldg 0333	53022	22750, 46168, 53039	Chemray; Sprlt,Sprlt, Htzn	ASR,glove,coverall, ear plugs
Army	SDSRR-ME Bldg 0345	53022	22750, 46168, 53039	Chemray; Sprlt,Sprlt, Htzn	ASR,glove,coverall, ear plugs
Army	SDSRR-ME Bldg 0357	53022	22750, 46168, 53039	Chemray; Sprlt,Sprlt, Htzn	ASR,glove,coverall, ear plugs
Army	SDSRR-ME Bldg 0360	53022	22750, 46168, 53039	Chemray; Sprlt,Sprlt, Htzn	ASR,glove,coverall, ear plugs
Army	SDSRR-ME Bldg 0373	53022	22750	Chemray; Sprlt	ASR,glove,coverall, ear plugs
Army	SDSRR-ME Bldg 0407	53022	22750, 46168, 53039	Chemray; Sprlt,Sprlt, Htzn	ASR,glove,coverall, ear plugs
Army	SDSRR-ME Bldg 0591	epoxy	polyurethane	Chemray; P&L/Htzn	ASR,HMR,cotn. glove,cvrall,s.shoe
Army	SDSRR-ME Bldg 0654	epoxy	polyurethane	Chemray; P&L/Htzn/Niles	ASR,HMR,cotn. glove,cvrall,s.shoe

APPENDIX (continued) - Application Survey of Field Maintenance Units

DOD BR	COATING SITE	PRIMER	COATING TOPCOAT	MANUFACTURER	PROTECTIVE EQUIPMENT
Army	SDSRR-ME Bldg 0939	epoxy	polyurethane	Chemray; P&L/Htzn/Niles	ASR,HMR,cotn.glove, cvralls, shoe
Army	SDSRR-ME Bldg 1116	epoxy	polyurethane	Chemray; P&L/Htzn/Niles	ASR,HMR,cotn.glove, cvralls, shoe
Army	SDSRR-ME Bldg 1122	epoxy	polyurethane	Chemray; P&L/Htzn/Niles	ASR,HMR,cotn.glove, cvralls, shoe
Army	SDSRR-ME Bldg 1130	epoxy	polyurethane	Chemray; P&L/Htzn/Niles	ASR,HMR,cotn.glove, cvralls, shoe
Army	SDSRR-ME Bldg 1163	epoxy	polyurethane	Chemray; P&L/Htzn/Niles	ASR,HMR,cotn.glove, cvralls, shoe
Army	SDSRR-ME Bldg 1172	red epoxy	Laminar X500, aliphatic polyurethane, enamel	ConLux; DCM,Htzn,Randolph	ASR,HMR,glove, coverall, goggle
Army	Tobyhanna Depot, PA	53030, 53022	22750, 53039, 46168	Deft,Htzn/Niles;Crfd/Htzn, Htzn,Htzn/Niles	ASR,glove,coverall
Army	Watervliet Arsenal, NY	2 part epoxy	CARC (black,tan), alkyd enamel (green)	Htzn; Htnz,P&L	ASR,glove,coverall
MC	Camp Lejeune, NC	53022, 53030	WBCC	Deft/Htzn/Niles; Htzn/Niles/Spectrum/S-W	
MC	Camp Pendleton, CA	53022, 53030	WBCC	Deft/Htzn/Niles; Htzn/Niles/Spectrum/S-W	
MC	Log Base-Albany, GA	53022, 53030	WBCC	Deft/Htzn/Niles; Htzn/Niles/Spectrum/S-W	
MC	Log Base-Barstow, CA	53022, 53030	WBCC	Deft/Htzn/Niles; Htzn/Niles/Spectrum/S-W	
MC	Pearl Harbor NSY, HI	Bar Rust 235	WBCC	Ameron; Htzn/Niles/Spectrum/S-W	

APPENDIX (continued) Application Survey of Field Maintenance Units

DOD BR	SITE	FACILITY LOCATN	HEATING	COOLING	HUMIDITY	VENTING	FILTRN
AF	Dover,DE	indoor	steam	none	wet floor	make-up, open doors	dry/none
AF	Dyess, TX						
AF	Edwards, CA						
AF	Eglin, FL	indoor	yes/none	none	wet floor	make-up, open doors	dry/none
AF	Fairchild, WA						
AF	Hurlburt, FL	indoor	yes/no	none	wet floor	door cross flow, spray booth	none/dry
AF	Langley, VA						
AF	Little Rock, AR						
AF	Luke AFB, AZ	indoor	gas	none	wet floor	yes	dry/none
AF	McGuire, NJ	indoor	steam	none	wet floor	yes	dry
AF	Minot, ND						
AF	Mtn. Home, ID	indoor	gas	none	wet floor	44K cfm	dry?
AF	Nellis, NV						
AF	OC-ALC, OK	indoor	steam	none	wet floor	81K cfm, 43K cfm	dry
AF	Offutt, NE						
AF	OO-ALC, UT	indoor	steam/gas	none	wet floor	yes	wet (small), ?
AF	Patrick, FL	indoor?	???	???	wet floor	fans	???
AF	SA-ALC, TX	indoor	gas	chilled water	wet floor	yes	dry
AF	Seymour Johnson, NC						
AF	SM-ALC, CA	indoor	steam	chilled water	wet floor	466K cfm	dry
AF	WR-ALC, GA	indoor	gas/steam	none/freon	none/wet floor	vent, doors, 125K cfm	dry
Army	Anniston Depot, AL	indoor	yes?	???	???	yes	dry/wet
Army	Corpus Christi Depot, TX						
Army	Rock Island Arsnl, IL	indoor	yes	yes???	none	yes	dry
Army	SDSRR-ME Bldg 0323	indoor	yes	?	?	make-up/exhaust air	dry
Army	SDSRR-ME Bldg 0333	indoor	yes	?	?	make-up/exhaust air	dry
Army	SDSRR-ME Bldg 0345	indoor	yes	?	?	make-up/exhaust air	dry
Army	SDSRR-ME Bldg 0357	indoor	yes	?	?	make-up/exhaust air	dry
Army	SDSRR-ME Bldg 0360	indoor	yes	?	?	make-up/exhaust air	dry
Army	SDSRR-ME Bldg 0373	indoor	yes	?	?	make-up/exhaust air	dry
Army	SDSRR-ME Bldg 0407	indoor	yes	?	?	make-up/exhaust air	dry
Army	SDSRR-ME Bldg 0591	indoor	no	no	no	yes	dry

APPENDIX (continued) Application Survey of Field Maintenance Units

DOD BR	SITE	FACILITY LOCATN	HEATING	COOLING	HUMIDITY	VENTING	FILTRN
Army	SDSRR-ME Bldg 1116	indoor	no	no	no	yes	dry
Army	SDSRR-ME Bldg 1122	indoor	no	no	no	yes	dry
Army	SDSRR-ME Bldg 1130	indoor	no	no	no	yes	dry
Army	SDSRR-ME Bldg 1163	indoor	no	no	no	yes	dry
Army	SDSRR-ME Bldg 1172	indoor	?	?	?	?	?
Army	Tobyhanna Depot, PA	indoor	yes	none	none	down/cross draft, make-up	dry
Army	Watervliet Arsenal, NY	indoor	yes	?	?		dry
MC	Camp Lejeune, NC	indoor	yes	?	?	open doors	dry (comp)
MC	Camp Pendleton, CA	indoor	no	?	?	open doors	dry (comp)
MC	Log Base-Albany, GA	indoor	yes	?	?	open doors	dry (comp)
MC	Log Base-Barstow, CA	indoor	no	?	?	open doors	dry (comp)
MC	Pearl Harbor NSY, HI	indoor	no	?	?	open doors	dry (comp)

APPENDIX (continued) Application Survey of Field Maintenance Units

DOD BR	SITE	NOTES
AF	Dover,DE	20 air cap, 1.4 mm fluid nozzle; 1.4 fluid needle
AF	Dyess, TX	12 air cap, 1.4mm nozzle, 1.4 needle
AF	Edwards, CA	95P air cap, 1.4mm nozzle, 54-3950 needle
AF	Eglin, FL	Graco Pro 4500 info: GG3-307 air cap, 0.9mm nozzle, 0.9 needle
AF	Fairchild, WA	SGF air cap, 63mm nozzle, 63 needle
AF	Hurlburt, FL	
AF	Langley, VA	721 air cap
AF	Little Rock, AR	33 air cap
AF	Luke AFB, AZ	
AF	McGuire, NJ	
AF	Minot, ND	12 air cap, 1.4mm nozzle, 1.4 needle
AF	Mtn. Home, ID	Airverter info: 12 air cap, 1.4mm nozzle, 1.4 needle
AF	Nellis, NV	95P air cap, 1.4mm nozzle, 54-3950 needle
AF	OC-ALC, OK	
AF	Offutt, NE	12 air cap, 1.4mm nozzle, 1.4 needle
AF	OO-ALC, UT	
AF	Patrick, FL	
AF	SA-ALC, TX	depot closing due to BRAC; will move function to OC-ALC
AF	Seymour Johnson, NC	10 air cap, 1.2mm nozzle, 1.2 needle
AF	SM-ALC, CA	strip for overhaul; scuff sand for repair; depot closing due to BRAC; will move function to OO-ALC
AF	WR-ALC, GA	
Army	Anniston Depot, AL	conveyor,drying ovens, 70'x18'x14' booth; conv: 10-30gal, 66 AN, 66/65 FN/N, 35-50psi AP, 3/8"AL&FL; HVLP: 10gal, 92 AN, 91/54-3941 FN/N, 10-15psi AP, 3/8"AL&FL
Army	Corpus Christi Depot, TX	CCAD is primary overhaul facility for rotary wing a/c repair; powder coat application system used in Engine Paint Shop
Army	Rock Island Arsnl, IL	60'x20' spray booths, 16' width conveyor line; going to AAA in the future; 2.5gal pot; 63 PB air nozzle; 66/565 fluid nozzle/needle; 60psi air pressure; 0.25" air&fluid line
Army	SDSRR-ME Bldg 0323	Steam heated convection ovens with nominal operating temperature of 160oF; vehicle&man lifts; spray gun specifics provided
Army	SDSRR-ME Bldg 0333	Steam heated convection and IR ovens with nominal operating temperature of 160°F; 6 ton monorail and hoist; spray gun specifics provided
Army	SDSRR-ME Bldg 0345	Steam heated convection with nominal operating temperature of 160°F; chain conveyor and rotating hooks; spray gun specifics provided
Army	SDSRR-ME Bldg 0357	Steam heated convection with nominal operating temperature of 160°F; 1 ton monorail and hoist; spray gun specifics provided
Army	SDSRR-ME Bldg 0360	Steam heated convection with nominal operating temperature of 160°F; X ton monorail and hoist; spray gun specifics provided
Army	SDSRR-ME Bldg 0373	2 ton monorail and hoist; spray gun specifics provided
Army	SDSRR-ME Bldg 0407	Steam heated convection with nominal operating temperature of 160°F; X ton monorail and hoist; spray gun specifics provided
Army	SDSRR-ME Bldg 0591	15'x30' spray booth; spray gun specifics provided
Army	SDSRR-ME Bldg 0654	8' x6' open spray booth; spray gun specifics provided
Army	SDSRR-ME Bldg 0939	25' x14' spray booth with sliding doors; spray gun specifics provided

APPENDIX (continued) Application Survey of Field Maintenance Units

DOD BR	SITE	NOTES
Army	SDSRR-ME Bldg 1130	18'x6' open spray booth; spray gun specifics provided
Army	SDSRR-ME Bldg 1163	8'x6' open spray booth; spray gun specifics provided
Army	SDSRR-ME Bldg 1172	spray gun specifics provided
Army	Tobyhanna Depot, PA	HVLP no longer used; up to 16'x16'x50' booth; 5gal, 2.5gal, small siphon cup; 66 SH air nozzle; 66/65 fluid nozzle/needle; 45-55psi air press; 3/8" airline; 1/4" fluid line
Army	Watervliet Arsenal, NY	
MC	Camp Lejeune, NC	
MC	Camp Pendleton, CA	
MC	Log Base-Albany, GA	
MC	Log Base-Barstow, CA	
MC	Pearl Harbor NSY, HI	0.035" to 0.070" nozzles for conventional and HVLP guns

NOTES: FG = fiberglass; Ep = epoxy; Gr = graphite, Comp = composite, St = Steel,

NOTES: CCC = chromate conversion coating;SS = scuff sanding;HS = hand sanding;CF = chemical film;SAA = sulfuric acid anodize;ZnP = zinc phosphate (TT-C-490)

: WHB = walnut hull blasting; abr bl = abrasive blasting = steel shot, stainless steel shot, steel grit, aluminum oxide, green lightning, coal slag, garnet, glass bead

: psvt = passivated, anod = anodized, dcr = dichromated; wpr = (Randolph) wash primer (DOD-P-15328) if required

NOTES: P&L = Pratt & Lambert; Crtd = Courtaulds; Htzn = Hentzen; Crfd = Crawford; Sprlt = Spraylat; UNIC = Unichem Coating Co; DFI = Daniels Frost Inc

NOTES: n/a = not applicable or info not provided.

NOTES: ASR = air supplied respirator; HMR = half mask respirator

NOTES: for the Air Force, all equipment under airless is actually air assisted airless

NOTES: for the USMC, all filtration equipment available for components only

PHASE 3
LOW VOC CARC
STRIPPING AND DISPOSAL

Final SERDP Technical Report

by

Charles H. Cundiff

Southwest Research Institute

Contract No. F09603-95-D-0176
SwRI No. 011357-104

Prepared for

Coatings Technology Integration Office
Wright-Patterson Air Force Base, OH

April 2000

LOW VOC CARC STRIPPING and DISPOSAL

INTRODUCTION

The Strategic Environmental Research and Development Program (SERDP) funded a tri-service effort to develop a low Volatile Organic Compound (VOC) Chemical Agent Resistant Coating (CARC) system for use on Army, Marine Corps, and Air Force systems. The overall objective of this project was to develop a SERDP Low VOC CARC system suitable for use on military equipment by all services, in which the materials and processes for the reformulation, application, stripping and disposal are optimized and in compliance with the current and anticipated regulatory requirements. The primary objective was to reduce the VOC of the polyurethane topcoat from 3.5lb/gal to 1.8lb/gal. A secondary objective was to eliminate the hazardous air pollutants (HAPs) and toxic solvents used in the current topcoat formulation. The secondary objective was to develop a "drop in" low VOC replacement for the current CARC material. New application and removal processes and equipment were to be minimized as much as possible.

The technical effort has been divided into three phases consisting of formulation, application, and removal with each agency overseeing one of the phases. The Army Research Laboratory (ARL) conducted the formulation efforts; Naval Surface Warfare Center, Carderock Division (NSWCCD) the application studies; and the Air Force Research Laboratory (AFRL) the removal studies.

In support of the project, the AFRL, in conjunction with Southwest Research Institute (SwRI), initiated in-house coatings stripping, and stripping process waste disposal studies task to determine how existing processes should be modified (if necessary) to meet the depaint requirements of each service. This action was pursued in order that a complete CARC system, i.e., coating formulation, application, and stripping, will be made available through the efforts of this SERDP project.

ARL has developed a low VOC formulation based on water-reducible chemistry along with polymeric bead extenders that met the VOC goals and exhibited improved mechanical and weathering properties than the current MIL-C-46168 CARC. This material was manufactured by Hentzen Coatings as part of a pilot plant, quality performance batch.

Production depaint requirements were established in terms of stripping efficiencies in relation to production throughput, and surface finish constraints imposed for acceptable substrate conditions following CARC system removal. Baseline testing of the existing CARC system was accomplished to provide a basis for comparative strippability analysis. Both the application and stripping studies utilized a full range of substrates, including metallic and nonmetallic (composites) materials in the test protocols.

EXPERIMENTAL

Efforts have been completed to characterize typical depaint processes and requirements for removal of the current CARC, or alternative systems[1] (the Marine Corps does not use the same coating as the Army). Baseline information pertaining to depaint processes was acquired through on-site and written surveys of Army, Marine Corps, and Air Force depot operations. A detailed strippability test plan was compiled on the basis of this characterization that reflected those depaint processes identified through the survey efforts. Strippability testing was also accomplished in a manner intended to replicate the range of typical stripping processes used for maintenance operations involving use of CARC, or equivalent coatings systems.

Depaint Process Characterizations

Various DoD maintenance operations were visited to obtain on-site information pertaining to the depaint processes used for the current CARC, or alternative systems associated with those operations. The selection of the operations to visit was intended to provide representative CARC depaint information for the different DoD services participating in this project. Baseline information pertaining to associated depaint requirements, and range of applications associated with these operations was acquired through these efforts. Supplementary information was also obtained from these sites by use of written questionnaires. The specific sites visited and polled included the following:

Anniston Army Depot (ANAD)
Letterkenny Army Depot (LEAD)
Tobyhanna Army Depot (TYAD)
Red River Army Depot (RRAD)
Corpus Christi Army Depot (CCAD)
Marine Corps Logistics Base (MCLB), Maintenance Center Albany, Albany, GA
Marine Corps Logistics Base (MCLB), Maintenance Center Barstow, Barstow, CA
Sacramento Air Logistics Center (SM-ALC).

The on-site survey efforts were concluded in January 1998, and efforts to obtain supplementary information via a questionnaire sent to these sites were concluded in the year 1999. Final results derived through this survey are given in Appendix A.

Strippability Test Plan

Information derived through the Depaint Process Characterizations phase of this study provided the basis for development of a CARC Strippability Test Plan. The test plan included considerations for testing of the coatings systems currently used as CARC, the SERDP Low VOC CARC formulation, typical primers associated with different

---

[1] The Water Borne Camouflage Coating (WBCC) is used by the Marine Corps Logistics Directorate (MIL-C-29475) instead of MIL-C-46168D. This coating meets local environmental regulations, but is not an approved CARC.

combinations of substrate materials, varying degrees of substrate sensitivity to damage produced by a stripping process, and possible variations of strippability due to aging conditions. The test plan also includes on-site testing of typical abrasive blast depaint processes, testing of a commercially available ablative process, and laboratory tests of chemical stripping processes typically used for stripping of small parts.

The test plan was designed to derive sufficient data to determine any necessity for modification, or replacement of any of the current stripping processes identified by this study. This was to be accomplished through evaluations of only significant representative materials and stripping processes, not every possible variable combination. The inability of various sites surveyed to define a quantifiable production requirement prompted the concept of concurrent testing of the new SERDP Low VOC CARC along with current CARC systems at different sites or operations, using the actual stripping processes of those operations to provide baseline data for comparison.

The selection of substrate and other test materials (Appendix B) was made through common consent of the DoD representatives comprising the work group for this SERDP funded project. The specific site, and/or stripping process evaluations were selected to avoid redundant testing. This approach assumes that a stripping process used at more than one operation will not exhibit fundamental changes from site-to-site even when tested at a single site. This was considered reasonable since this effort is designed to identify fairly gross strippability changes, or production impacts, and slight variations between different operations would not be considered significant. In addition, by group consensus, depaint processes that are seldom used, or comprise a very low use rate in relation to overall workload were not included into considerations for assessment.

Original planning also included considerations for any materials testing to qualify any new or modified depaint processes. This was considered prudent since it was very possible that a coating that was tougher to remove, might require a more aggressive depaint process. In turn, if a more aggressive process were to be used to maintain production requirements, this process would have to be demonstrated to be safe to use, dependent on the substrate. This concern holds especially true with more damage sensitive materials, such as the thinner aluminum alloys and composite materials, common to aerospace construction.

Other data acquired in accordance with the test plan as an effort to ensure quality control, and coating systems integrity included dry film thickness measurements during test material preparations. Additional data, which was outside of the Formal Test Plan, were developed for two pulsed Nd:YAG laser stripping systems since these processes represent emerging depaint technology that was considered to be of general interest. As such, these assessments were considered informative only, and had no significant bearing on overall project results.

CARC Strippability Test Materials and Preparations

Strippability assessment substrate materials included:

2024-T3 bare alloy, 0.063 inch and 0.032 inch (used with assessments of less aggressive depaint processes)
1010 alloy steel, 0.063 inch
fiberglass/epoxy, 8 ply (0/90 weave), 0.062 inch, per MIL-I-24768/27 GEE-F

Material preparations included:

Aluminum surface preparations and chromate conversion treatment in accordance with (IAW) Air Force T.O. 1-1-8,
Steel surface preparations with Zinc phosphate pre-treatment IAW TT-C 490
Fiberglass test panels were prepared IAW T.O. 1-1-24
Primers and Topcoats were applied IAW the applicable MIL-SPECS.

Coatings used for strippability assessments included:

Primer, MIL-P-53022 (used on steel and aluminum substrate)
Primer, MIL-P-23377, Type 1, Class C (used on aluminum substrate only)
Topcoat, MIL-C-46168D CARC 383 Green, Color # 34094 (baseline/current CARC)
Topcoat MIL-C-29475 Water Borne Camouflage Coating (WBCC) 383 Green, Color #, (baseline Marine Corps topcoat)
Topcoat, SERDP SERDP Low VOC CARC - Light Grey, Color # 36251
Topcoat, SERDP SERDP Low VOC CARC – 383 Green, Color # 34094

Materials conditioning was applied to either simulate natural aging, or accelerated coatings curing. Natural aging was simulated by cyclic exposure to UV light, followed by a water condensate period (UV/CON). This cycle was 8 hours of UV + 4 hours of condensate, and was repeated for a total of 40 complete cycles. The UV/CON conditions were as follows:

UV exposure @ 70° C
Condensate exposure @ 50° C
UV exposure will be with UVB 313 bulbs at an irradiance of 0.63 W/m^2, or UVA 340 bulbs[2] at an irradiance of 0.72 W/m^2.

Accelerated coatings curing/aging by oven has been used by the Air Force for several years for conditioning strippability test materials, and it is also similar to practices sometimes followed in maintenance operations to accelerate production throughput for painted materials. The oven aging used for this project consisted of exposure at for 96 hours at 210° F.

---

[2] UVA bulb exposure was added to the test matrix as another method of simulated aging at the request of the Army Research Laboratory (ARL). ARL expressed some concern that the UVB bulb exposure could be too harsh, thereby possibly skewing the strippability data.

Note: All test materials were given a minimum of 7 days cure at room temperature (75±5° F) prior to any other conditioning.

CARC Strippability Assessments of Standard Blast Processes

The dry media blast (DMB) strippability assessments were conducted with various depaint processes at the following sites:

Maintenance Site	Depaint Process
Anniston AD	Stainless Steel Blast
Letterkenny AD	Walnut Hull Media Blast
Tobyhanna AD	Zirconia Alumina Abrasive Blast
Corpus Christi AD	Wheat Starch Media Blast
MCLB Albany	Garnet Media Blast and Type II Plastic Media Blast (PMB)
Ogden ALC[3]	Type V PMB.

All blast depaint processes were assessed in typical production modes, i.e., blast processes were applied manually and with process parameters typical for that specific depaint operation. Nozzle standoff distances and blast impingement angles are approximate, and varied somewhat through operator response to stripping effectiveness at the time of the assessment. Strip rates were calculated through measuring the area stripped completely, for the elapsed time for the stripping. Irregular stripped areas had 4-6 measurements made in a given direction, and the average of these dimensions were used to calculate area. Elapsed time was measured with a stopwatch and recorded to the nearest 0.1 second.

Strippability Process Parameters

The process parameters for each of blast processes, and the chronological order that strippability assessments were conducted are as follows:

Walnut Hull - Blast Pressure = 70 psi
Standoff Distance of 8 - 12 inches
Blast Impingement Angle of 60° - 80°
Media Size = 20 Mesh
Nozzle - 1/2 inch Diameter Standard Venturi

Zirconia Alumina - Blast Pressure = 90 psi
Standoff Distance of 4 - 6 inches
Blast Impingement Angle of approximately 90°
Media Size = Fine

---

[3] A portion of the workload identified at SM-ALC was transitioned to Ogden ALC (OO-ALC) during the course of this study, which necessitated conducting assessments with the depaint process used by OO-ALC. OO-ALC also represented an opportunity to conduct assessments with a Type V PMB depaint process.

Nozzle - 3/16 inch Diameter Standard Venturi

Type II PMB - Blast Pressure = 90 psi
Standoff Distance of 18 - 20 inches
Blast Impingement Angle of 60° - 80°
Media Size = 16 - 20 mesh
Nozzle - 1/2 inch Diameter Standard Venturi

Garnet Abrasive - Blast Pressure = 80 psi
Standoff Distance of 36 - 40 inches
Blast Impingement Angle of 60° - 80°
Media Size = 30 - 60 mesh
Nozzle - 1/2 inch Diameter Standard Venturi

Stainless Steel Shot - Blast Pressure = 80 psi
Standoff Distance of 8 - 12 inches
Blast Impingement Angle of 60° - 80°
Grit Size = 50
Nozzle - 1/2 inch Diameter Standard Venturi

Type V PMB - Blast Pressure = 40 psi
Standoff Distance of 18 - 20 inches
Blast Impingement Angle of 60° - 80°
Media Size = 20 - 30[4] mesh
Nozzle - 1/2 inch Diameter Standard Venturi

Wheat Starch - Blast Pressure = 35 psi
Standoff Distance of 12 - 18 inches
Blast Impingement Angle of approximately 60°
Media Size = 20 - 30 mesh[5]
Nozzle - 1/2 inch Diameter Standard Venturi.

CARC Strippability with Chemical Depaint Processes

Although the original intent and scope of this SERDP project was focused on evaluating stripping processes other than chemical stripping, it was determined at the end of the Depaint Process Characterization phase that there is a significant level of CARC stripping by chemical agents. This type of stripping process is used primarily for smaller parts, and/or parts that have been removed from a larger part (vehicle, aircraft, etc.) during the maintenance process.

---

[4] OO-ALC uses the 20 - 30 mesh media for replenishment, and sizing screens are used to maintain a 20 - 50 mesh distribution of the working media.

[5] A majority of media size is maintained at a range of 30 - 90 mesh through special sizing screens in-line with the media reclamation system incorporated into the blast facility. The 20 - 30 mesh distribution represents the virgin, or make-up media, mesh distribution.

To this end laboratory testing of representative chemical stripping processes were added to the CARC Strippability Test Plan. The processes and associated substrate materials for evaluation were based on current methods used by the various maintenance operations surveyed. A small-scale laboratory replication of production chemical stripping processes was considered a simpler, more reliable approach to this testing, and was included in the test plan in this fashion. Parameters for the chemical stripping processes were supplied by maintenance operations involved in the initial survey efforts.

Process parameters were replicated in a laboratory environment, and a qualitative assessments of each chemical stripping process was conducted. The procedures used for these tests are presented below. The chemical stripping processes, and the maintenance operations using these processes identified by this study, are given in Table 1, Appendix D.

Chemical Depaint Process Testing Procedures

In general the chemical strippability testing procedures consisted of the immersion of test specimens, prepared as noted in Appendix D, into a bath of a chemical stripper. The temperature of the immersion bath was controlled during the dwell period, except as noted, by placing the beaker containing the chemical stripper in an explosion proof, temperature controlled oven. Temperatures for these tests were maintained per parameters supplied by the individual maintenance operations. The ambient temperature testing was conducted in an area for which the measured temperature was 26 ° C (78 ° F). The test area on the individual test panels was $\approx 15\ \text{cm}^2$ ($6\ \text{in}^2$). Panel edges were masked with pressure sensitive aluminum backed tape to prevent chemical intrusion in an effort to mitigate any edge effects that would tend to artificially enhance strippability.

CARC Strippability Assessments of Applied Light Energy Processes

CARC strippability assessments were conducted with several applied light energy paint stripping processes. One of the three processes, the Boeing FlashJet™ system, is a newer technology that will be used at several DoD maintenance operations in the very near future. FlashJet™ uses high power xenon (UV light) pulses to ablate the coating system. The FlashJet™ process is applied concurrently with a "scrubbing" of the coating residue by a CO_2 pellet blasting system. The CO_2 blast also provides cooling of the substrate. The primary use project for this process is on composite materials. For that reason the evaluations made with the FlashJet™ process were conducted with fiberglass test materials only.

The FlashJet™ process parameters that were observed during assessments with this process are as follows:

Flash Head Traverse Rate - 0.9 in/sec
Input - 2300 volts
Flash Rate - 3.6 Hz
Standoff - 2.2 inches measured from lens assembly.

The other two processes are based on pulsed Nd:YAG laser, which emits radiation in the infrared light range. The processes differ in the method by which coatings removal is accomplished. The laser system produced by General Lasertronics Corporation (GLC) is designed to ablate the coating system. The other laser system, which is produced by Craig Walters Associates (CWA) relies on laser shock. These different effects are achieved through different combinations of power, pulse duration, and pulse frequency.

The General Lasertronics Corporation (GLC) Laser Coating Remover as used for this project is a controlled tool for removal of coatings and finishes from the external surfaces of aircraft. The semi-automated system selectively removes coating/finish layers using energy pulses from a Q-switched, solid-state laser. The laser is a Neodymium-doped, Yttrium Aluminum Garnet (Nd: YAG), so the wavelength of the pulse light energy is appropriate for transmission along an optical fiber. The laser light pulses were transmitted to a lightweight, hand-held end effector through flexible optical fiber. The laser pulse width was approximately 130 nanoseconds (ns) and the laser wavelength was 1064 nanometers (nm). The fluence used in the tests was 3.1 J/cm^2 per pulse and the average laser power employed was 100 W.

The CARC test panels stripped by the CWA system used a recently developed handheld tool, which delivers pulsed Nd:YAG laser beams from a 40-foot umbilical cable to a work surface. Three separate laser beams impinged the work piece simultaneously, each over a 4-mm diameter circle. The three circular irradiance areas are automatically scanned transversely to the stripping path, which is formed as the operator draws the tool along the work piece surface. Several passes on a single area shaped the stripped areas on the CARC panels. The fluence used in the tests was 1.5 J/cm^2 per pulse. The pulse repetition rate was 12 Hz and the average laser power employed was 6.9 W. The laser pulse width was <20 ns and the laser wavelength was 1064 nm.

RESULTS

Depaint Process Characterization Results

Maintenance operations representing each branch of the DoD involved in this effort were visited, from September 1997 through January 1998. Much of the information necessary to develop comprehensive documentation of CARC, or an equivalent coating system, stripping was obtained. These visits established the basis for on-going relations with each of the participants, and each of these facilities has given verbal approval for return visits. Future visits were anticipated to accomplish the milestones of this project, such as field-testing and process integration. A synopsis of the findings relative to each site visited are given below. Appendix A contains charts summarizing all of the findings obtained in this effort.

Anniston Army Depot

Anniston was visited September 1997. This visit obtained on-site information, and identified Mr. Steve Guthrie as the point of contact for CARC issues. The current CARC stripping requirements associated with this depot involve CARC removal for overhaul, repair, and inspection of vehicle and artillery components.

Anniston has previously conducted technical studies to support selection of more durable dry media for use in CARC depainting efforts. This study specifically compared the results of mineral based dry media to that of steel shot. The survey of current CARC removal needs versus future needs for Anniston identified the continued concern of disposal of associated hazardous waste products. Anticipated increases of workload produced by base realignments make this concern more significant, since the volume of the waste stream would be expected to increase proportionally.

The request to identify current and future production requirements was cited as not being readily quantifiable. Current and future environmental concerns for the Anniston Army Depot continue to concentrate on hazardous waste disposal of dry media.

Marine Corps Logistics Base, Albany, GA

A visit to the Marine Corps Logistics Base, Albany, GA was conducted in October 1997. This visit obtained on-site information, and identified Mr. Ron Vargo as the point of contact for CARC (MIL-C-29475) stripping issues. The current CARC stripping requirements for this maintenance center involve the removal of coatings systems for overhaul, repair, and inspection of heavy equipment components.

The survey of Albany's current CARC removal needs versus future needs identified the need for a chemical stripper to remove CARC from parts that can not be abrasively blasted. To this end, Albany has previously conducted studies to assess replacing methylene chloride stripping processes with environmentally compliant chemical strippers. High-pressure water blasting as an alternative to dry media blasting has been evaluated by Albany with favorable results, but no implementation of such a process has been initiated. Current and future environmental concerns were identified as a continuing need for the recycling of depaint process waste products, waste stream reduction, cost reductions associated with disposal issues, and a prerequisite that acceptable stripping processes must minimize the potential for release of hazardous waste products.

Tobyhanna Army Depot

The visit to Tobyhanna Army Depot was conducted in November 1997. This visit obtained on-site information, and identified Mr. Ron Scarnulis as the point of contact for CARC issues. The current CARC stripping requirements involve the removal of CARC from various types of electronic equipment for overhaul, repair, and inspection. These components contain substrate materials ranging from fiberglass to heavy steel structures.

The primary stripping methods identified for CARC removal are dry media stripping and chemical baths.

Tobyhanna identified no previous technical efforts directed towards evaluation of CARC depaint processes. The Tobyhanna survey of current CARC removal needs versus future needs identified a requirement that integration of the SERDP Low VOC CARC will provide effective, economical CARC removal methods for thin skinned substrates while generating minimal hazardous waste products. Current and future production requirements were cited as not being readily quantifiable.

Letterkenny Army Depot

The visit to Letterkenny Army Depot was conducted in November 1997. This visit obtained on-site information, and identified Mr. Dennis Reed as the point of contact for CARC issues. The current CARC stripping requirements associated with this depot involve the removal of CARC for overhaul, repair, and inspection of heavy equipment and missile components. It was determined that the primary method of CARC stripping is dry media blasting, and these processes are augmented by chemical stripping on a smaller scale.

Marine Corps Logistics Base, Barstow, CA

A visit to Marine Corps Logistics Base, Barstow, CA was made in November 1997. This visit obtained on-site information, and identified Mr. Leonard Jimenez as the point of contact for coatings stripping issues[6]. Mr. Jimenez has since been replaced by Mr. A. Schnurr.

The current stripping requirements are for coatings removal for overhaul, repair, and inspection of heavy equipment components. Other stripping work for various operations is done by request, which may add some unforeseeable variances to the workload, current acceptance criteria, and the stripping processes used since this may be governed by customer requirements.

Barstow has previously conducted technical studies involving process containment, which concentrated on the reduction of air emissions. Barstow also indicated that the area the depot is located within has a very low tolerance to any possible source of pollution to the water supply. This was given as the reason no significant considerations have been given to water blast technology for CARC, and would restrict such technology for considerations as an alternative stripping process for this operation. There are no changes anticipated of current coatings removal workload versus future coatings removal workload through any addition or reduction of work due to base realignments.

The request to identify current and future production requirements was cited as not being readily quantifiable. Current and future environmental concerns for this maintenance

---

[6] MIL-C-29475 is used to comply with local environmental regulations for the Navy/Marine Corps depots chemical agent resistance requirements.

operation continue to concentrate on maintaining compliance with stringent California State EPA requirements.

Sacramento Air Logistics Center (SM-ALC)

SM-ALC was visited in December 1997, and the point of contact at that time was Mr. Ed White. Due to changes in staff associated with base realignments and restructuring within the ALC, Mr. White is no longer available for this effort, and no alternate has been identified. It is also anticipated that most of the maintenance work done at SM-ALC that might involve a CARC requirement is to be transitioned to other maintenance operations that perform similar maintenance functions. Efforts are being made to ascertain the status of the transition of this workload.

The only applications identified by SM-ALC that have any possible CARC requirements are associated with maintenance activities for vans and shelter components used with ground radar. SM-ALC identified no previous technical efforts specifically for the development for CARC depaint processes. Tobyhanna Army Depot, which has been identified as the operation likely to receive the bulk of the transitioned workload, has indicated that it will use the depaint process specified by the AF System Directorate responsible for these products. The primary stripping process used by SM-ALC for this application is dry abrasive blasting with Type II plastic media, and it is assumed that this will continue to be the depaint process used by any operations assuming responsibility for these applications.

Red River Army Depot

The visit to Red River Army Depot was conducted in December 1997. This visit obtained on-site information, and identified Mr. Mike Starkes as the point of contact for CARC issues. The primary CARC stripping requirements for this depot involve the removal of CARC for overhaul, repair, and inspection of the Bradley Fighting vehicle and associated components.

The survey of Red River's current CARC removal needs versus potential for future needs identified the continued concern for disposal of hazardous wastes. Like other maintenance operations participating in this survey effort, Red River would be very reluctant to accept any modifications of depaint processes that could produce any increase of hazardous waste products.

The request to identify current and future production requirements identified a slight reduction, from 95 to 75 man-hours/shift, in aluminum substrate workload while steel substrate workload is projected to remain a constant 5 man-hours/shift. Strippability testing results of baseline (current CARC, or equivalent) versus the SERDP Low VOC CARC will be used to determine any impacts on these requirements.

Other environmental concerns expressed by Red River Army Depot for now and the immediate future regard EPA mandated reductions in hexavalent chromium exposure, which will impact cleaning processes used at the Depot.

Corpus Christi Army Depot

A visit to Corpus Christi Army Depot was conducted in January 1998. This visit obtained on-site information, and identified Mr. Ed Cooper as the point of contact for CARC issues. The CARC stripping requirements associated with Corpus Christi involve the removal for overhaul, repair, and inspection of helicopter airframes and components.

Corpus Christi has conducted technical studies to reduce the utilization of hazardous chemicals for coatings stripping, which include CARC systems. These studies included reviews of wheat starch blasting, plastic media blasting, laser removal, flash lamp, carbon dioxide blasting, ice crystal blasting, and water blasting. To date, Corpus Christi has successfully implemented a wheat starch media blasting facility to use with more damage sensitive components/substrate materials. Other dry media blasting (DMB), such as Type V plastic media is also used for applications that are not as sensitive.

The Corpus Christi survey of current CARC removal needs and future needs identified a requirement to improve design deficiencies of their existing media facilities to match throughput requirements. These facilities have been given funding for a refurbishment project, and are currently being repaired/upgraded. This may dictate changes in the strippability testing associated with this maintenance operation, but this has not been determined at this time.

The request to identify current and future production requirements were provided as; FY98 estimates ~4358 hours based on 40 hour week for 3 men and 69 aircraft, FY99 and future not known. On-site testing will be conducted to compare current process(es) stripping efficiencies for current CARC and SERDP Low VOC CARC.

Current and future environmental concerns for the Corpus Christi Army Depot continue to concentrate on the elimination of the use of methylene chloride for stripping, disposal of wheat starch, and other spent dry blast media containing chromated materials from the primer component of the CARC system. Evaluations of an ablative depaint process utilizing high energy flashes of UV light have been initiated as a possible means to achieve these goals.

CARC Strippability with Standard Blast Processes

Assessments were conducted to establish strippability comparisons of the SERDP Low VOC CARC to current coating systems. The baseline coatings were considered to be either the current CARC, MIL-C-46168, or the Marine Corps equivalent, MIL-C-29475 used with either MIL-P-23022 or MIL-P-23377 primers. Strippability data were developed with different combinations of topcoat, substrate, primer, aging conditions, and to a limited extent topcoat color per the Project Test Plan (Appendix B). All DMB strippability data, with associated graphical presentations, acquired in this effort are given in Appendix C. The graphical presentations represent a mean strip rate value, i.e., area of coating system removed per unit time (ft^2/min), for specific combinations of primer, topcoat, and substrate. The strip rate data for different aging conditions were included in the mean value for a given combination. Individual data points may be seen in the tabulated data.

Walnut Hull Abrasive Blasting

The strippability data in tabulated and graphical formats for this process are found in Table 1, and Figures 1 through 3, Appendix C.

A comparison of the stippability data (Table 1) for oven cured test materials versus UV/CON conditioned test materials indicates that the oven cured coating systems were generally tougher to remove than UV/CON materials with this DMB process. This is based on the observation that the strip rate data for the oven cured materials is lower for 6 of the 9 data sets (specific combinations of substrate+primer+topcoat). At the same time it appears that there is little difference between the strippability data for either of the UV/CON.

As may be seen in the data plotted in Figure 1, the SERDP Low VOC CARC is stripped more easily than both the current CARC (MIL-C-46168), and the WBCC (MIL-C-29475), with MIL-P-23377 primer on aluminum substrate. From Figure 2 it may be observed that, while the differences are relatively small, SERDP Low VOC CARC strippability is not as good on steel substrate with the combination of MIL-53022 primer and the two baseline topcoats.

Figure 3 shows that stripping of the topcoat only, of the SERDP Low VOC CARC is better than the old CARC, but the difference is not real large. However, the strippability of the WBBC over MIL-P-53022 on the aluminum substrate is much greater than that of the SERDP Low VOC CARC.

It should be noted that in all instances of this data set (WBCC/MIL-P-53022) the mean strip rates used for comparison are for the topcoat only. Letterkenny production engineering support indicated that this condition would be satisfactory, and typically a depaint technician would stop stripping efforts at that point.

Zirconia Alumina Abrasive Blasting

The strippability data in tabulated and graphical formats for this process are found in Table 2, and Figures 4 through 6, Appendix C.

A comparison of the stippability data (Table 2) for oven cured test materials versus UV/CON conditioned test materials indicates that the oven cured coating systems were generally tougher to remove than UV/CON materials with this DMB process. This is based on the observation that the strip rate data for the oven-cured materials is lower for the majority of the 9 data sets (specific combinations of substrate+primer+topcoat). Some of the differences observed for this comparison are not that substantial, and do not tend to make a particularly strong argument that the oven aged materials are significantly tougher. The strippability data also does not appear to support any argument that there are significant differences between the strippability for either type of UV/CON conditioning.

Figures 4 and 6, Appendix C, again indicate that the SERDP Low VOC CARC is generally easier to strip than the baseline coatings. An exception may be seen in Figure 5, in that the SERDP Low VOC CARC appears tougher to remove than either baseline coating with MIL-P-53022 on aluminum substrate. The difference illustrated in this figure between the SERDP Low VOC CARC and the WBCC is greater than the difference observed between new and current CARC.

Type II PMB

The strippability data in tabulated and graphical formats for this process are found in Table 3, and Figures 7 and 8, Appendix C. As may be seen in Figures 7 and 8 some strippability comparisons were made between SERDP Low VOC CARC colors (Grey and Green). All data for this process were developed with aluminum substrate materials since this process is typically not cost effective for use on steel substrate.

A comparison of the stippability data (Table 3) for oven cured test materials versus UV/CON conditioned test materials indicates that the oven cured coating systems were generally tougher to remove than UV/CON materials with this DMB process. This is based on the observation that the strip rate data for the oven cured materials was determined to be lower for 6 of the 9 data sets (specific combinations of substrate+primer+topcoat). Some of the differences observed for this comparison are somewhat greater than seen previously, and do make a bit stronger argument for tougher strippability of the oven aged materials. These strippability data do not appear to support any argument that there are significant differences between the strippability for either type of UV/CON conditioning.

Strippability data for this DMB process indicate that the SERDP Low VOC CARC based on the mean of the strippability data for the two colors is removed more easily than either baseline system with MIL-P-23377 primer. As may be seen in Figure 7, both colors are stripped more readily than either baseline system.

Figure 8 indicates that data for the MIL-P-53022 primer exhibits some variances in strippability. The gray strips easier than the WBCC, but the strippability of the AF gray are nearly identical to the current CARC. In this particular data set the Navy green appears to be the toughest of the set, as opposed to the data presented in Figure 7 showing a better strip rate for the green. The mean strip rate for the two SERDP Low VOC CARC colors is slightly higher than the WBCC, but lower than the current CARC.

Garnet Abrasive Blasting

The strippability data in tabulated and graphical formats for this process are found in Table 4, and Figures 9 through 11, Appendix C.

A comparison of the strippability data (Table 4) for oven cured test materials versus UV/CON conditioned test materials does not support any argument that the oven cured coating systems were tougher to remove than UV/CON materials with this DMB process. These strippability data do not appear to support any argument that there are significant differences between the strippability for either type of UV/CON conditioning.

As may be seen in Figure 9, the strip rate for the SERDP Low VOC CARC is lower, i.e. reduced strippability, than that of the WBCC with MIL-P-53022 on steel substrate. The strip rate for the SERDP Low VOC CARC is higher than that for the current CARC. Figures 10 and 11 indicate that the SERDP Low VOC CARC strip rates are higher than either baseline system with both primers.

Type V PMB

The strippability data in tabulated and graphical formats for this process are found in Table 5, and Figures 12 and 13, Appendix C. As may be seen in Figures 12 and 13 some strippability comparisons were made between SERDP Low VOC CARC colors (Grey and Green). All data for this process were developed with aluminum substrate materials since this process is typically used for application on aluminum substrate only.

The strippability data found in Table 5 indicates fairly clearly that the oven cured materials are tougher to strip than the UV/CON conditioned materials. Data in this table also shows a very distinct difference in strippability between all of the MIL-P-23377 and MIL-P-53022 materials. The strip rates from test materials based on the MIL-P-53022 were lower by a factor of 2 or more. Once again there are no appreciable differences seen in comparisons of UV/CON strip rates for most of the data sets.

Data presented by Figures 12 and 13 are fairly consistent in that both colors of the SERDP Low VOC CARC stripped more readily than either baseline system, but an overall variance with this DMB process was seen with these data in the strippability between the SERDP Low VOC CARC colors. The grey was easier to strip with the MIL-P-53022 than the green. The relationship is reversed with the MIL-P-2377 based test materials.

Stainless Steel Shot Blasting

The strippability data in tabulated and graphical formats for this process are found in Table 6, and Figures 14 and 15, Appendix C.

A comparison of the strip rates derived from oven conditioned materials, which may be found in Table 6, does not give indication that the UV/CON conditioned materials are easier to strip with this process. In fact the data compared over the entire range is rather close, and it may be more accurate to say there is no significant differences seen between any of the aging processes with this DMB process.

Figure 14 depicts the strip rate data for aluminum test materials prepared with MIL-P-23377. It may be seen from this figure that SERDP Low VOC CARC strips faster than the WBCC, but while very close in strip rate to the current CARC, it has a slightly lower strip rate.

Figure 15 presents data for two data sets, which are data from aluminum and steel substrate prepared with MIL-P-53022. Strip rates for the SERDP Low VOC CARC versus the current CARC are seen to be higher for both data sets, but this is not true in the comparison of strip rates to the WBCC materials. The strip rates determined for the WBCC materials on steel substrate are higher than those of the SERDP Low VOC CARC.

Wheat Starch Dry Media Blasting

The strippability data in tabulated and graphical formats for this process are found in Table 7, and Figures 16 and 17, Appendix C. Strippability data was not developed for any metallic substrate materials since this process is used by CCAD exclusively on composite materials. There were no test materials conditioned by UV/CON since it was believed that the condensate phase of the cyclic exposure could easily damage the substrate material.

Strip rate data presented in Figure 16 shows that the strippability of the SERDP Low VOC CARC was higher than seen with either baseline system based on a system with MIL-P-23377. Strip rate data presented in Figure 17 for test materials based on MIL-P-53022 once again show a slightly higher strip rate derived from the WBCC materials when compared to the SERDP Low VOC CARC test materials test results. However, the current CARC is seen to have a lower strip rate than either the WBCC or the SERDP Low VOC CARC.

CARC Strippability with Chemical Depaint Processes

Assessments of strippability of various combinations of substrate, primer, topcoat and artificial aging were conducted on a limited basis with chemical depaint processes identified as currently in use at the several DoD maintenance operations surveyed in this study. Testing was limited due to a limited supply of test materials. In addition, several of the chemical strippers are used for either ferrous or non-ferrous materials, and not both materials. This effort was added to the Test Plan late into the project, and it was decided to conduct as much testing as feasible with the materials available. All available data has been tabulated, and is presented in Appendix D. Table 1, Appendix D, lists the various processes tested for this study.

Penetone NPX (Methylene Chloride Based) used for All Metallic Applications

Coating system blistering was fairly rapid, and tended to proceed as smaller blisters joining together until the entire coating system lifted from the substrate. Complete strip times associated with the aluminum panels primed with MIL-P-53022 and oven aged were longer by 5 to 6 times than those seen with other material combinations tested with this chemical stripper. This particular effect was seen with all topcoats. However, the strip time required for the SERDP Low VOC CARC was greater than that of the WBCC, while less than that required for the current CARC.

All test results were within the boundaries for acceptable strip or dwell time, and with the exception of the aforementioned variances, there are little to no differences in these data overall. Test results/observations are summarized in Table 2, Appendix D.

Sodium Hydroxide/Sodium Gluconate Solution (70:30 by volume) used for Ferrous Materials

Chemical reaction with all of the coating systems with this process was very limited. None of the test samples showed complete stripping within normal operational boundaries, but it must be remembered that this process is not intended for coatings removal. It is used for rust removal primarily, and any coatings removal is extra benefit.

Most of the data developed for this process is virtually the same with two variances seen with new SERDP Low VOC CARC samples where approximately 50% of the coating system was removed after the 24 hour dwell period. Both of these samples were UV/CON conditioned. All test results are found in Table 3, Appendix D.

Ameratec ADL-220 (1:1 solution w/H_2O) used for Ferrous Materials

Stripping trials conducted using the specified solution, 2-hour dwell, and bath temperature cited for the RRAD process did not produce any appreciable stripping of any of the test materials. RRAD has given indications that this process is quite unpredictable, and that this result should not be construed as unusual. RRAD is currently assessing alternative methods. Test results are summarized in Table 4, Appendix D.

Calgon EZE -545 used for Non-Ferrous Materials

Strippability characteristics were observed to be similar to those of the Penetone NPX. This chemical stripper exhibited significantly longer complete strip times (4 to 10 times greater) with aluminum materials primed MIL-P-53022. This effect is also seen in one of the data sets based on MIL-P-2337 with oven aged test materials. Data from 5 of the 6 data sets presented also indicate that the oven aged materials are harder to strip than the UV/CON conditioned test materials. All test results for this process are summarized in Table 5, Appendix D.

Turco 6088 Thin

There were two different processes tested based on the Turco 6088 Thin. It is a dip tank process chemical used by both Tobyhanna AD and Red River AD, but with some differences in the process parameters. The Red River process parameters are intended to produce satisfactory stripping with a 30-minute dwell with a bath temperature of 140°F. The Tobyhanna process permits a longer dwell (2 to 4 hours), but uses a lower bath temperature (120°F). Test results for the Red River and Tobyhanna processes are tabulated in Tables 6 and 7, Appendix D, respectively. The test results for both processes are very similar. Stripping of the SERDP Low VOC CARC is generally acceptable per individual depot criteria

There are exceptions to the above general results that are seen with the Red River AD process. These exceptions in one case may not be significant, i.e., 45 minutes for 100% stripping versus the desired 30 minutes, but the other instance resulted in stripping at 3 hours versus the desired 30 minutes. In both instances the test materials were primed with MIL-P-53022. What is more significant however, is that the current CARC was not completely stripped after 12 hours of dwell. This effect is also seen with the Tobyhanna process in combination with MIL-P-53022 materials top-coated with MIL-C-46168.

CARC Strippability with Applied Light Energy Processes

As mentioned previously the several forms of applied light energy stripping processes assessed are currently in varying levels of development. The Flashjet™ process is production ready, and represents a technology that will be implemented at several DoD maintenance operations, including Corpus Christi AD. Since this process will be limited in use at CCAD to composite materials, the test materials for this process were fiberglass substrate only, with the typical primer/topcoat combinations.

It should be noted that acceptable stripping for this process was complete removal of the topcoat, with minimal primer removal. This is the standard applied by CCAD for stripping applications of this nature. All data acquired for this process is tabulated, and also presented in graphical form in Appendix E.

Assessments conducted with the two laser based stripping processes were not performed in a production ready mode, and do not represent technology that is certain to be implemented into DoD maintenance operations. As seen in the data (Appendix E), the strip rates are quite low in comparison to production stripping processes, which is partly due to the small area stripped by these processes, as well as restricted technical development. Strip rate data developed for these processes were acquired through several (6-12) discrete areas on individual test panels. Therefore, the strip rate data presented (Tables 2 and 3, Appendix E) for these processes are mean values derived from these smaller areas.

FlashJet™ Xenon Flash Stripping

Figures 1 and 2, Appendix E, indicate that the strip rates for this process with all of the coating systems is at a level that would easily be considered productive by most maintenance operations that involve these types of materials. This is especially pertinent for aerospace applications since strip rate is usually kept low to avoid potential substrate damage. However, the more significant point to see from these data as regards this study is that the SERDP Low VOC CARC strips more readily, or equally as in the case of WBCC with MIL-P-23377 primer, with the FlashJet™ process than either baseline system with this process.

GLC and CWA Pulsed Nd:YAG Laser Stripping

Data for both laser-stripping processes are tabulated, and presented in graphical format in Appendix E. Table 2 and Figures 3 through 6 are the data developed with the General Lasertronics Corporation laser stripping process. Data developed with the Craig Walters Associates laser stripping process are presented in Table 3, and Figures 7 through 10.

The results for both sets of data are very similar even though the means off coatings removal differ. This difference was evident in observations of the stripping trials. GLC laser stripping produced more vaporized material (ablative process), and the CWA laser stripping process tended to produce large pieces of coating system (laser shock) that separated from the substrate. The primary differences between the data produced by the two systems are the actual strip rate data. The GLC strip rate data tended to be higher by about an order of magnitude. Strip rate data produced by both processes tended to be a couple orders of magnitude lower than the lowest (wheat starch DMB) production process included in this study.

The strippability trends are nearly identical for both processes. Data for each process, in nearly every data set, indicates that the SERDP Low VOC CARC is more readily stripped by either laser process than either baseline coating system. This trend also holds true over the range of substrate materials, which for these processes included fiberglass test substrate.

4.0 CONCLUSIONS/RECOMMENDATIONS

The overall conclusion to be reached on the basis of the CARC stripping requirements survey is that the preponderance of this work in the depots is done with some form of dry abrasive blasting. Another obvious conclusion to be drawn from this survey is that there is a common concern pertaining to any increases of hazardous waste products associated with the SERDP Low VOC CARC. If any of the stripping processes proved to require modification, and/or to be replaced, these concerns would be paramount in any considerations for such efforts. These issues would need to be the foundation for acceptance criteria to guide development of any stripping process modifications.

CARC strippability data for the various dry media depaint processes suggests that the strippability of the SERDP Low VOC CARC should not be expected to present an adverse impact to depaint operations. There were some instances where the data indicates that the SERDP Low VOC CARC may prove to be more difficult to remove than the other topcoats. However, there are indications that the SERDP Low VOC CARC is more easily stripped than the current CARC for most of the data sets developed in this study.

The chemical strippability data suggests that stripping productivity of the SERDP Low VOC CARC using these processes is not expected to be impacted significantly. The most significant change in strippability was exhibited by the tests conducted with a secondary stripping process (Calgon EZE-545) used by Red River Army Depot for ferrous materials. The results of the depaint requirements survey indicated that work on ferrous materials at this depot is very low in proportion to the work done with aluminum materials, which means that while there may be an impact, the impact itself appears to be insignificant to that operation. In addition, Red River has given indications that evaluations are being conducted of a chemical stripping process that if successful, may replace their entire current chemical stripping processes.

Strippability with the SERDP Low VOC CARC with the applied light energy processes must be considered a non-issue. No data were developed that indicate that the SERDP Low VOC CARC will present any strippability problems with these processes, and very likely with any similar processes.

The final conclusion is, given that there is no firm foundation from the data to support modifying or replacing current depaint processes to accommodate the SERDP Low VOC CARC, there will also be no need to be concerned over waste disposal. Since there are no changes in current processes seeming to be necessary, the disposal associated with these processes should not be effected.

5.0 REFERENCES

1. "Low Volatile Organic Compound (VOC) Chemical Agent Resistant Coating (CARC)" Strategic Environmental Research & Development Program (SERDP) FY98 Annual Technical Report Project #PP 1056/78, November 1998

6.0 PRESENTATIONS

1. "SERDP LOW VOC CARC STRIPPABILITY", William P. Hoogsteden and Charles Cundiff, 1999 Air Force Corrosion Managers' Conference, Macon, GA, Mar 10, 1999

2. SERDP LOW VOC CARC Removal, presented by William P. Hoogsteden and Charles Cundiff, 1999 DOD/Industry Aerospace Coatings Conference, Monterey, CA, May 19, 1999

APPENDIX A

CARC STRIPPING SURVEY RESULTS

Table 1. CARC Stripping Requirements for Several DoD Maintenance Operations

CARC NEEDS & REQUIREMENTS DEFINITION PHASE			
Base	**Anniston Army Depot**	**Corpus Christi Army Depot**	**Letterkenny Army Depot**
Location	Anniston, AL	Corpus Christi, TX	Chambersburg, PA
Point of Contact	Tony Pollard	Susan Veatch	Dennis Reed
Numbers (voice & fax)	256/235-7071 (v)	361/961-2767 (v) 363/961-2765 (f)	717/267-8376 (v) 717/267-9299 (f)
Date of Last Visit	5 Sep 97	20 Jan 98	19 Nov 97
1. CARC Stripping Requirements	Vehicle and Artillery	Helicopters	Missiles & Heavy Equipment
2. Facilities & Usage (%)	6 Booths Table Spinner 4 Glove Boxes 3 Dip Tanks	4 Booths 70% 10 Glove Boxes 10% 6 Dip Tanks 10% 5 Chem Areas 10%	4 Booths 1 Rotor Spinner 1 Tumbler Glove Boxes Dip Tanks
3. Methods & Usage (%)	Blast 75% Chemical 25%	Blast 80% Chemical 20%	Blast 85% Chemical 15%
3a. Media & Usage (%)	Steel Shot 0.5% Green Lightening 60% Black Beauty 30% Walnut 7% Glass Bead 2% Aluminum Oxide 0.5%	Type II 10% Type V 60% Wheat Starch 10%	Walnut = primary Garnet PMB Steel Shot Glass
3b. Chemicals & Usage (%)	Penetone NPX 100%	Methylene Chloride 10% N-Methyl Pyrrolidone(NMP) /Diethylene glycol b-butyl ether 10%	Sodium Hydroxide Turco 6088A
4. Substrates & Portion of Workload (%)	Steel 75% Aluminum 25%	Aluminum (0.016-0.064) Titanium (>0.064) Magnesium (>0.064) Stainless Steel (>0.064) Composites	Steel = typically > 1/8" thick 5000 series Al 7000 series Al Honeycomb Composites
5. Acceptance Criteria	Visual Inspection (white metal)	Composites = no broken fibers Al = Almen $\Delta h \leq$2mils	TBD
6. Production	Not Quantifiable	FY98 4358 manhrs/yr budgeted, no future data supplied	TBD
7. Environmental Concerns	Hazardous Waste Disposal	Eliminate Mythlene Chloride, reduce spent PMB and Wheat Starch waste products	Pennsylvania EPA has closely scruntized depot waste disposal and compliance
8. Needs	Increasing workload will allow no reduced throughput	Improved facilities	Chemical stripping needed for geometries not easily stripped by blasting processes
9. Technical Efforts	Shift to more durable media & methylene chloride replacement	Tested various dry and wet stripping techniques	TBD
10. Specifications/Pertinent Data	None provided	TO 1-1-8, ATCOM AED A1116B (Army General PMB Techniques), NAVAIR 01-1A-509 (Aircraft weapons cleaning and corrosion control), D6-56993 (Wheat Starch Blasting of Composites), CCAD Process Standards A.05,A.10,A.12;A.21, & C.08)Various documents for composite repair	TBD
11. Miscellaneous Issues	None	Recycling for PMB. PMB on thin Aluminum	Better adhesion on rough surface w/o chromate conversion

Table 1. CARC Stripping Requirements for Several DoD Maintenance Operations

CARC NEEDS & REQUIREMENTS DEFINITION PHASE			
Base	**Red River Army Depot**	**Tobyhanna Army Depot**	**Sacramento ALC**
Location	Texarkana, TX	Scranton, PA	Sacramento, CA
Point of Contact	Mike Starkes	Ron Scarnulis	Ed White
Numbers (voice & fax)	903/334-2601 (v) 903/334-3650 (f)	570/895-8223 (v) 570/895-8412 (f)	916/643-4886(v)
Date of Last Visit	3 Dec 97	18 Nov 97	23 Nov 97
1. CARC Stripping Requirements	1996 total gallons applied: 8307 one part, 3807 two part 1997 lower (Numbers not in.) 1998 50% of 1996 levels (Bradley Fighting Vehicle)	Mil-C-53039, Mil-C-46168, Mil-C-22750, Mil-P-53030, MIL-C-53072, DOD-P-15328 (Electronic Components, Vans & Shelters)	Vans & Shelters for Ground Radar
2. Facilities & Usage (%)	7 Booths 90% 11 Rotor Spinners/tumblers 3% 11 Glove Boxes 2% 10 Dip Tanks 5%	3 Booths 20% 1 Rotor Spinner 20% 1 Tumbler 20% Glove Boxes 20% Dip Tanks 20%	Single Booth 100%
3. Methods & Usage (%)	Blast 95% Chemical 5%	Blast 90% Chemical 10%	Blast 100%
3a. Media & Usage (%)	Steel Shot 75% Garnet 24% Walnut 1%	Zirconia Alumina 65% Steel Shot 35%	PMB Type II 80% Handsanding 20%, touchup
3b. Chemicals & Usage (%)	Turco 6088A-Thin 75% (Primary) Calgon EZE-545 (Secondary) Ameratec ADL-220 25%	Turco 6088A-Thin 90% Turco 6813-LO 10% (Formic Acid/Benzyl Alcohol)	
4. Substrates & Portion of Workload (%)	5000 series Al, 1-1.5", 1/8" thick minimum 95% Various Steels 5%	2024, 5052, 6061, 7075 Al 65% (0.03-0.375") Steel 30% (0.03-0.375") Composites 5% (0.06-0.375")	5000 series Al 50% Steel 50%
5. Acceptance Criteria	Surface finish, desirable/acceptable at 2-4 μm	Mil-C-53072	Visual Evaluation for Damage such as Panel Warpage and Good Surface Finish
6. Production	Rough Estimates Al = 95 manhrs/shift (75 for future) Steels = 5 manhrs/shift (5 for future)	Unavailable	Unavailable
7. Environmental Concerns	Potential reduction in hexavalent chromium exposure levels from OSHA may affect cleaning methods.	Decreasing OSHA limits for Cadmium and PA EPA	California EPA maintains close scrutiny on base discharge
8. Needs		Remove CARC from thin skin effectively & economically while minimizing hazardous wastes	
9. Technical Efforts	Ongoing work with venders.	None	None
10. Specifications/Pertinent Data	There are some available but most refer to the 2-4 μm surface finish	None	None
11. Miscellaneous Issues	None	None	None

Table 1. CARC Stripping Requirements for Several DoD Maintenance Operations

CARC NEEDS & REQUIREMENTS DEFINITION PHASE		
Base	**Marine Corps Logistics Base, Albany, Georgia**	**Marine Corps Logistics Base, Barstow, California**
Location	Albany, GA	Barstow, CA
Point of Contact	Ron Vargo	Skip Schnur
Numbers (voice & fax)	912/439-5503, 5504 (v) 912/439-6824 (f)	760/577-7295 (v) 760/577-7294 (f)
Date of Last Visit	8 Oct 97	3 Nov 97
1. CARC Stripping Requirements	Remove CARC system from items of equipment in preparation for other work to be performed as required Paint removal is accomplished in accordance with instructions as appropriate (Heavy Equipment)	Customer driven since much of the workload is for other DoD functions (Primarily Heavy Equipment)
2. Facilities & Usage (%)	5 Booths 75% 1 Tumble Blasters 4% 2 Rotor Spinners 17%	2 Booths 1 Table Spinner 1 Rotor Spinner 1 Tumbler 2 Glove Boxes
3. Methods & Usage (%)	Blast 100%	Blast 90% Chemical 10%
3a. Media & Usage (%)	PMB 10% Garnet 69% Steel Shot/Grit 20% Glass Bead 1%	Steel Shot 50 % Garnet 30% Type V PMB 20%
3b. Chemicals & Usage (%)	N/A	Sodium Hydroxide 60% Sodium Glutonate 40%
4. Substrates & Portion of Workload (%)	Steel 60% Aluminum 35% Fiberglass 2% Wood 1% Rubber 2%	Steel Aluminum Composites
5. Acceptance Criteria	Varies and is detailed in SOW for each product	Customer Determined
6. Production	Current requirement in Cost Center of 657 manhours per month as: Steel Parts = 500hrs Aluminum Parts = 150hrs Rubber Parts = 5hrs Fiberglass Parts = 1hr Wood = 1hr Future requirements cannot be easily quantified	Not Made Available
7. Environmental Concerns	Recycle, waste reduction, cost, release risk.	Recycling of waste products & California EPA close scrutiny
8. Needs	Currently only blast capable. Need chemical method to reduce risk of damage to smaller components.	Improved chemical strippers that are environmentally benign.
9. Technical Efforts	Study was done to replace Methylene Chloride with NMP Samples of ferrous and nonferrous CARC painted material sent to 8 chemical stripper companies in 1997 High pressure water blasting investigated with favorable results	Process Containment (i.e., air emissions)
10. Specifications/Pertinent Data	None	TM 3080-50
11. Miscellaneous Issues	None	Better adhesion on rough surface w/o chromate conversion

APPENDIX B

CARC STRIPPABILITY TEST PLAN

CARC STRIPPABILITY TEST PLAN

by

R. Leverette
Southwest Research Institute

Prepared for

AFRL/MLSS

August 1998

Approved:

C.H. Cundiff Project Manager

CARC STRIPPABILITY TEST PLAN

1.0 Scope

This test plan was written to support the TRW/Southwest Research Institute (SwRI) Coatings Technology Stripping Reliability/Maintainability Improvement Project. It is designed to develop a valid means to determine the effective stripping capability of current depaint processes with a new low VOC chemical agent resistant coating (CARC). This new SERDP Low VOC CARC is being developed by Strategic Environmental Research and Development Program (SERDP).

The primary goals for this project were first outlined in the SwRI Project Plan ACoatings Technology Stripping Reliability/Maintainability Improvement.@

These goals include:

1. Testing of existing stripping processes/methods with the SERDP Low VOC CARC materials to determine if further testing and/or development is required to meet R&M goals and to compare against current CARC materials.

2. Optimization of existing and/or newly developed stripping technologies to comply with R&M goals.

3. Stripping process materials characterization testing as required for qualification of modified or new stripping processes. (The exact scope of this effort will be substrate material and specific application dependent.)

2.0 Equipment/Resource Requirements and Schedule

2.1 Equipment

The following equipment will be needed to conduct the tests:
Paint Booth
Curing Oven
QUV
Test Facilities (Baseline and comparison depaint testing will be conducted at various DOD Installations), and laboratory facilities for chemical stripping process testing.

2.2 Resources

To conduct the tests, sufficient quantities of the following materials will be required to prepare the test panels:
1010 alloy steel of 0.063" thickness to make 60 2'x2' test panels
2024-T3 alloy aluminum of 0.063" thickness to make 120 2'x2' test panels
2024-T3 alloy aluminum of 0.032" thickness to make 64 2'x2' test panels
Fiberglass/Epoxy 8-ply 0.062" thickness to make test panels to make 72 1'x2' test panels
Zinc-Phosphate pre-treatment in accordance with (IAW) T-T-C 490
Chromate Conversion Coating IAW TO 1-1-8
Primer MIL-P-53022
Primer MIL-P-23377, Type 1, Class C
Topcoat MIL-C-46168D CARC 383 Green (Color #34094)
Topcoat MIL-C-29475 Water Borne Camouflage Coating (WBCC) 383 Green (Color #34094)
Topcoat SERDP Low Volatile Organic Compounds (VOC) CARC - Air Force Light Grey (Color # 36251)
Topcoat SERDP SERDP Low VOC CARC - Navy Green (Color # 383)
Penetone Penstrip NPX chemical stripper
Calgon EZE 545 chemical stripper

Ameritech ADL-220 chemical stripper
Altochem Turco 6088A-Thin chemical stripper.

2.3 Schedule

The test panel preparation and field level testing phases of this project will be conducted over a one year period (or less) contingent upon acceptance of this test plan and the availability of a surface preparation room, paint booth, and depaint facilities at field test sites. The proposed schedule is shown in Figure 1.

In general, test panels will be prepared, coated, and allowed to dry for a minimum of seven days. The test panels will be artificially aged by one of two processes, ultra-violet/condensate (UV/CON) chamber or by elevated temperature.

3.0 Preparation Chart and Testing Matrix

The specific parameters for test material preparation and test matrix details are given below. The test matrix has been designed to accomplish the goal of maximizing the number of panels tested at the minimum number of test facilities.

3.1 Test Panel Preparation Chart

Test Panel Preparation Chart

Substrate		Alloy	Thickness	Pre-Treatment	Primer	Topcoat	Cure	# Panels
S1	Steel	1010	0.063 in	Zinc-phosphate (T-T-C 490)	MIL-P-53022	MIL-C-46168D	QUV	15
	Steel	1010	0.063 in	Zinc-phosphate (T-T-C 490)	MIL-P-53022	MIL-C-46168D	Oven	5
S2	Steel	1010	0.063 in	Zinc-phosphate (T-T-C 490)	MIL-P-53022	MIL-C-29475	QUV	15
	Steel	1010	0.063 in	Zinc-phosphate (T-T-C 490)	MIL-P-53022	MIL-C-29475	Oven	5
S3	Steel	1010	0.063 in	Zinc-phosphate (T-T-C 490)	MIL-P-53022	Low VOC CARC	QUV	15
	Steel	1010	0.063 in	Zinc-phosphate (T-T-C 490)	MIL-P-53022	Low VOC CARC	Oven	5
							Total	60
A1	Aluminum	2024-T3	0.063 in	CRO_4 conv (TO 1-1-8)	MIL-P-53022	MIL-C-46168D	QUV	15
	Aluminum	2024-T3	0.063 in	CRO_4 conv (TO 1-1-8)	MIL-P-53022	MIL-C-46168D	Oven	5
	Aluminum	2024-T3	0.032 in	CRO_4 conv (TO 1-1-8)	MIL-P-53022	MIL-C-46168D	QUV	6
	Aluminum	2024-T3	0.032 in	CRO_4 conv (TO 1-1-8)	MIL-P-53022	MIL-C-46168D	Oven	2
A2	Aluminum	2024-T3	0.063 in	CRO_4 conv (TO 1-1-8)	MIL-P-23377, Type 1, Class C	MIL-C-46168D	QUV	15
	Aluminum	2024-T3	0.063 in	CRO_4 conv (TO 1-1-8)	MIL-P-23377, Type 1, Class C	MIL-C-46168D	Oven	5
	Aluminum	2024-T3	0.032 in	CRO_4 conv (TO 1-1-8)	MIL-P-23377, Type 1, Class C	MIL-C-46168D	QUV	6
	Aluminum	2024-T3	0.032 in	CRO_4 conv (TO 1-1-8)	MIL-P-23377, Type 1, Class C	MIL-C-46168D	Oven	2
A3	Aluminum	2024-T3	0.063 in	CRO_4 conv (TO 1-1-8)	MIL-P-53022	MIL-C-29475	QUV	15
	Aluminum	2024-T3	0.063 in	CRO_4 conv (TO 1-1-8)	MIL-P-53022	MIL-C-29475	Oven	5
	Aluminum	2024-T3	0.032 in	CRO_4 conv (TO 1-1-8)	MIL-P-53022	MIL-C-29475	QUV	6
	Aluminum	2024-T3	0.032 in	CRO_4 conv (TO 1-1-8)	MIL-P-53022	MIL-C-29475	Oven	2
A4	Aluminum	2024-T3	0.063 in	CRO_4 conv (TO 1-1-8)	MIL-P-23377, Type 1, Class C	MIL-C-29475	QUV	15
	Aluminum	2024-T3	0.063 in	CRO_4 conv (TO 1-1-8)	MIL-P-23377, Type 1, Class C	MIL-C-29475	Oven	5
	Aluminum	2024-T3	0.032 in	CRO_4 conv (TO 1-1-8)	MIL-P-23377, Type 1, Class C	MIL-C-29475	QUV	6
	Aluminum	2024-T3	0.032 in	CRO_4 conv (TO 1-1-8)	MIL-P-23377, Type 1, Class C	MIL-C-29475	Oven	2
A5	Aluminum	2024-T3	0.063 in	CRO_4 conv (TO 1-1-8)	MIL-P-53022	Low VOC CARC	QUV	15
	Aluminum	2024-T3	0.063 in	CRO_4 conv (TO 1-1-8)	MIL-P-53022	Low VOC CARC	Oven	5

	Aluminum	2024-T3	0.032 in	CRO_4 conv (TO 1-1-8)	MIL-P-53022	Low VOC CARC	QUV	6
	Aluminum	2024-T3	0.032 in	CRO_4 conv (TO 1-1-8)	MIL-P-53022	Low VOC CARC	Oven	2
A6	Aluminum	2024-T3	0.063 in	CRO_4 conv (TO 1-1-8)	MIL-P-23377, Type 1, Class C	Low VOC CARC	QUV	15
	Aluminum	2024-T3	0.063 in	CRO_4 conv (TO 1-1-8)	MIL-P-23377, Type 1, Class C	Low VOC CARC	Oven	5
	Aluminum	2024-T3	0.032 in	CRO_4 conv (TO 1-1-8)	MIL-P-23377, Type 1, Class C	Low VOC CARC	QUV	6
	Aluminum	2024-T3	0.032 in	CRO_4 conv (TO 1-1-8)	MIL-P-23377, Type 1, Class C	Low VOC CARC	Oven	2
							Total	168
N1	Aluminum	2024-T3	0.032 in	CRO_4 conv (TO 1-1-8)	MIL-P-53022	LV.Carc-Navy Color	QUV	6
	Aluminum	2024-T3	0.032 in	CRO_4 conv (TO 1-1-8)	MIL-P-53022	LV.Carc-Navy Color	Oven	2
N2	Aluminum	2024-T3	0.032 in	CRO_4 conv (TO 1-1-8)	MIL-P-23377, Type 1, Class C	LV.Carc-Navy Color	QUV	6
	Aluminum	2024-T3	0.032 in	CRO_4 conv (TO 1-1-8)	MIL-P-23377, Type 1, Class C	LV.Carc-Navy Color	Oven	2
							Total	16
F1	Fiberglass	8-ply	0.062in	N/A	MIL-P-53022	MIL-C-46168D	Oven	12
F2	Fiberglass	8-ply	0.062in	N/A	MIL-P-23377, Type 1, Class C	MIL-C-46168D	Oven	12
F3	Fiberglass	8-ply	0.062in	N/A	MIL-P-53022	MIL-C-29475	Oven	12
F4	Fiberglass	8-ply	0.062in	N/A	MIL-P-23377, Type 1, Class C	MIL-C-29475	Oven	12
F5	Fiberglass	8-ply	0.062in	N/A	MIL-P-53022	Low VOC CARC	Oven	12
F6	Fiberglass	8-ply	0.062in	N/A	MIL-P-23377, Type 1, Class C	Low VOC CARC	Oven	12
							Total	72

3.2 Stripping Processes Assessments per Substrate

Substrate	Stripping Processes
Steel	Garnet, Steel Shot, PMB Type II, Walnut Hull, Zirconia Alumina, Penetone NPX, ADL-220, and Turco 6088A-Thin
Aluminum	Garnet, Steel Shot, PMB Type II & V, Walnut Hull, Zirconia Alumina, Wheat Starch, Turco 6088A-Thin, Calgon EZE-545, and Penetone NPX
Fiberglass	PMB Type V, Wheat Starch, and Flash Jet

3.3 Strippability Test Matrix/Facility (Site)

Base	Proposed Test Date	Process	Substrate
Letterkenny/ Tobyhanna Army Depots	October 19, 1998	Walnut	Steel & Aluminum
	November 9, 1998	Zirconia Alumina	Steel & Aluminum
Albany Marine depot	January 25, 1999	Steel Shot	Steel & Aluminum
		Garnet	Steel & Aluminum
	February 15, 1999	PMB Type V	Aluminum & Fiberglass

Corpus Christi Army Depot	November 23, 1998	Wheat Starch	Aluminum & Fiberglass
Boeing, St. Louis Division	March 29, 1999	Flash Jet	Fiberglass
McClellan AFB	December 15, 1998	PMB Type II	Steel & Aluminum
CTIO Dayton	September 16, 1998 (prelim) November 16, 1998 (complete)	Chemical	Steel & Aluminum

4.0 Panel Preparation General Procedures

4.1 Panel Preparation

Application of coatings systems and pre-application surface preparations will be IAW the following:

1. Steel test panels will be prepared and Zinc-phosphate pre-treated IAW T-T-C 490D. Primers and Topcoats will be applied IAW the applicable MIL-SPECS listed in the Test Panel Preparation Chart of Section 3.1.

2. Aluminum test panels will be prepared IAW TO 1-1-691. Chromate Conversion pre-treatment will be applied IAW TO 1-1-8. Primers and Topcoats will be applied IAW the applicable MIL-SPECS listed in the Test Panel Preparation Chart of Section 3.1.

3. Fiberglass test panels will be prepared IAW MIL-I-24768/27 GEE-F. Primers and Topcoats will be applied IAW the applicable MIL-SPECS listed in the Test Panel Preparation Chart of Section 3.1.

4.2 Panel Aging

All test panels will undergo accelerated aging by one of two methods. Procedures for this accelerated aging are as follows:

1. Test panels undergoing UV/CON aging will be conditioned for 40-12 hour cycles of UV light exposure followed by a period of water condensate exposure. Each 12 hour cycle will comprise an 8 ± 0.25 hours UV exposure @ $70° \pm 2°$ C, followed by a 4 ± 0.25 hours condensate exposure @ $50° \pm 2°$ C. UV exposure will be with UVB 313 bulbs, with an irradiance of $0.63\ W/m^2$.

2. Test panels undergoing elevated temperature aging will be conditioned in an oven at $210° \pm 2°$ F for 96 ± 0.25 hours.

5.0 Strippability Test Procedures

Dry media depaint processes will be applied by qualified operators IAW the standard operating procedures for the removal of the current CARC from each substrate for each process listed in the Test Site Utilization Chart of Section 3.3. In order to eliminate variables that could be introduced by multiple operators, all testing will be scheduled in such a fashion that one operator will be able to complete the test during a single shift. In addition, each operator will be briefed on the tests to be conducted. During this briefing, it is important that the operator understand the importance of maintaining standoff distance, strip rate, and angle of impingement as consistent as possible. The intent of this measure will be to mitigate possible effects resulting from operator related variables, and provide a consistency of application of the blast process so that confident comparisons can be made between individual test panels.

After stripping each panel, the following data will be recorded: strip rate, standoff distance, angle of impingement, maximum flow rate, pressure, nozzle parameters, and overall quality (or effectiveness) of the stripping process. This data will be recorded in a Lab Record Book. This data will be used as the basis for comparison between the baseline material (existing CARC) and the sample material (SERDP Low VOC CARC).

Chemical depaint processes will be applied by CTIO personnel IAW the standard operating procedures specified by each base for the removal of the current CARC from each substrate for each process listed in the Test Site Utilization Chart of Section 3.3. Test specimens for these tests will be materials cut from larger strippability test panels to ensure that there is consistency between these test materials, and those to be used for strippability testing with other depaint processes. Chemical strippability data sets will be comprised of a minimum of three samples of each combination of coating system and substrate materials included in the strippability evaluation, with the exception of fiberglass substrate materials.

After stripping each panel, the following data will be recorded: time to initial bubbling of the coating system, and the time to complete removal of the coating system. This data will be recorded in a Lab Record Book. This data will be used as the basis for comparison between the baseline material (existing CARC systems) and the sample material (SERDP Low VOC CARC).

6.0 Adhesion Testing

The adhesion of each coating system used for evaluation of the test matrix will be characterized by use of the Modified Patti-Test method. The Modified Patti-Test method was developed at SwRI and will be performed IAW ASTM D4541, and will be performed following the procedures detailed in CTIO SOP-DRY-11. Adhesion tests will be conducted on witness panels that will be coated concurrently with test panels intended for use in the test matrix evaluation. Adhesion characterization will be based on mean adhesion values derived from measurements consisting of three measurements from each witness panel. Each coating system will have three witness panels for these measurements, which means the mean adhesion value will be based on a minimum of nine distinct measurements.

The Modified Patti-Test method will use test apparatus rings adhesively bonded to the coating system, and then allowed to cure overnight (minimum of 12 hours) before adhesion testing. In order to improve the efficiency of this method, a vacuum chuck may be used to restrain the sample during measurement.

7.0 Dry Film Thickness Measurements

Dry film thickness measurements (DFTM) will be made on each test panel per CTIO SOP-DRY-02. Nine DFTM are to be made on each test panel for the primer and primer+topcoat conditions. The nine individual DFTM per test panel will be made in a symmetric array. Each test panel will have a registration mark placed on the rear (unpainted) surface to define the orientation of the test panel for DFTMs. This mark will define the upper left corner of the test panel. DFTM location identification for data recording will be numbered 1 through 9 in a clockwise fashion, with location #1 as the measurement location adjacent to the registration marking.

8.0 Data Acquisition, Recording, and Quality Assurance

All data will be recorded on Data Sheets that are in compliance with the data requirements listed below for specific portions of this project. In addition, a Paint Report will be completed for each batch of panels coated with a specific primer and topcoat. All data acquired for this, and subsequent matrix development efforts will be placed in Lab Record Books, which will be made available to the Project Manager as needed. Any observations, suggestions, or comments derived from these efforts will also be recorded in the Lab Record Books used for this project.

8.1 Dry Film Thickness Measurement Data

Record DFTM for each location measured on each test panel. Also determine and record the statistical mean and standard deviation values for each data set. A data set will consist of the measurements for each panel.

8.2 Coatings Adhesion Data

Record all adhesion data for the complete coating system as represented by witness panels prepared concurrently with the test panels. Other data to be recorded include the mean value for each panel tested, and mode of coating failure.

8.3 Stripping Effectiveness Assessment Data

Record the strip rate, standoff distance, angle of impingement, maximum flow rate, pressure, nozzle parameters, and overall quality (or effectiveness) of the stripping process.

8.4 Quality Assurance

SwRI Quality Assurance is to ensure that the equipment required for this study have the appropriate calibration certificates as required. SwRI Quality Assurance will also ensure that these calibration certificates remain valid throughout the period that this study is conducted.

If comparison analysis of the data yielded by this plan finds that a process needs to be modified or a new process must be introduced in order to meet production requirements, this test plan will be amended to include additional testing and qualification procedures for modified or new processes.

APPENDIX C

CARC STRIPPABILITY DATA FOR DRY MEDIA BLASTING PROCESSES

Table 1. Letterkenny Army Depot Walnut Hull Strippability Data

SUBSTRATE	**PRIMER**	**TOP COAT**	**Age/Cure**	**Strip Rate, ft^2/min**	**Set Avg, ft^2/min**	**Notes**
AL	MIL-P-53022	MIL-C-46168	UV-B	2.00	**1.77**[1]	primer left on
AL	"	"	UV-B	1.86		primer left on
AL	"	"	UV-B	1.87		
AL	"	"	**Oven**[2]	1.37		primer left on (removal 0.35ft^2/min)
AL	MIL-P-23377	MIL-C-46168	UV-B	3.21	**3.50**	
AL	"	"	UV-B	3.58		
AL	"	"	UV-B	3.79		
AL	"	"	**Oven**	3.45		
AL	MIL-P-53022	MIL-C-29475	UV-A	2.86	**3.00**[1]	primer left on (removal 0.42ft^2/min)
AL	"	"	UV-B	3.34		primer left on
AL	"	"	UV-B	3.16		primer left on (removal 0.59ft^2/min)
AL	"	"	**Oven**	2.65		primer left on (removal 0.35ft^2/min)
AL	MIL-P-23377	MIL-C-29475	UV-B	3.55	**4.35**	
AL	"	"	UV-A	4.15		
AL	"	"	UV-A	4.98		
AL	"	"	UV-B	4.72		
AL	"	"	**Oven**	4.38		
AL	MIL-P-53022	Low VOC CARC	UV-B	1.68	**1.93**	
AL	"	"	UV-B	1.76		little primer left behind
AL	"	"	UV-A	2.76		
AL	"	"	**Oven**	1.52		primer left on
AL	MIL-P-23377	Low VOC CARC	UV-A	11.06	**10.19**	Strip rate w/o Ov = 11.94ft^2/min
AL	"	"	UV-B	12.30		
AL	"	"	UV-B	12.44		
AL	"	"	**Oven**	4.95		
ST	MIL-P-53022	MIL-C-46168	UV-B	0.86	**0.89**	
ST	"	"	UV-B	1.08		.$^1/_2$ test area (timer). Good prim/tc adhesion
ST	"	"	UV-B	1.03		
ST	"	"	**Oven**	0.60		
ST	MIL-P-53022	MIL-C-29475	UV-A	0.72	**0.88**	
ST	"	"	UV-A	0.74		
ST	"	"	UV-B	1.23		
ST	"	"	UV-B	0.96		topcoat separated from primer
ST	"	"	**Oven**	0.75		
ST	MIL-P-53022	Low VOC CARC[1]	UV-B	0.47	**0.70**	
ST	"	"	UV-B	0.72		good prim/tc adhesion
ST	"	"	UV-B	0.59		
ST	"	"	**Oven**	1.01		

1 - Average based on topcoat stripping only.

2 - Oven cure consists of 7 day minimum room temperature cure, followed by 96 hours at 210°F.

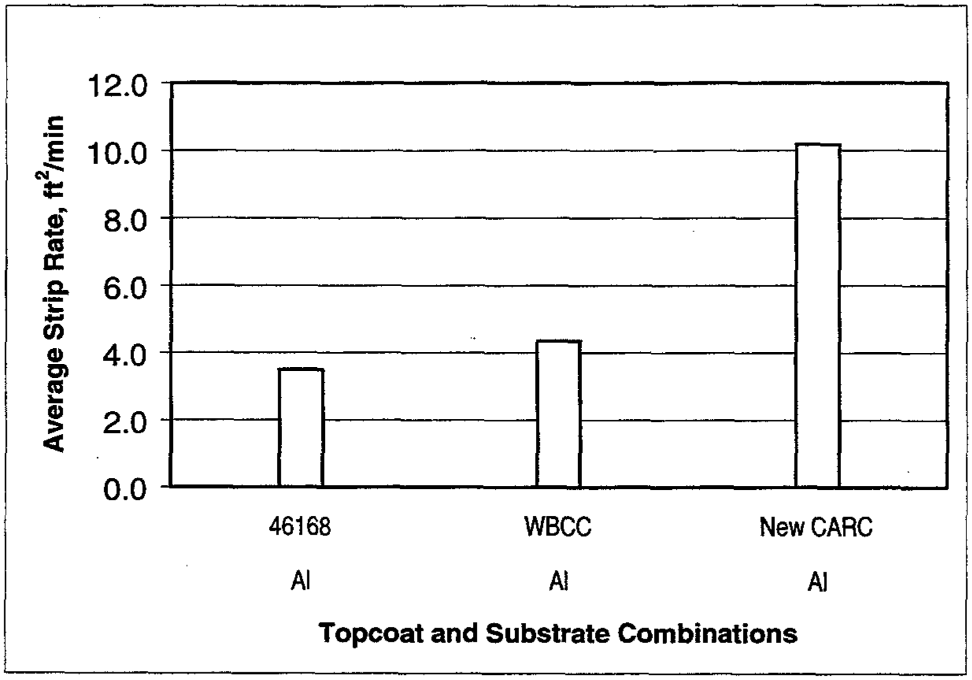


Figure 1. Letterkenny Walnut Hull DMBStrippability with MIL-P-23377 Primer System

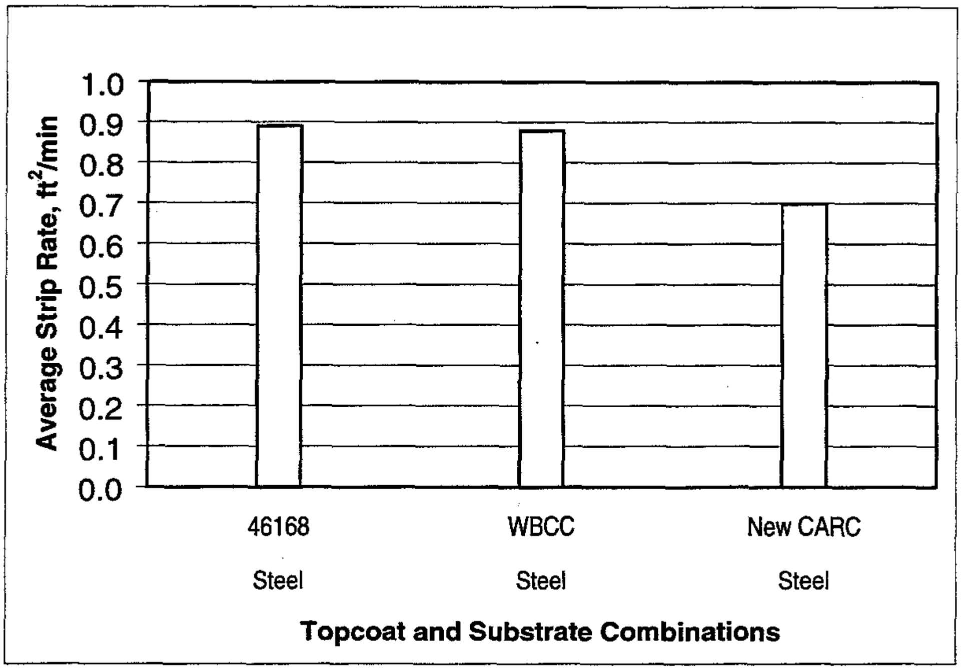


Figure 2. Letterkenny Walnut Hull DMB Strippability with MIL-P-53022 Primer System

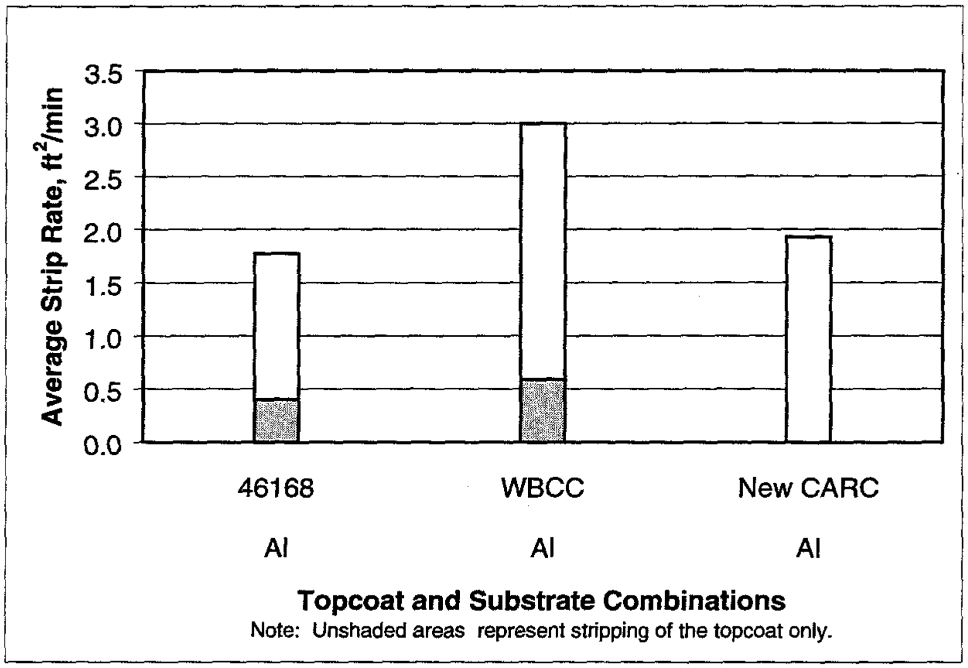


Figure 3. Letterkenny Walnut Hull DMB Strippability with MIL-P-53022 Primer

SUBSTRATE	PRIMER	TOP COAT	Age/Cure	Strip Rate, ft^2/min	Set Avg, ft^2/min	Notes
AL	MIL-P-53022	MIL-C-46168	UV-B	0.81	**0.91**	1st machine
AL	"	"	UV-B	0.93		2nd machine
AL	"	"	UV-B	1.01		2nd machine
AL	"	"	**Oven**	0.88		2nd machine
AL	MIL-P-23377	MIL-C-46168	UV-B	0.79	**0.78**	1st machine
AL	"	"	UV-B	0.80		2nd machine
AL	"	"	UV-B	0.77		1st machine
AL	"	"	**Oven**	0.75		2nd machine
AL	MIL-P-53022	MIL-C-29475	UV-B	0.95	**1.01**	1st machine
AL	"	"	UV-B	0.95		2nd machine
AL	"	"	UV-B	1.05		2nd machine
AL	"	"	**Oven**	1.07		2nd machine
AL	MIL-P-23377	MIL-C-29475	UV-B	0.84	**0.87**	1st machine
AL	"	"	UV-B	0.86		1st machine
AL	"	"	UV-B	0.85		1st machine
AL	"	"	**Oven**	0.93		Vacuum system loss for 30 sec. 2nd machine.
AL	MIL-P-53022	Low VOC CARC	UV-B	0.53	**0.64**	1st machine
AL	"	"	UV-B	0.66		1st machine
AL	"	"	UV-B	0.76		2nd machine
AL	"	"	**Oven**	0.59		2nd machine
AL	MIL-P-23377	Low VOC CARC	UV-B	1.12	**0.99**	? +10-15 sec. 1st machine.
AL	"	"	UV-B	1.40		T/C came off in large chuncks. 2nd machine.
AL	"	"	UV-B	0.80		1st machine
AL	"	"	**Oven**	0.64		T/C came off before primer. 2nd machine.
ST	MIL-P-53022	MIL-C-46168	UV-B	0.71	**0.75**	2nd machine.
ST	"	"	UV-B	0.75		2nd machine.
ST	"	"	UV-B	0.84		2nd machine.
ST	"	"	**Oven**	0.71		1st machine
ST	MIL-P-53022	MIL-C-29475	UV-B	0.72	**0.69**	1st machine
ST	"	"	UV-B	0.64		T/C lifted off primer. 2nd machine.
ST	"	"	UV-B	0.71		1st machine
ST	"	"	**Oven**	0.67		2nd machine.
ST	MIL-P-53022	Low VOC CARC[1]	UV-B	0.81	**0.78**	2nd machine.
ST	"	"	UV-B	0.94		2nd machine.
ST	"	"	UV-B	0.68		1st machine
ST	"	"	**Oven**	0.69		2nd machine.

1 - Navy color.

Table 2. Tobyhanna Zirconia Alumina Strippability Data

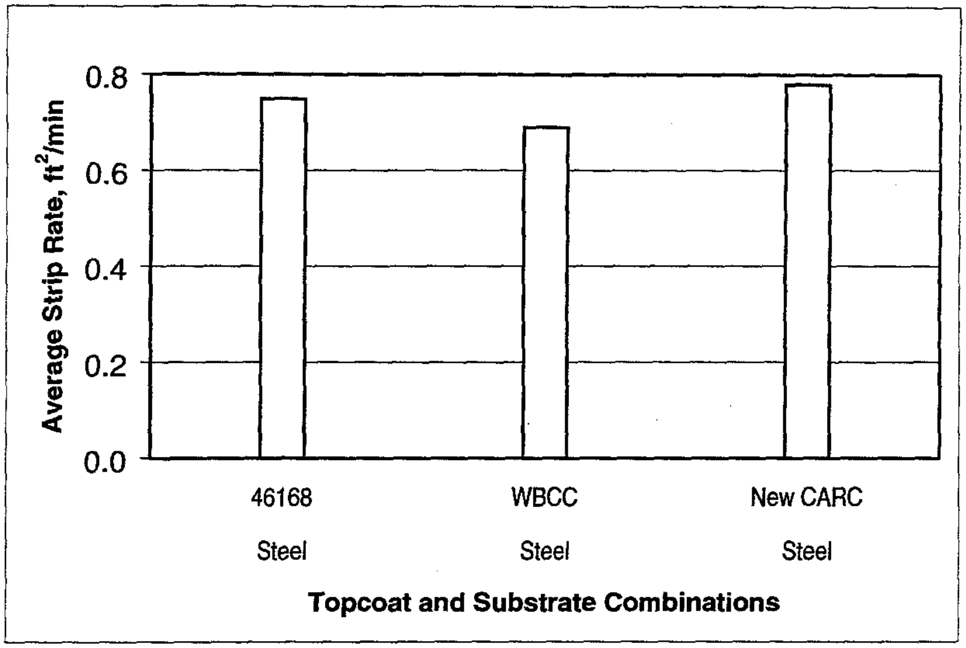


Figure 4. Tobyhanna Alumina Zirconia DMB Strippability with MIL-P-53022 Primer

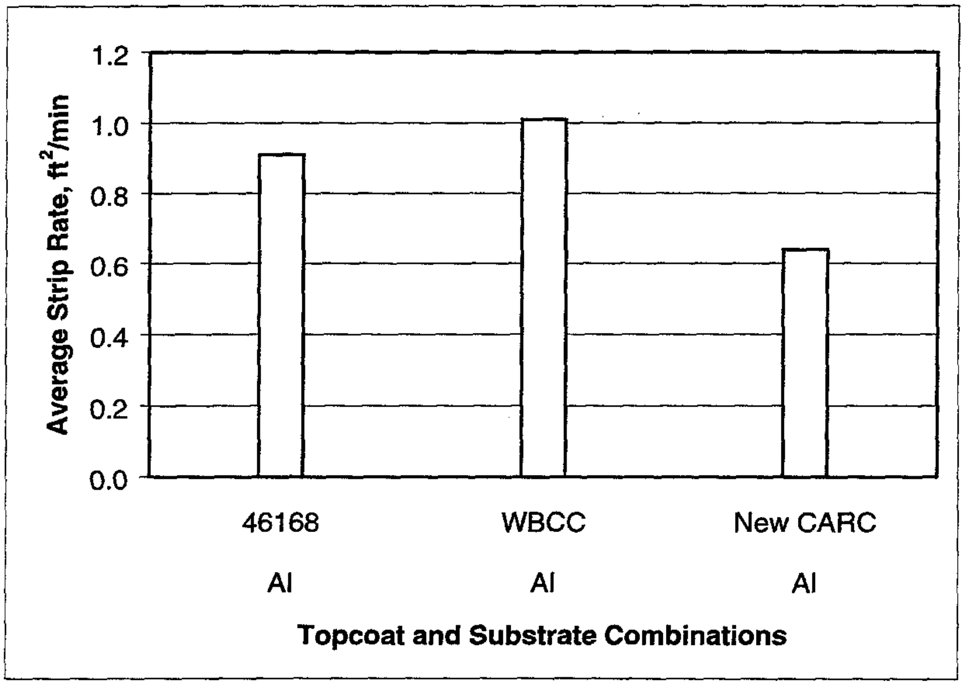


Figure 5. Tobyhanna Alumina Zirconia DMB Strippability with MIL-P-53022 Primer

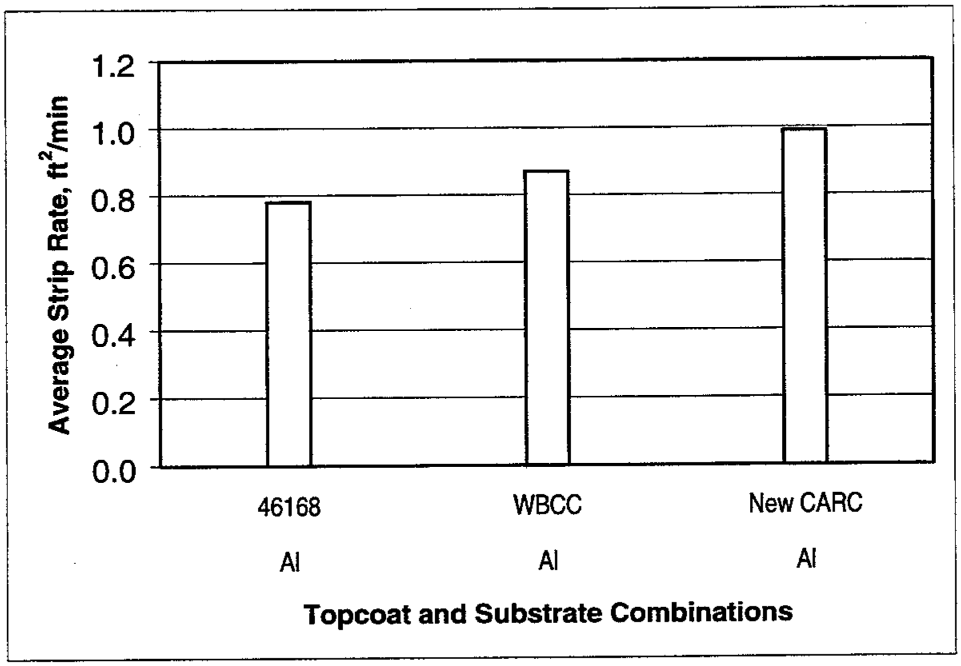


Figure 6. Tobyhanna Alumina Zirconia DMB Strippability with MIL-P-23377 Primer

Table 3. Marine Corps Logistics Base-Albany Type II DMB Process Strippability

SUBSTRATE	PRIMER	TOP COAT	Age/Cure	Strip Rate, ft^2/min	Avg ft^2/min	Notes
AL	MIL-P-53022	MIL-C-46168	UV-B	1.69	**1.20**	
AL	"	"	UV-B	1.40		
AL	"	"	UV-A	1.11		
AL	"	"	UV-A	1.24		
AL	"	"	**Oven**	0.57		
AL	MIL-P-53022	MIL-C-29475	UV-B	1.22	**0.93**	5% TC remained and subtracted from total area.
AL	"	"	UV-B	0.79		
AL	"	"	UV-A	0.99		
AL	"	"	UV-A	1.06		
AL	"	"	**Oven**	0.61		
AL	MIL-P-53022	LVC-Navy Green	UV-B	0.86	**0.78**	
AL	"	"	UV-B	1.00		
AL	"	"	UV-A	0.74		
AL	"	"	UV-A	0.68		
AL	"	"	**Oven**	0.61		
AL	MIL-P-53022	LVC-AF Gray	UV-B	1.55	**1.19**	5% TC remained and subtracted from total area.
AL	"	"	UV-B	1.15		10% TC remained and subtracted from total area.
AL	"	"	UV-A	1.02		
AL	"	"	**Oven**	1.31		
AL	"	"	UV-A	0.95		2% TC remained and subtracted from total area.
AL	MIL-P-23377	MIL-C-46168	UV-B	2.07	**2.65**	
AL	"	"	UV-B	3.43		
AL	"	"	UV-A	2.84		
AL	"	"	UV-A	3.43		
AL	"	"	**Oven**	1.49		2% TC remained and subtracted from total area.
AL	MIL-P-23377	MIL-C-29475	UV-B	2.43	**2.44**	
AL	"	"	UV-B	na		Missed Data Point
AL	"	"	UV-A	na		Missed Data Point. ~20-30sec
AL	"	"	UV-A	2.43		
AL	"	"	**Oven**	2.47		
AL	MIL-P-23377	LVC-Navy Green	UV-B	6.64	**4.91**	
AL	"	"	UV-B	6.22		
AL	"	"	UV-A	5.53		
AL	"	"	UV-A	3.11		
AL	"	"	**Oven**	3.07		
AL	MIL-P-23377	LVC-AF Gray	UV-B	5.24	**4.07**	
AL	"	"	UV-B	4.74		
AL	"	"	UV-A	4.15		
AL	"	"	UV-A	3.21		
AL	"	"	**Oven**	2.99		

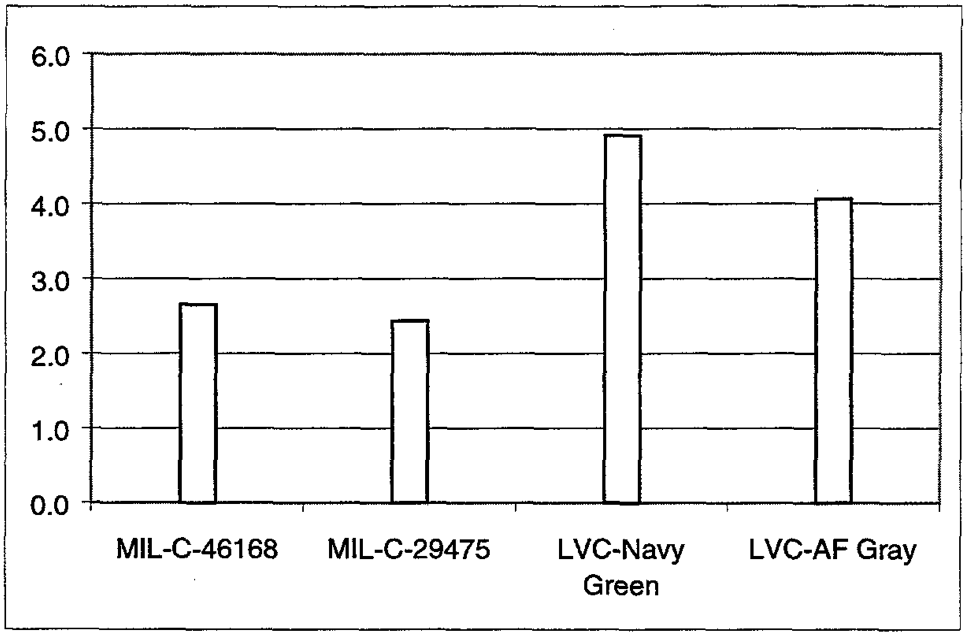


Figure 7. Albany Type II DMB Strippability with MIL-P-23377 Primer and Aluminum Substrate

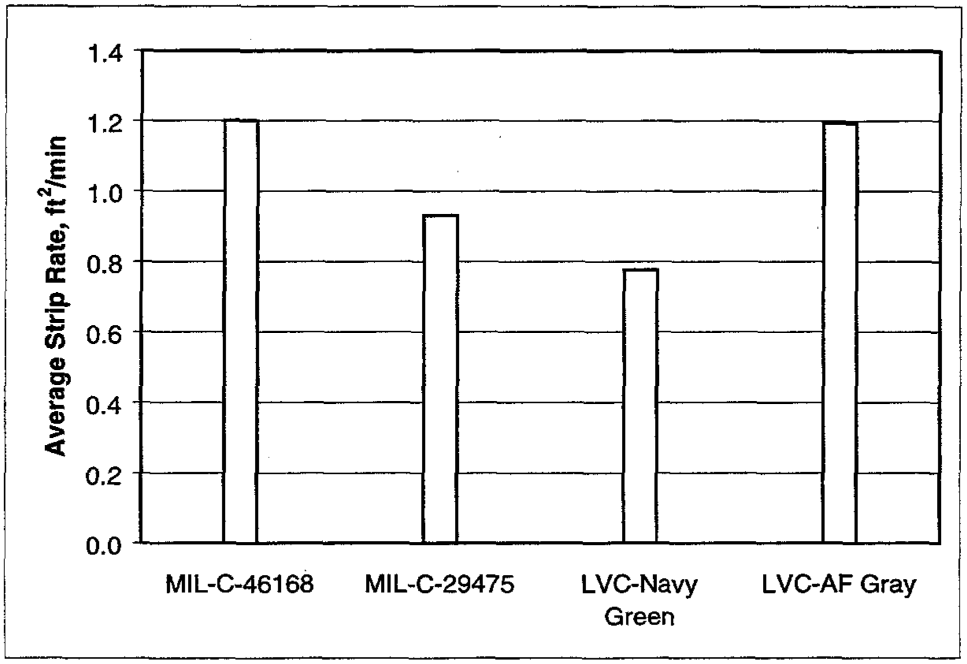


Figure 8. Albany Type II DMB Strippability with MIL-P-53022 Primer and Aluminum Substrate

Table 4. Albany Garnet Grit DMB Process Strippability Data

SUBSTRATE	PRIMER	TOP COAT	Age/Cure	Strip Rate, ft^2/min	Avg ft^2/min	Notes
AL	MIL-P-53022	MIL-C-46168	UV-B	4.27	**4.88**	
AL	"	"	UV-B	5.19		2% TC remained and subtracted from total area.
AL	"	"	UV-B	4.74		1% TC remained and subtracted from total area.
AL	"	"	**Oven**	5.33		
AL	MIL-P-23377	MIL-C-46168	UV-B	5.19	**7.15**	1% TC remained and subtracted from total area.
AL	"	"	UV-B	5.27		1% TC remained and subtracted from total area.
AL	"	"	UV-B	10.53		1% TC remained and subtracted from total area.
AL	"	"	**Oven**	7.61		
AL	MIL-P-53022	MIL-C-29475	UV-B	4.26	**5.34**	1% TC remained and subtracted from total area.
AL	"	"	UV-B	5.51		2% TC remained and subtracted from total area.
AL	"	"	UV-B	6.55		
AL	"	"	**Oven**	5.04		
AL	MIL-P-23377	MIL-C-29475	UV-B	9.28	**9.89**	
AL	"	"	UV-B	8.07		1% TC remained and subtracted from total area.
AL	"	"	UV-B	8.88		1% TC remained and subtracted from total area.
AL	"	"	**Oven**	13.32		
AL	MIL-P-53022	Low VOC CARC	UV-B	6.19	**6.00**	
AL	"	"	UV-B	7.40		1% TC remained and subtracted from total area.
AL	"	"	UV-B	5.55		1% TC remained and subtracted from total area.
AL	"	"	**Oven**	4.85		1% TC remained and subtracted from total area.
AL	MIL-P-23377	Low VOC CARC	UV-B	16.41	**15.83**	
AL	"	"	UV-B	19.69		
AL	"	"	UV-B	19.69		
AL	"	"	**Oven**	7.53		
ST	MIL-P-53022	MIL-C-46168	UV-B	4.92	**6.15**	
ST	"	"	UV-B	6.15		
ST	"	"	UV-B	6.56		
ST	"	"	**Oven**	6.95		
ST	MIL-P-53022	MIL-C-29475	UV-B	10.20	**7.86**	
ST	"	"	UV-B	8.82		2% TC remained and subtracted from total area.
ST	"	"	UV-B	6.56		
ST	"	"	**Oven**	5.86		1% TC remained and subtracted from total area.
ST	MIL-P-53022	Low VOC CARC[1]	UV-B	6.77	**6.97**	1% TC remained and subtracted from total area.
ST	"	"	UV-B	5.58		1% TC remained and subtracted from total area.
ST	"	"	UV-B	8.95		
ST	"	"	**Oven**	6.58		

1 - Navy color.

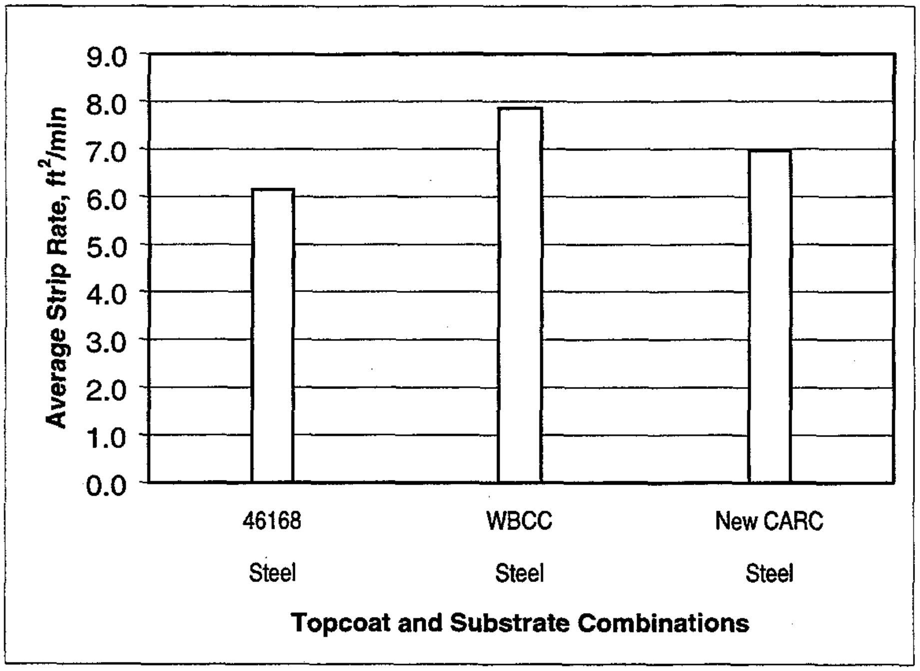


Figure 9. Albany Garnet Grit DMB Strippability with MIL-P-53022 Primer

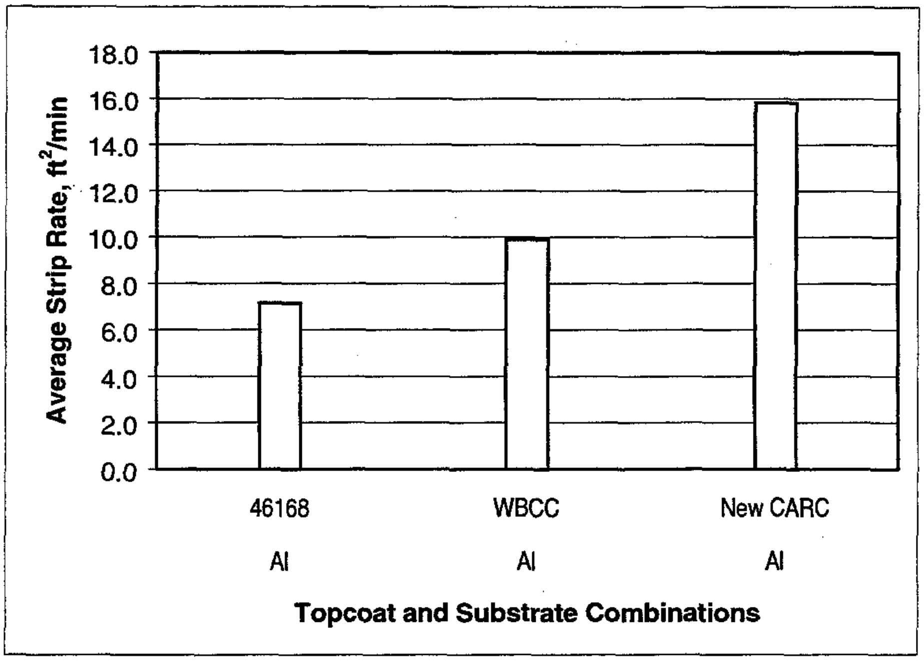


Figure 10. Albany Garnet Grit DMB Strippability with MIL-P-23377 Primer

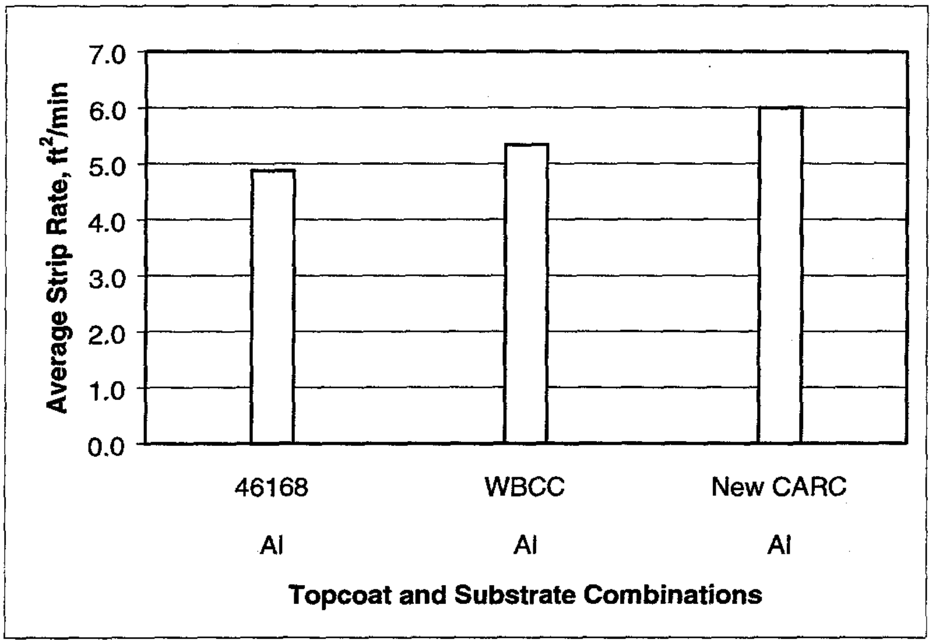


Figure 11. Albany Garnet Grit DMB Strippability with MIL-P-53022 Primer

Table 5. Ogden-Air Logistics Center Type V Process Strippability Data

SUBSTRATE	PRIMER	TOP COAT	Age/Cure	Strip Rate, ft^2/min	Set Avg, ft^2/min	Notes
AL	MIL-P-23377	MIL-C-46168	UV-B	2.12	**2.94**	
AL	"	"	UV-B	2.01		
AL	"	"	UV-A	3.56		
AL	"	"	UV-A	5.08		
AL	"	"	**Oven**	1.95		
AL	MIL-P-23377	MIL-C-29475	UV-B	2.76	**3.36**	
AL	"	"	UV-B	3.35		
AL	"	"	UV-A	4.00		
AL	"	"	UV-A	3.30		
AL	"	"	**Oven**	3.41		
AL	MIL-P-23377	Low VOC CARC[1]	UV-B	6.82	**6.79**	
AL	"	"	UV-B	11.43		
AL	"	"	UV-A	6.15		
AL	"	"	UV-A	6.93		
AL	"	"	**Oven**	2.64		
AL	MIL-P-23377	Low VOC CARC[2]	UV-B	6.15	**5.71**	
AL	"	"	UV-B	6.88		
AL	"	"	UV-A	4.89		
AL	"	"	UV-A	6.56		
AL	"	"	**Oven**	4.08		
AL	MIL-P-53022	MIL-C-46168	UV-B	0.12	**0.50**	
AL	"	"	UV-B	0.23		
AL	"	"	UV-A	0.98		
AL	"	"	UV-A	1.09		
AL	"	"	**Oven**	0.08		
AL	MIL-P-53022	MIL-C-29475	UV-B	0.25	**0.38**	Topcoat removed in 66s
AL	"	"	UV-B	0.21		Topcoat removed in 67s
AL	"	"	UV-A	0.60		
AL	"	"	UV-A	0.75		
AL	"	"	**Oven**	0.10		Topcoat removed in 90s
AL	MIL-P-53022	Low VOC CARC[1]	UV-B	0.68	**0.71**	
AL	"	"	UV-B	0.86		Topcoat removed in 36s
AL	"	"	UV-A	0.80		
AL	"	"	UV-A	1.07		
AL	"	"	**Oven**	0.14		
AL	MIL-P-53022	Low VOC CARC[2]	UV-B		**1.75**	
AL	"	"	UV-B			
AL	"	"	UV-A	2.00		
AL	"	"	UV-A	2.60		
AL	"	"	**Oven**	0.64		

1 - Navy color.

2 - AF Gray

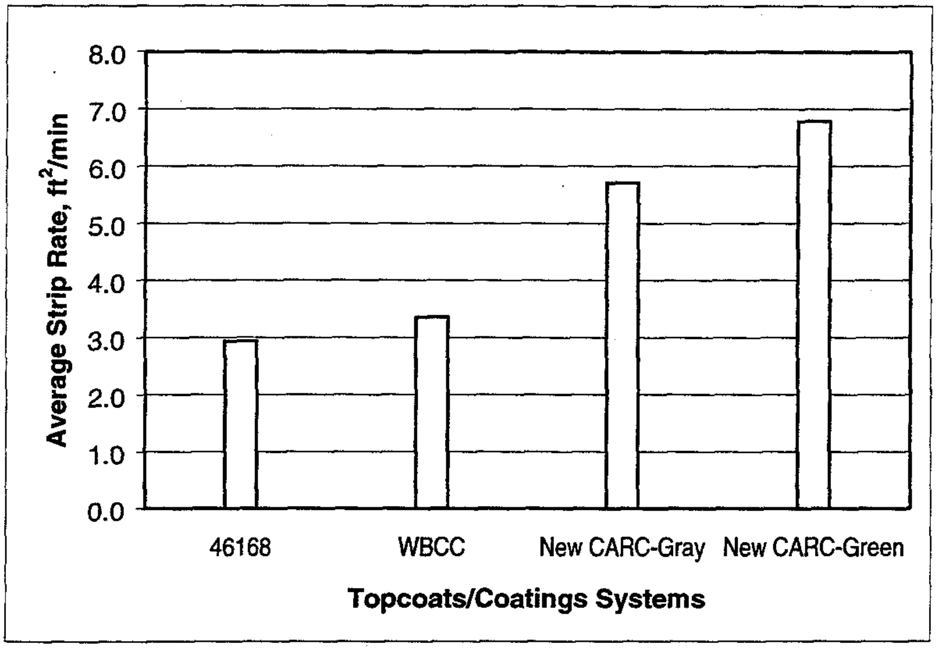


Figure 12. Ogden-ALC Type V DMB Strippability with AL Substrate and MIL-P-23377 Primer

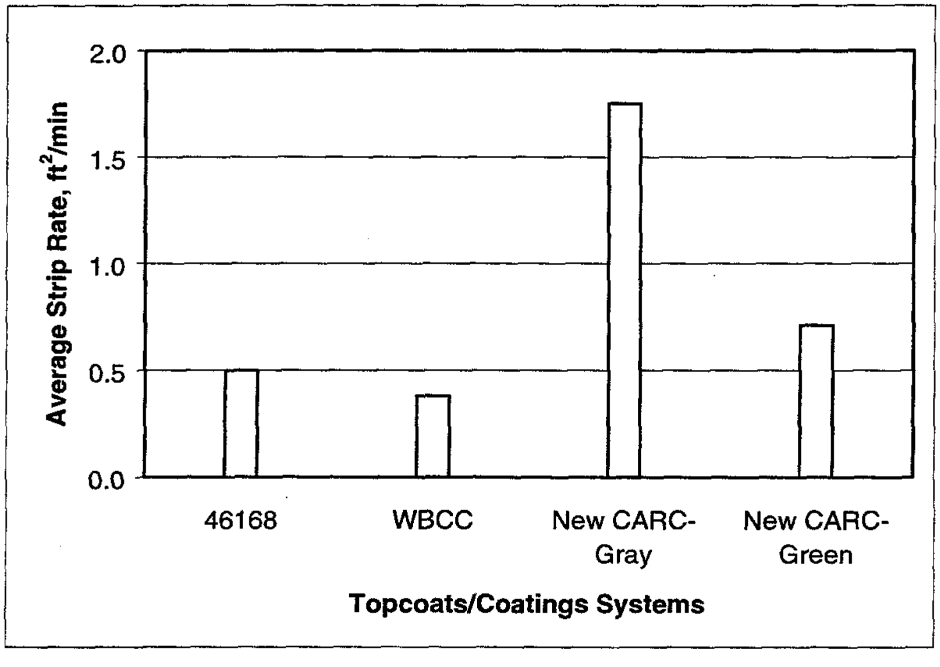


Figure 13. Ogden-ALC Type V DMB Strippability with AL Substrate and MIL-P-53022 Primer

Table 6. Anniston Army Depot Steel Shot Process Strippability Data

SUBSTRATE	PRIMER	TOP COAT	Age/Cure	Strip Rate, ft^2/min	Set Avg, ft^2/min	Notes
AL	MIL-P-53022	MIL-C-46168	UV-B	1.71	**1.71**	5% TC remained and subtracted from total area.
AL	"	"	UV-B	1.71		5% TC remained and subtracted from total area.
AL	"	"	UV-B	1.75		5% TC remained and subtracted from total area.
AL	"	"	Oven	1.66		2% TC remained and subtracted from total area.
AL	MIL-P-23377	MIL-C-46168	UV-B	4.37	**3.74**	
AL	"	"	UV-B	3.29		
AL	"	"	UV-B	3.86		
AL	"	"	Oven	3.43		
AL	MIL-P-53022	MIL-C-29475	UV-B	1.97	**1.99**	2% TC remained and subtracted from total area.
AL	"	"	UV-B	2.02		2% TC remained and subtracted from total area.
AL	"	"	UV-B	1.75		5% TC remained and subtracted from total area.
AL	"	"	Oven	2.22		5% TC remained and subtracted from total area.
AL	MIL-P-23377	MIL-C-29475	UV-B	3.16	**2.98**	
AL	"	"	UV-B	1.69		
AL	"	"	UV-B	3.73		2% TC remained and subtracted from total area.
AL	"	"	Oven	3.35		
AL	MIL-P-53022	Low VOC CARC	UV-B	2.62	**2.50**	2% TC remained and subtracted from total area.
AL	"	"	UV-B	2.62		2% TC remained and subtracted from total area.
AL	"	"	UV-B	2.66		2% TC remained and subtracted from total area.
AL	"	"	Oven	2.09		2% TC remained and subtracted from total area.
AL	MIL-P-23377	Low VOC CARC	UV-B	3.31	**3.47**	
AL	"	"	UV-B	3.75		
AL	"	"	UV-B	3.87		
AL	"	"	Oven	2.94		2% TC remained and subtracted from total area.
ST	MIL-P-53022	MIL-C-46168	UV-B	3.46	**3.79**	
ST	"	"	UV-B	4.12		
ST	"	"	UV-B	3.65		
ST	"	"	Oven	3.92		
ST	MIL-P-53022	MIL-C-29475	UV-B	3.73	**3.90**	2% TC remained and subtracted from total area.
ST	"	"	UV-B	4.59		
ST	"	"	UV-B	3.71		
ST	"	"	Oven	3.57		
ST	MIL-P-53022	Low VOC CARC[1]	UV-B	3.73	**3.83**	
ST	"	"	UV-B	4.12		
ST	"	"	UV-B	3.42		
ST	"	"	Oven	4.07		

1 - Navy Color

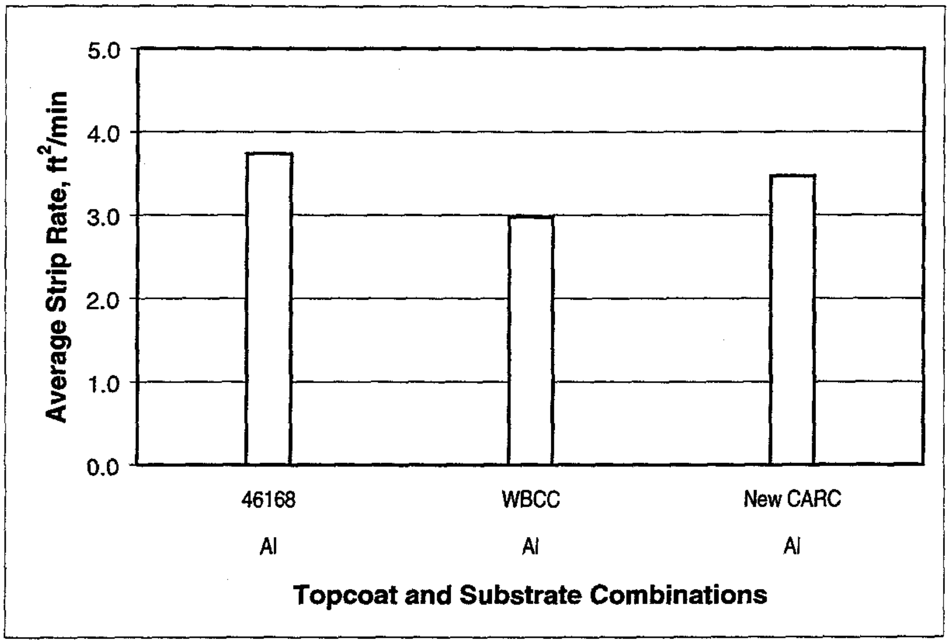


Figure 14. Anniston Steel Shot DMB Strippability with MIL-P-23377 Primer

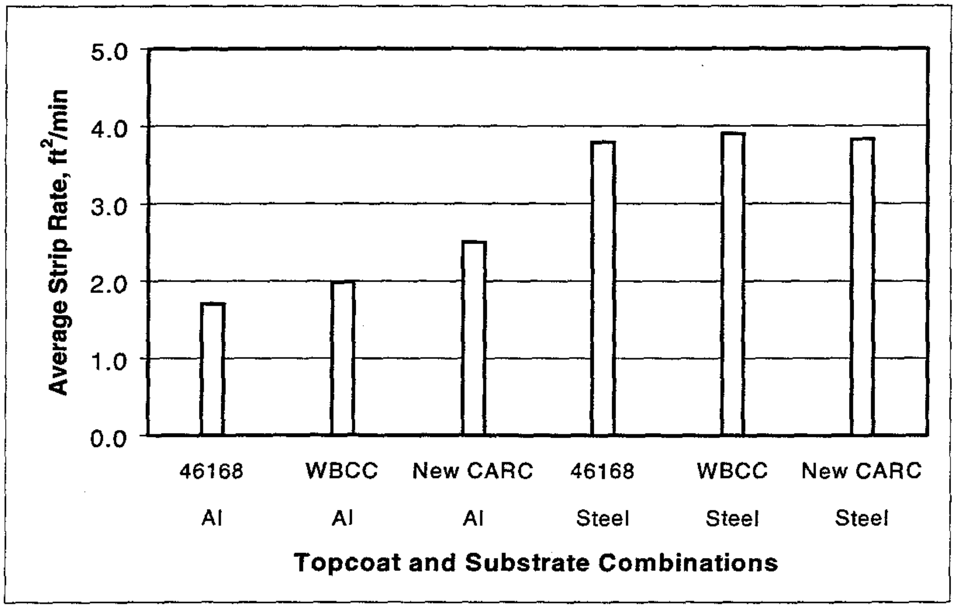


Figure 15. Anniston Steel Shot DMB Strippability with MIL-P-53022 Primer

Table 7. Corpus Christi Army Depot Wheatstarch Media Strippability Data

SUBSTRATE	PRIMER	TOP COAT	Age/Cure	Strip Rate, ft^2/min	Set Avg, ft^2/min	Notes
Fiberglass	MIL-P-53022	MIL-C-46168	**Oven**	0.34	**0.34**	
	"	"	**Oven**	0.34		
	"	"	**Oven**	0.35		
Fiberglass	MIL-P-53022	MIL-C-29475	**Oven**	0.55	**0.53**	
	"	"	**Oven**	0.60		
	"	"	**Oven**	0.44		
Fiberglass	MIL-P-53022	Low VOC CARC[1]	**Oven**	0.40	**0.46**	
	"	"	**Oven**	0.43		
	"	"	**Oven**	0.54		
Fiberglass	MIL-P-23377	MIL-C-46168	**Oven**	0.42	**0.38**	
	"	"	**Oven**	0.36		
	"	"	**Oven**	0.37		Stop Watch SU/ET Estimate
Fiberglass	MIL-P-23377	MIL-C-29475	**Oven**	0.49	**0.39**	
	"	"	**Oven**	0.40		
	"	"	**Oven**	0.28		
Fiberglass	MIL-P-23377	Low VOC CARC[1]	**Oven**	0.57	**0.56**	
	"	"	**Oven**	0.56		
	"	"	**Oven**			

[1] - Navy Color

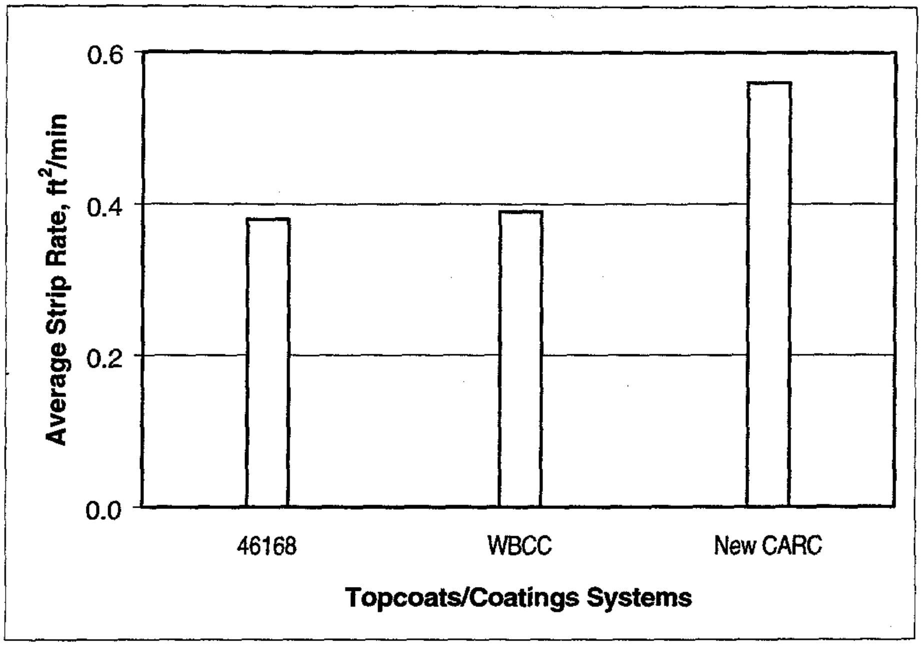


Figure 16. CCAD Wheatstarch Media Strippability with Fiberglass Substrate and MIL-P-23377 Primer

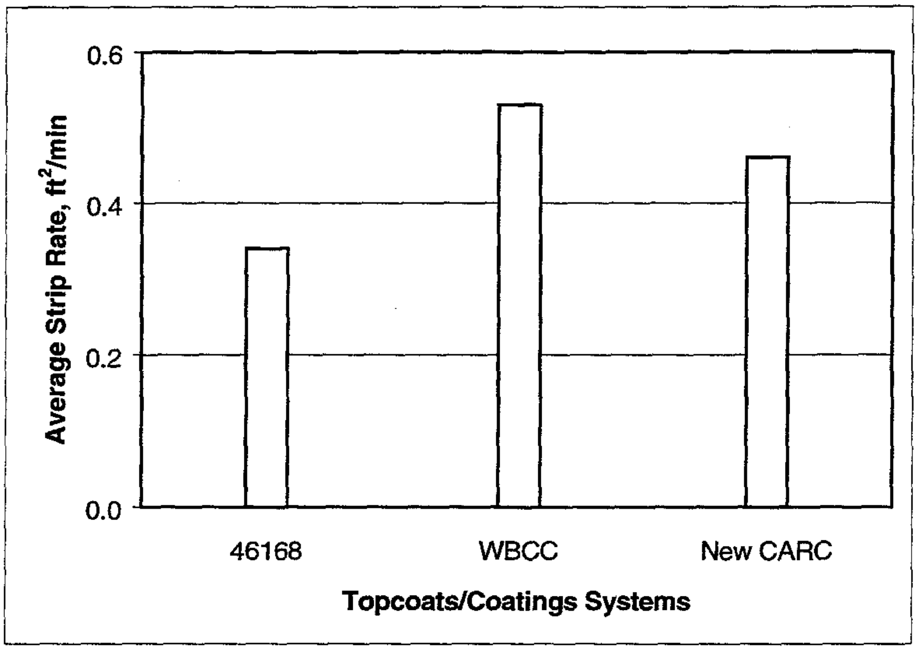


Figure 17. CCAD Wheatstarch Media Strippability with Fiberglass Substrate and MIL-P-53022 Primer

APPENDIX D

CHEMICAL DEPAINT STRIPPABILITY DATA

General Procedures

Samples representing each topcoat, primer, substrate combination were sheared to approximately 3" x 4" in size. Three hundred (300) milliliters of each chemical was placed in a 1000 ml beaker. Beakers were then placed into an oven and temperature was elevated as specified by each base's identified procedure. Temperature was checked by thermocouple probe and when at temperature, sample specimens were added. Each specimen was checked every 15 minutes for strip status. When each sample specimen was completely stripped, its actual strip time was noted. If any abnormal results were noted, the respective base was called for consultation and a second test was performed as deemed necessary. Base specific procedures and results are discussed in Table 1.

Table 1. Chemical Stripping Process(es) and Associated Maintenance Operation

Organization	Chemical ID	Substrate	Bath Temp	Dwell	Post Bath Process
Anniston Army Depot	Penetone NPX	Both	Ambient	0.25 - 2 hrs	cold water rinse w/water hose, hot water bath at 60C(140F)
Barstow Marine Depot	70% Sodium Hydroxide 30% Sodium Gluconate	Ferrous	93C(200F)	1-12 hrs	warm water rinse
Red River Army Depot	Ameratec ADL-220	Ferrous	82C(180F)	≤ 2 hrs	hot water rinse at 82C(180F), apply 25% phosphoric acid, cold water rinse
Red River Army Depot	Calgon EZE-545	Non-ferrous	60C(140F)	0.5 hrs	hot water rinse at 82C(180F), mechanically abrade as necessary to remove residue
Red River Army Depot[1]	Turco 6088A-Thin	Non-ferrous	60C(140F)	0.5 hrs	hot water rinse at 82C(180F)
Tobyhanna Army Depot	Turco 6088A-Thin	Non-ferrous	49C(120F)	≤ 12 hrs	warm water rinse

1 - Primary process used for non-ferrous materials by Red River.

Anniston Army Depot

Anniston Army Depot (ANAD) identified Penetone NPX is used for their chemical stripping efforts for both ferrous and non-ferrous materials. ANAD uses this chemical in immersion vats at ambient temperatures with an immersion time as little as 15 minutes.

Local testing of this chemical was performed per the General Procedures section and the results are noted in Table 2.

Table 2. Anniston Army Depot: Penetone NPX[1] at Ambient Temperature

Panel Serial #	Substrate	Primer	Topcoat	Aging Process	Expected Duration	Actual Strip Time[3]	Notes
189	Steel	53022	46168	Oven	15m-2h	15m	
213	Steel	53022	29475	Oven	15m-2h	15m	
230	Steel	53022	LVC[2](Grey)	Oven	15m-2h	15m	
188	Steel	53022	46168	UVB	15m-2h	15m	
207	Steel	53022	29475	UVB	15m-2h	15m	
233	Steel	53022	LVC(Grey)	UVB	15m-2h	15m	
6	Aluminum	53022	46168	Oven	15m-2h	1h-45m	
53	Aluminum	53022	29475	Oven	15m-2h	1h	
86	Aluminum	53022	LVC(Grey)	Oven	15m-2h	1h-30m	
33	Aluminum	23377	46168	Oven	15m-2h	15m	
73	Aluminum	23377	29475	Oven	15m-2h	15m	
113	Aluminum	23377	LVC(Grey)	Oven	15m-2h	15m	
123	Aluminum	53022	46168	UVA	15m-2h	15m	
131	Aluminum	53022	29475	UVA	15m-2h	15m	
139	Aluminum	53022	LVC(Grey)	UVA	15m-2h	15m	
155	Aluminum	23377	46168	UVA	15m-2h	15m	
163	Aluminum	23377	29475	UVA	15m-2h	15m	
147	Aluminum	23377	LVC(Grey)	UVA	15m-2h	15m	
10	Aluminum	53022	46168	UVB	15m-2h	15m	
52	Aluminum	53022	29475	UVB	15m-2h	15m	
94	Aluminum	53022	LVC(Grey)	UVB	15m-2h	15m	
156	Aluminum	23377	46168	UVB	15m-2h	15m	
164	Aluminum	23377	29475	UVB	15m-2h	15m	
148	Aluminum	23377	LVC(Grey)	UVB	15m-2h	15m	

1. Penetone NPX is a methylene chloride based stripper.
2. LVC (SERDP Low VOC CARC)
3. All panels in this set had 100% stripping of tested area.

Barstow Marine Deport

Barstow Marine Depot identified a mixture of Sodium Hydroxide and Sodium Gluconate in a 70%/30% solution, respectively. This process is used for their chemical stripping efforts for ferrous materials. Barstow uses this chemical in immersion vats heated to 200F with an immersion time of 1 hour – 12 hours.

These chemicals were procured and mixed per the Barstow ratios. Local testing of this chemical was performed per the General Procedures section and the results are noted in Table 3.

Table 3. Barstow Marine Depot: Sodium Hydroxide/Gluconate[1] at 200F for 12 hours

Panel Serial #	Substrate	Primer	Topcoat	Aging Process	Expected Duration	Actual Strip Time (Area)[2]	Notes
194	Steel	53022	46168	Oven	1-12h	12h (<10%)	3
217	Steel	53022	29475	Oven	1-12h	12h (<10%)	3
233	Steel	53022	LVC(Grey)	Oven	1-12h	12h (<10%)	3
196	Steel	53022	46168	Oven	1-12h	12h (<10%)	3,4
218	Steel	53022	29475	Oven	1-12h	12h (<10%)	3,4
234	Steel	53022	LVC(Grey)	Oven	1-12h	12h (<10%)	3,4
188	Steel	53022	46168	UVB	1-12h	12h (<10%)	3
207	Steel	53022	29475	UVB	1-12h	12h (<10%)	3
233	Steel	53022	LVC(Grey)	UVB	1-12h	12h (<50%)	3
195	Steel	53022	46168	UVB	1-12h	12h (<10%)	3,4
216	Steel	53022	29475	UVB	1-12h	12h (<10%)	3,4
234	Steel	53022	LVC(Grey)	UVB	1-12h	12h (<50%)	3,4

1. Ferrous materials only.
2. Stripped area of panel at maximum expected duration shown in parentheses, if not 100%.
3. Barstow reports results not abnormal. Chemical normally used for rust removal. Parts are removed when rust removal has been accomplished or 24 hours whichever comes first.
4. Second set was performed to verify data.

Red River Army Depot

This chemical is used at Red River Army Depot (RRAD) for CARC removal on ferrous materials. RRAD uses this chemical in immersion vats at a temperature of 180°F with immersion times as much as 2 hours.

Local testing of this chemical was performed per the General Procedures section and the results are noted in Table 4.

Table 4. Red River Army Depot: Ameritech ADL-220[1] at 180F for 2 hours

Panel Serial #	Substrate	Primer	Topcoat	Aging Process	Expected Duration	Actual Strip Time (Area)[2]	Notes
194	Steel	53022	46168	Oven	≤ 2 hours	2h (0%)	3
217	Steel	53022	29475	Oven	≤ 2 hours	2h (0%)	3
233	Steel	53022	LVC(Grey)	Oven	≤ 2 hours	2h (0%)	3
195	Steel	53022	46168	Oven	≤ 2 hours	2h (0%)	3,4
218	Steel	53022	29475	Oven	≤ 2 hours	2h (0%)	3,4
234	Steel	53022	LVC(Grey)	Oven	≤ 2 hours	2h (0%)	3,4
188	Steel	53022	46168	UVB	≤ 2 hours	2h (0%)	3
207	Steel	53022	29475	UVB	≤ 2 hours	2h (0%)	3
233	Steel	53022	LVC(Grey)	UVB	≤ 2 hours	2h (0%)	3
195	Steel	53022	46168	UVB	≤ 2 hours	2h (0%)	3,4
216	Steel	53022	29475	UVB	≤ 2 hours	2h (0%)	3,4
234	Steel	53022	LVC(Grey)	UVB	≤ 2 hours	2h (0%)	3,4

1. Ferrous materials only.
2. Stripped area of panel at maximum expected duration shown in parentheses, if not 100%.
3. Red River reports normal results for chemical and are researching a replacement.
4. Second set was performed to verify data.

This chemical is used at Red River Army Depot (RRAD) for CARC removal on non-ferrous materials. RRAD uses this chemical in immersion vats at a temperature of 140°F with an immersion time as little as 30 minutes.

Local testing of this chemical was performed per the General Procedures section and the results are noted in Table 5.

Table 5. Red River Army Depot: Calgon EZE-545[1] at 140F for 30 minutes minimum

Panel Serial #	Substrate	Primer	Topcoat	Aging Process	Expected Duration	Actual Strip Time[2]	Notes
11	Aluminum	53022	46168	Oven	30m min	2h 45m	
50	Aluminum	53022	29475	Oven	30m min	2h 45m	
91	Aluminum	53022	LVC(Green)	Oven	30m min	4h 15m	
31	Aluminum	23377	46168	Oven	30m min	45m	
75	Aluminum	23377	29475	Oven	30m min	30m	
105	Aluminum	23377	LVC(Green)	Oven	30m min	1h	
124	Aluminum	53022	46168	UVB	30m min	1h 15m	
132	Aluminum	53022	29475	UVB	30m min	2h 30m	
140	Aluminum	53022	LVC(Green)	UVB	30m min	3h 15m	
156	Aluminum	23377	46168	UVB	30m min	45m	
164	Aluminum	23377	29475	UVB	30m min	30m	
172	Aluminum	23377	LVC(Green)	UVB	30m min	30m	
123	Aluminum	53022	46168	UVA	30m min	1h 45m	
131	Aluminum	53022	29475	UVA	30m min	1h 45m	
139	Aluminum	53022	LVC(Green)	UVA	30m min	2h 45m	
155	Aluminum	23377	46168	UVA	30m min	30m	
163	Aluminum	23377	29475	UVA	30m min	30m	
171	Aluminum	23377	LVC(Green)	UVA	30m min	30m	

1. Non-Ferrous material only.
2. All panels in this set had 100% stripping of tested area.

This is the primary chemical used at Red River Army Depot (RRAD) for CARC removal on non-ferrous materials. RRAD uses this chemical in immersion vats at a temperature of 140°F with an immersion time as little as 30 minutes.

Local testing of this chemical was performed per the General Procedures section and the results are noted in Table 6.

Table 6. Red River Army Depot: Turco 6088A-Thin[1] at 140F for 30 minutes minimum

Panel Serial #	Substrate	Primer	Topcoat	Aging Process	Expected Duration	Actual Strip Time (Area)[2]	Notes
11	Aluminum	53022	46168	Oven	30m min	12h (25%)	
50	Aluminum	53022	29475	Oven	30m min	1h 15m	
91	Aluminum	53022	LVC(Green)	Oven	30m min	3h	
31	Aluminum	23377	46168	Oven	30m min	15m	
75	Aluminum	23377	29475	Oven	30m min	15m	
105	Aluminum	23377	LVC(Green)	Oven	30m min	15m	
124	Aluminum	53022	46168	UVB	30m min	15m	
132	Aluminum	53022	29475	UVB	30m min	45m	
140	Aluminum	53022	LVC(Green)	UVB	30m min	45m	
156	Aluminum	23377	46168	UVB	30m min	30m	
164	Aluminum	23377	29475	UVB	30m min	15m	
172	Aluminum	23377	LVC(Green)	UVB	30m min	30m	
18	Aluminum	53022	46168	UVA	30m min	1h	
131	Aluminum	53022	29475	UVA	30m min	1h	
25	Aluminum	53022	LVC(Green)	UVA	30m min	30m	
155	Aluminum	23377	46168	UVA	30m min	15m	
163	Aluminum	23377	29475	UVA	30m min	15m	
171	Aluminum	23377	LVC(Green)	UVA	30m min	15m	

1. Non-Ferrous material only.
2. Stripped area of panel at maximum expected duration shown in parentheses, if not 100%.

Tobyhanna Army Depot

This chemical is used at Tobyhanna Army Depot for CARC removal on non-ferrous materials. Tobyhanna uses this chemical in immersion vats at a temperature of 120°F with an immersion times of 1-12 hours.

Local testing of this chemical was performed per the General Procedures section and the results are noted in Table 7.

Table 7. Tobyhanna Army Depot: Turco 6088A-Thin[1] at 120F for 2-4 hours

Panel Serial #	Substrate	Primer	Topcoat	Aging Process	Expected Duration	Actual Strip Time (Area)[2]	Notes
12	Aluminum	53022	46168	Oven	1-12h	12h (25%)	
49	Aluminum	53022	29475	Oven	1-12h	2h	
90	Aluminum	53022	LVC(Green)	Oven	1-12h	4h	
29	Aluminum	23377	46168	Oven	1-12h	45m	
75	Aluminum	23377	29475	Oven	1-12h	30m	
103	Aluminum	23377	LVC(Green)	Oven	1-12h	30m	
10	Aluminum	53022	46168	UVB	1-12h	12h (25%)	
132	Aluminum	53022	29475	UVB	1-12h	1h 15m	
94	Aluminum	53022	LVC(Green)	UVB	1-12h	1h 15m	
156	Aluminum	23377	46168	UVB	1-12h	30m	
164	Aluminum	23377	29475	UVB	1-12h	15m	
172	Aluminum	23377	LVC(Green)	UVB	1-12h	15m	
21	Aluminum	53022	46168	UVA	1-12h	45m	
18	Aluminum	53022	29475	UVA	1-12h	1h	
25	Aluminum	53022	LVC(Green)	UVA	1-12h	45m	
155	Aluminum	23377	46168	UVA	1-12h	30m	
163	Aluminum	23377	29475	UVA	1-12h	15m	
171	Aluminum	23377	LVC(Green)	UVA	1-12h	30m	

1. Non-Ferrous material only.
2. Stripped area of panel at maximum expected duration shown in parentheses, if not 100%.

APPENDIX E

CARC STRIPPABILITY DATA for APPLIED LIGHT ENERGY PROCESSES

Table 1. Flashjet Strippability Data .

SUBSTRATE	PRIMER	TOP COAT	Age/Cure	Strip Rate, ft^2/min	Avg ft^2/min	Notes
FG	MIL-P-53022	MIL-C-46168	**Oven**	2.44	**2.18**	Significant Topcoat
FG	"	"	**Oven**	2.06		"
FG	"	"	**Oven**	2.06		"
FG	"	"	**Oven**	2.16		"
FG	MIL-P-23377	MIL-C-46168	**Oven**	3.09	**3.00**	Stripped to
FG	"	"	**Oven**	3.09		"
FG	"	"	**Oven**	3.00		"
FG	"	"	**Oven**	2.81		"
FG	MIL-P-53022	Low VOC [1]	**Oven**	4.08	**3.94**	Significant Bare
FG	"	"	**Oven**	4.05		Uniform Footprint. 50%
FG	"	"	**Oven**	3.80		Significant Bare
FG	"	"	**Oven**	3.84		Uniform Footprint30% Bare
FG	MIL-P-23377	MIL-C-29475	**Oven**	4.03	**4.10**	Some Primer
FG	"	"	**Oven**	4.13		"
FG	"	"	**Oven**	4.15		"
FG	"	"	**Oven**	4.10		"
FG	MIL-P-53022	MIL-C-29475	**Oven**	3.05	**3.18**	Small Areas of Bare
FG	"	"	**Oven**	3.38		"
FG	"	"	**Oven**	3.09		"
FG	"	"	**Oven**	3.19		"
FG	MIL-P-23377	Low VOC [1]	**Oven**	4.24	**4.13**	Some Primer
FG	"	"	**Oven**	4.10		"
FG	"	"	**Oven**	4.10		"
FG	"	"	**Oven**	4.08		"

1 - Navy Color

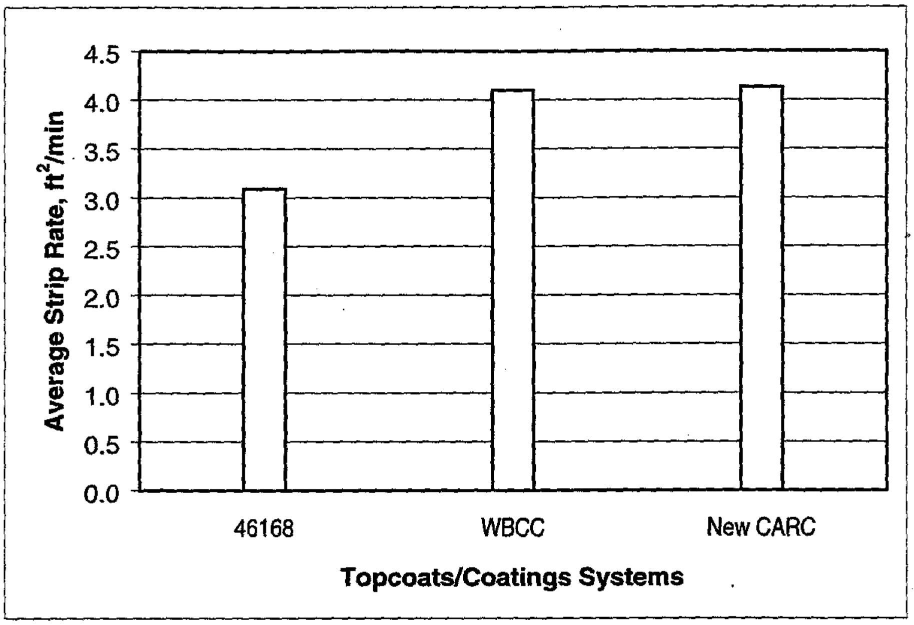


Figure 1. FlashJet™ Strippability with Fiberglass Substrate and MIL-P-23377 Primer

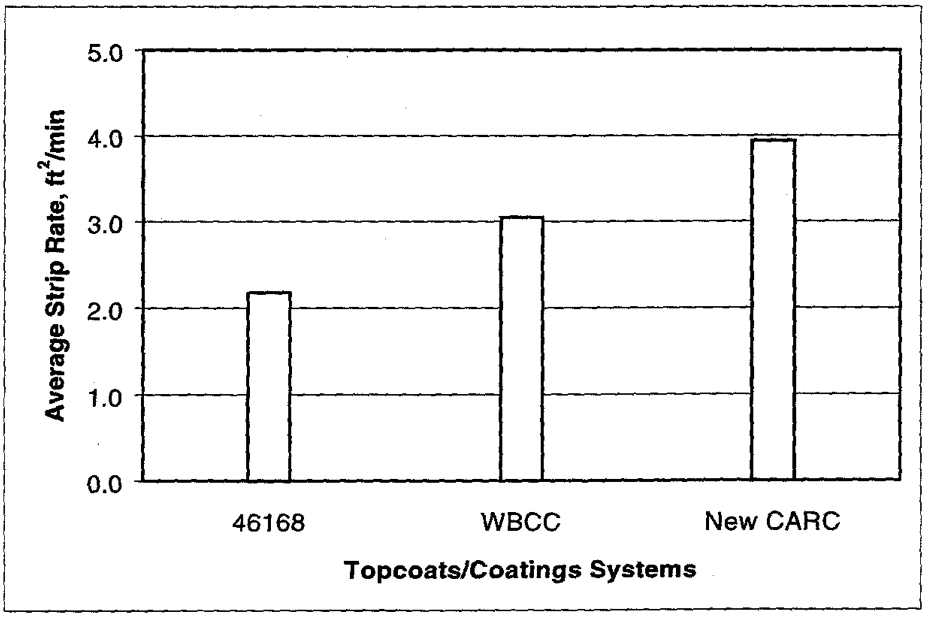


Figure 2. FlashJet™ Strippability with Fiberglass Substrate and MIL-P-53022 Primer

Table 2. GLC Pulsed Nd:YAG Laser Strippability Data

SUBSTRATE	PRIMER	Age/Cure	TOPCOAT	Avg Strip Rate, ft2/min
Al	MIL-P-53022	Oven	46168	0.0150
Al	"	Oven	WBCC	0.0128
Al	"	Oven	Low VOC CARC	0.0202
Steel	MIL-P-53022	Oven	46168	0.0125
Steel	"	Oven	Low VOC CARC	0.0190
Al	MIL-P-23377	Oven	46168	0.0157
Al	"	Oven	WBCC	0.0255
Al	"	Oven	Low VOC CARC	0.0293
FG	MIL-P-53022	Oven	46168	0.0098
FG	"	Oven	WBCC	0.0098
FG	"	Oven	Low VOC CARC	0.0135
FG	MIL-P-23377	Oven	46168	0.0110
FG	"	Oven	WBCC	0.0098
FG	"	Oven	Low VOC CARC	0.0122

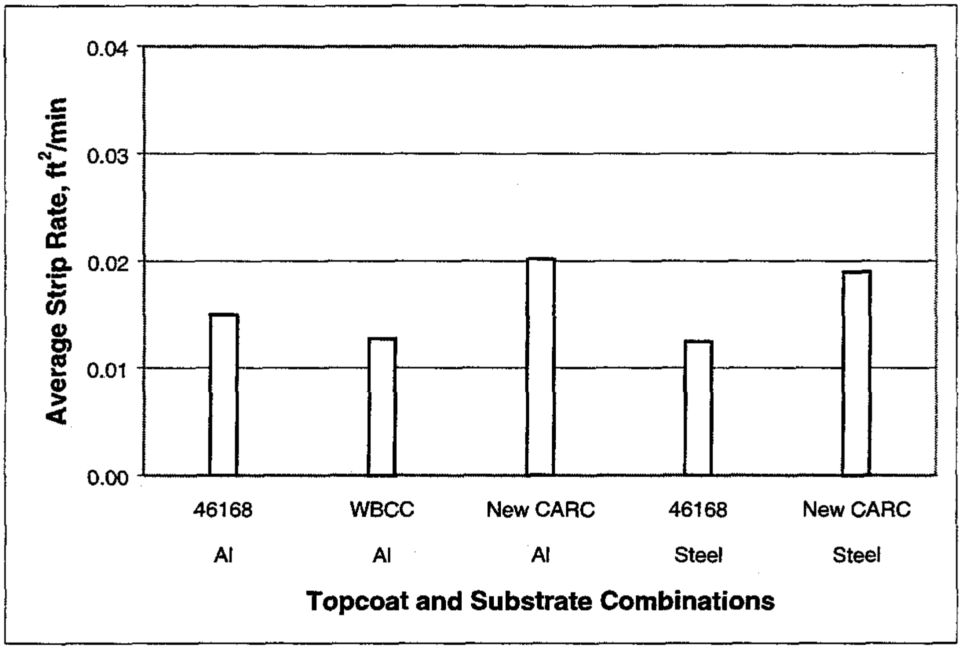


Figure 3. GLC Pulsed Nd:YAG Laser Strippability with MIL-P-53022 Primer

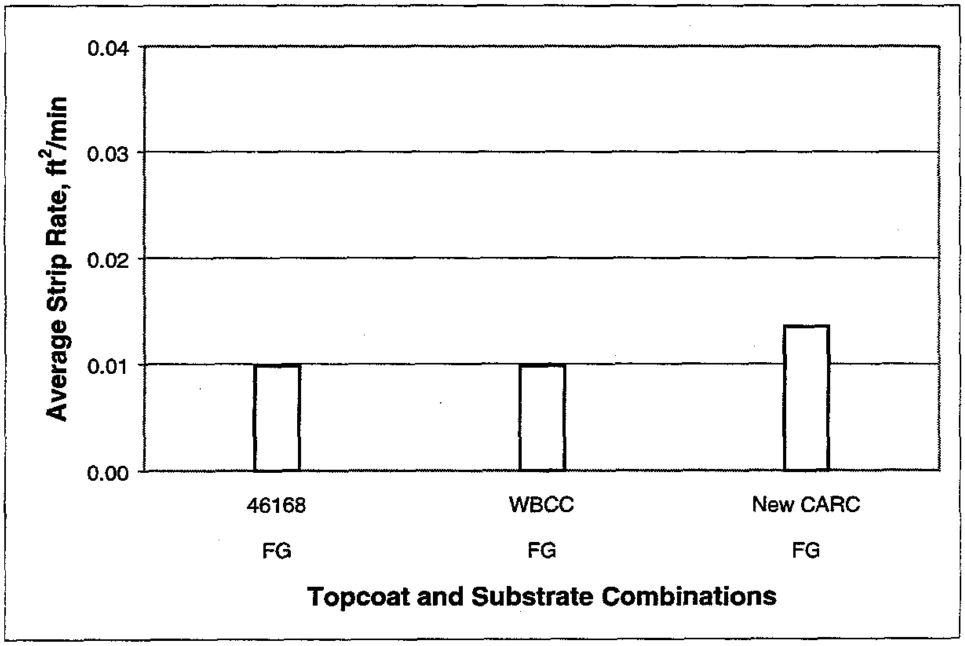


Figure 4. GLC Pulsed Nd:YAG Laser Strippability with MIL-P-53022 Primer

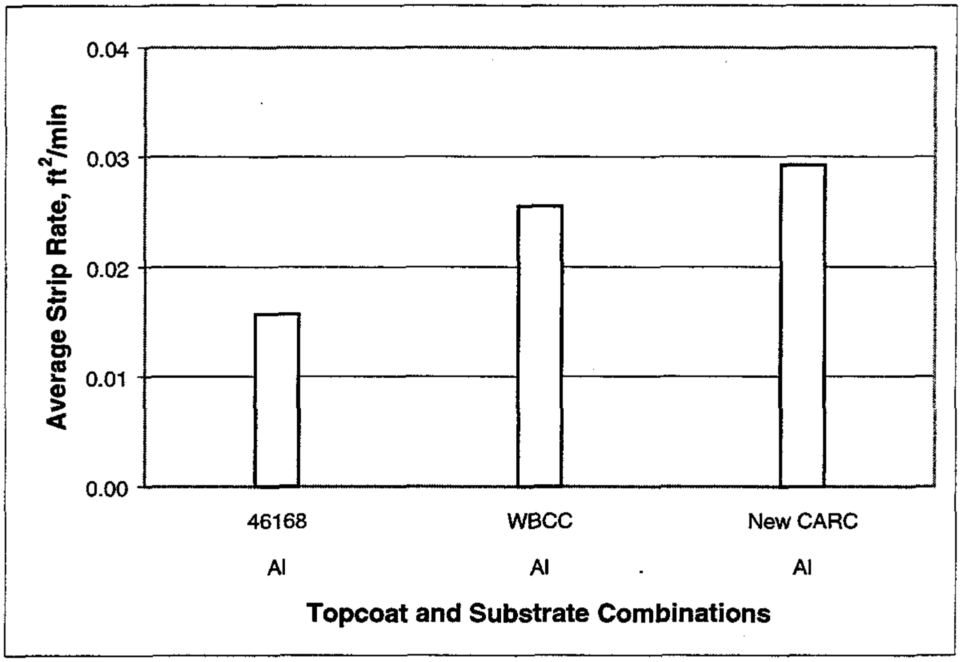


Figure 5. GLC Pulsed Nd:YAG Laser Strippability with MIL-P-2337Primer

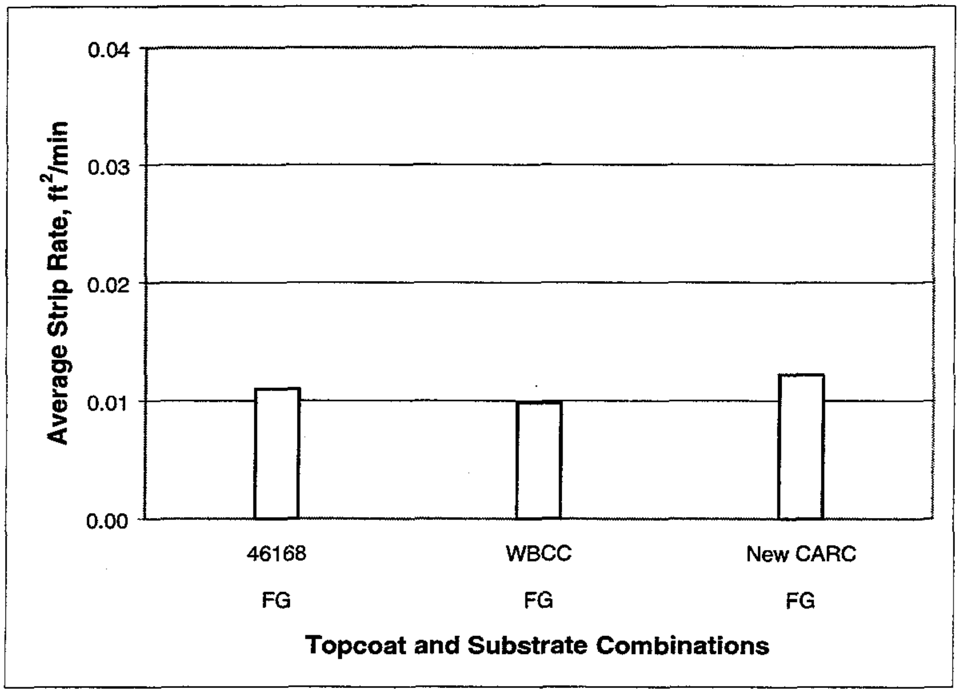


Figure 6. GLC Pulsed Nd:YAG Laser Stippability with MIL-P-23377 Primer

Table 3. CWA Pulsed Nd:YAG Laser Strippability Data

SUBSTRATE	PRIMER	Age/Cure	TOPCOAT	Avg Strip Rate, ft2/min
Al	MIL-P-53022	Oven	46168	0.0060
Al	"	Oven	WBCC	0.0024
Al	"	Oven	Low VOC CARC	0.0093
Steel	MIL-P-53022	Oven	46168	0.0049
Steel	"	Oven	Low VOC CARC	0.0059
Al	MIL-P-23377	Oven	46168	0.0018
Al	"	Oven	WBCC	0.0042
Al	"	Oven	Low VOC CARC	0.0351
FG	MIL-P-53022	Oven	46168	0.0046
FG	"	Oven	Low VOC CARC	0.0042
FG	MIL-P-23377	Oven	46168	0.0063
FG	"	Oven	WBCC	0.0074

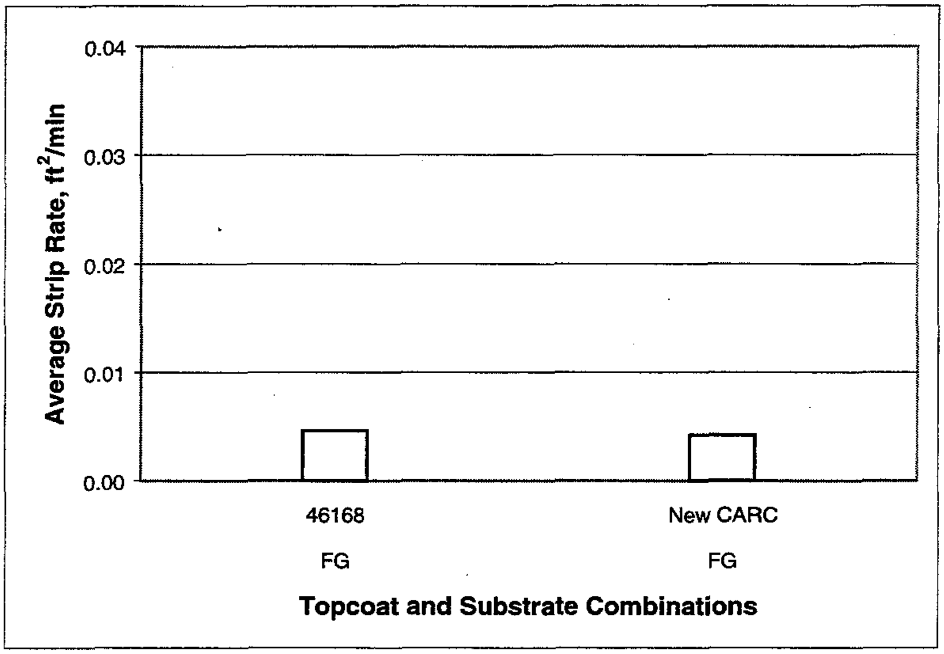


Figure 7. CWA Pulsed Nd:YAG Laser Strippability with MIL-P-53022 Primer

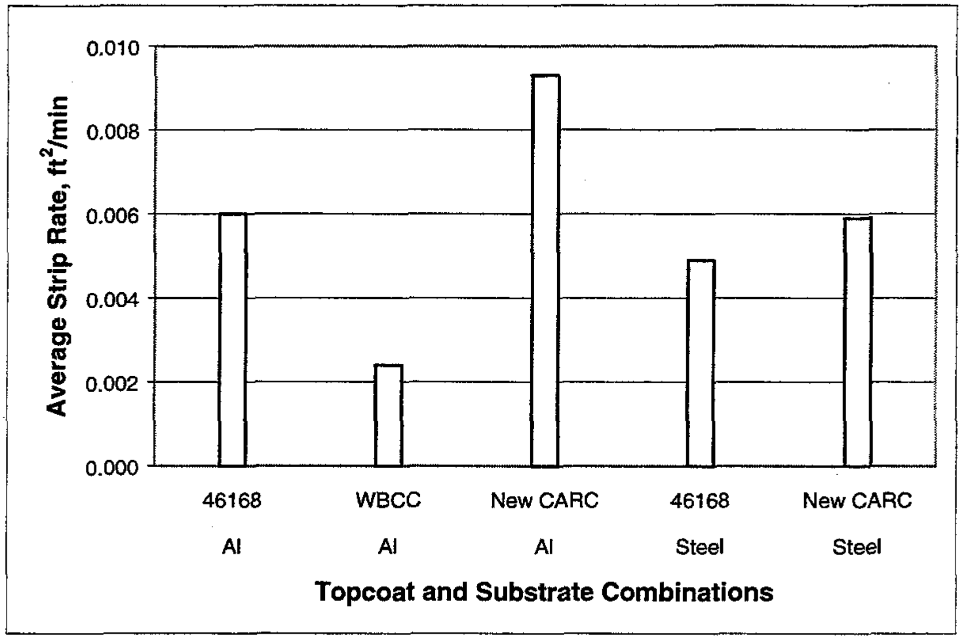


Figure 8. CWA Pulsed Nd:YAG LASER Strippability with MIL-P-53022 Primer

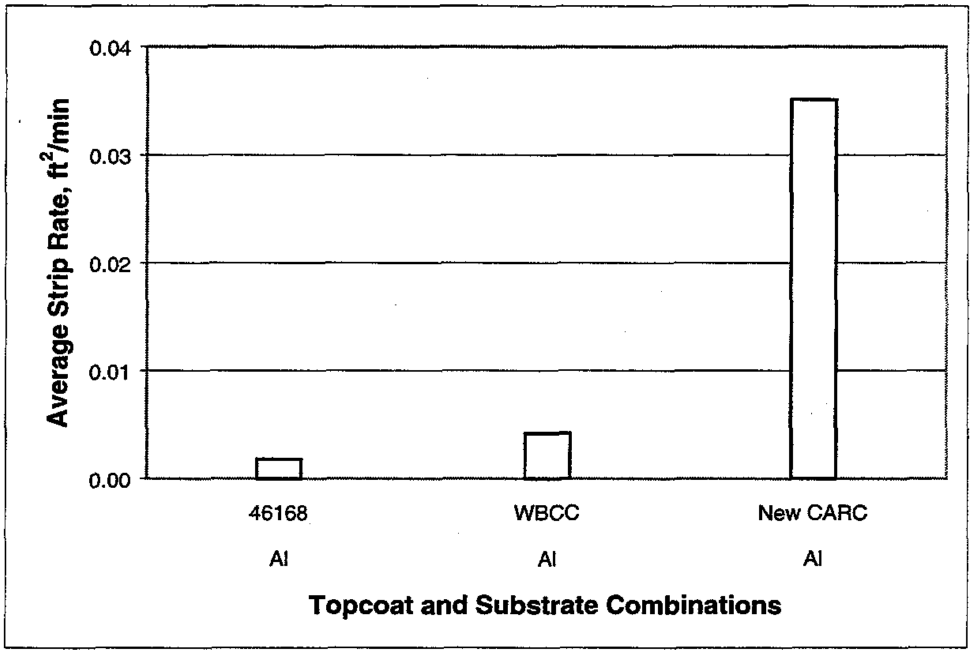


Figure 9. CWA Pulsed Nd:YAG Laser Strippability with Mil-P-23377 Primer

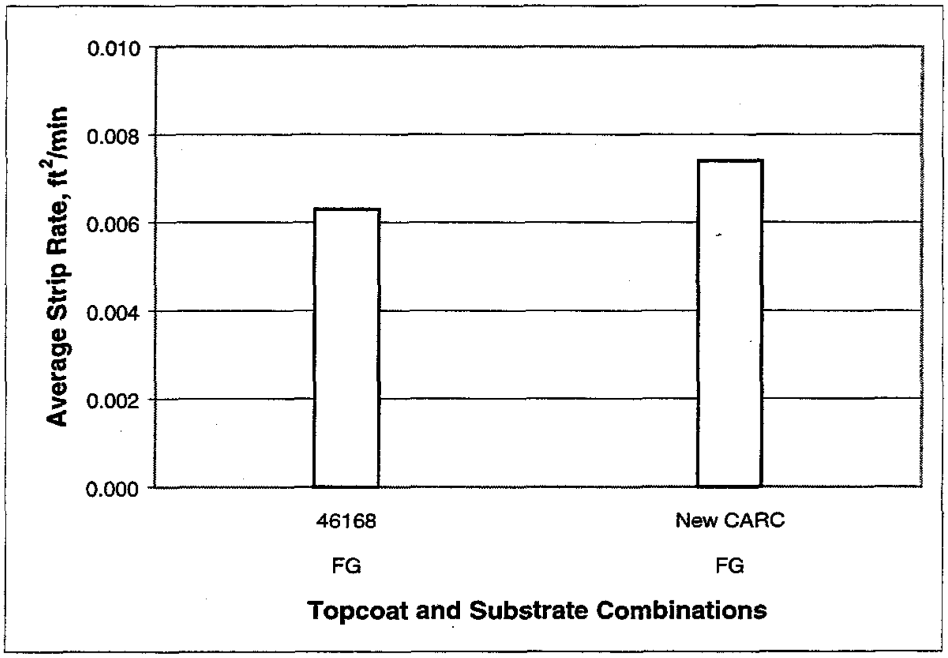


Figure 10. CWA Pulsed Nd:YAG Laser Strippability with MIL-P-23377 Primer