Item Unique Identification (IUID)
Environmental Survivability Testing Report 2012

Independent Assessment of Vendor-Supplied Materials

Naval Surface Warfare Center, Corona Division
IUID Center

September 2012

Version 1.0

Item Unique Identification (IUID) Environmental Survivability Testing Report 2012

Foreword

The IUID Center at the Naval Surface Warfare Center (NSWC), Corona Division was tasked by the Director of Administrative/Fiscal Division in the Office of the Assistant Secretary of the Navy (Financial Management and Comptroller) to conduct a follow-on environmental survivability study of available IUID marking products and provide technical performance data to the IUID community. This report presents the results and technical performance data of this follow-on study. Direct part marked plates, cable tags, and adhesive backed labels were tested on multiple surfaces, including chemical resistant coating (CARC), for survivability in various simulated environments. Similar testing was conducted in 2010-2011 and is published in a report entitled, "Item Unique Identification (IUID) Environmental Survivability Testing Report."[1] Thanks to input from users of the previous report, tests were added including adhesion to CARC, elevated temperature adhesion, UV exposure, pressure wash, and expanded chemical exposure tests. Additionally, tests that minimally impacted labels or had limited utility were removed including abrasion, salt fog, and high and low temperature exposure tests. Although abrasion and salt fog are well established and commonly conducted tests, they were not found to be pertinent to adhesive backed plastic labels after the 2010-2011 testing. Salt fog affects metals and induces corrosion but has little to no effect on most plastics. Given that most labels tested in this report were plastic, resources were diverted to other tests likely to show more effects on the label types. Abrasion, specifically the taber abraser, affected some label types significantly but there seems to be no way to correlate the testing to a quantity of real world degradation. Additionally, labels with laminates were affected by positioning and the test seemed to not test labels uniformly. For these reasons, this test was also removed.

In this round of testing, the number of tests more than doubled from 8 to 18; the number of label types tested increased from 18 to 47; direct part marks were included; products from 15 suppliers were tested compared to 8 previously; and CARC was added as an additional surface on which labels were tested. Users of this report can select IUID products already tested by NSWC Corona, the independent assessment center for the Navy, to fit the needs of their program or environment. Selection of IUID products durable enough for military applications should improve permanency of IUID data matrices and positively impact logistics, item traceability, and financial auditability by ensuring items are not lost due to inadequate labeling or inventoried multiple times by individuals improperly re-marking items where the data matrix has detached or become illegible.

Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not constitute or imply its endorsement or recommendation by the Department of Navy or the Department of Defense. The views and opinions of the authors expressed herein do not necessarily reflect those of the Department of Navy or the Department of Defense, and shall not be used for advertising or product endorsement purposes.

[1] http://www.acq.osd.mil/dpap/pdi/uid/docs/iuid_environmental_survivability_testing_report.pdf

Introduction

Prompted by findings from the Government Accountability Office (GAO) revealing a lack of accountability of its assets, the Department of Defense (DoD) developed a plan to address these findings. IUID is the centerpiece of that plan and involves, generally speaking, a definition of items which fall under the policy, a requirement to mark these items with an individually unique, two-dimensional (2D) Error Correction Code[2] (ECC) 200 data matrix symbol depicted in Figure 1. These marks are required to be as permanent as the normal life expectancy of the item and be capable of withstanding the environmental tests and cleaning procedures specified for the item to which it is affixed.

Figure 1. ECC200 data matrix symbol

These requirements are established for qualifying items by the Defense Federal Acquisition Regulation Supplement (DFARS)[3] and various DoD instructions (DoDI) and directives[4] (DoDD).

Although challenges exist in other facets of implementing IUID, this report addresses, in a limited way, some of the challenges with meeting the permanency requirements of IUID policy. Failure of the permanency requirement falls into two broad categories:

- Attachment failure – where the mark either falls off of the item or is forcefully removed.
- Degradation failure – where the mark is worn to the point where it is unreadable.

Although recounting the broad categories of failure seems to indicate a simple problem, it becomes incredibly complex under even modest examination. The diversity of environments in which the DoD operates (sea, space, air, desert, tropics, arctic, etc.) and the prolific variety of equipment the DoD employs to achieve its mission lead to a large number of permutations. In fact, so large is the variety of items and environments some combinations produce mutually exclusive solutions. For example, some IUID marks may need to be flexible for parachutes and others may need to be rigid to survive supersonic air streams. As such, it is impossible to define a singular marking material or methodology which is best, or even suitable, for all applications. Accordingly, the DoD has not specified marking materials nor methods, but rather has left these decisions to the item managers on an item by item basis. Dividing the problem among the item managers who know the environments to which their equipment will be subjected, solves the first half of the problem. Choosing which marking method to use is the second half of the problem.

The second half of the problem is addressed by each of the item managers individually identifying the materials and methods most suited to their items within their environments. In response to this need, the vendor community has developed hundreds of materials, tens of thousands of adhesives, multiple marking methods and protective coatings which can be mixed and matched to produce many permutations. The large number of permutations means most needs can be met, often in multiple ways. This allows for price

---

[2] ECC is also known as Error Checking and Correction by some.
[3] DFARS 211.274, DFARS 252.211-7003, DFARS 252.211-7007
[4] DoDI 5000.02, DoDI 5000.64, DoDI 8320.04, DoDD 8320.03

competition and the security of multiple suppliers. Unfortunately, the item manager is often overwhelmed by the available choices and has few tools to help navigate to an answer. To fulfill the need for adequate, comparable information regarding the performance and applicability of marking methods and materials, this independent assessment of commercially available marking methods and materials was performed.

This report is intended as an aid in the selection of appropriate marking materials for IUID implementation. The quantity of available materials and the wide range of environments in which the DoD operates make an exhaustive study of all possible permutations unfeasible. This report contains analysis of environmental test data collected from materials submitted by 13 companies, as well as labels from two companies that were of interest to NSWC Corona for a total of 47 label types. A list of the submitted label types is found in Table 1. Note that label types PO10 and PT10 were submitted internally by NSWC Corona. These label types were subjected to the same testing as other label types, but given that the submitter and testing laboratory were the same organization, results cannot, by definition, be fundamentally independent. Accordingly, readers may choose to discount the results of these label types if they have concern over lack of independence. For the purposes of this document, the term label refers to flexible adhesive backed materials, data plates, and materials submitted by companies for testing. The testing does not include all commercially available materials or all relevant tests.

Organization

This report is divided into a body and several appendices. The body contains limited detail and is intended to help the reader understand the basics of the IUID environmental survivability tests performed. The body should also provide sufficient information to determine which, if any, of the labels tested performed well enough in simulated environments to be used for the readers' intended IUID application.

The appendices provide more in-depth analysis of specific topics. Some of the appendices provide details of the test methods used. Other subjects such as statistics, data analysis methods, and verifier variability are also discussed in the appendices.

Testing Approach

Standardized tests are one method used to differentiate label quality for use in intended environments. Instances of IUID labels passing standardized tests (e.g., MIL-PRF-61002, MIL-DTL-15024, FED-STD-191, MIL-STD-13231) and then failing in the field have been reported. One example of this is labels passing the abrasion test described in American Society for Testing and Materials (ASTM) D4060 for a set number of cycles and then failing in abrasion intensive military environments such as Iraq and Afghanistan.

These types of failures suggest the need to adapt tests to be more applicable to data matrices. Many of the standard tests for labels and data plates were developed for linear bar codes and/or human readable information and are not optimized for IUID compliant two-dimensional data matrices. Another deficiency of many standard tests is adherence to specific pass/fail thresholds which may be applicable for particular environments, but may not be generally applicable.

Several standard tests were adapted to include assessments of data matrix legibility in an effort to establish IUID relevance. These adapted tests are detailed in Appendix 8 through Appendix 12 and the standard tests they were adapted from are given in the reference material section of the respective appendix. Data matrix legibility is assessed by a process known as verification[5]. Adapting tests to capture data on the quality of a data matrix as a function of test severity eliminates specific "pass/fail" thresholds and allows users of the data to determine how severe their environment is and select relevant testing thresholds. Where possible, tests were conducted until the data matrix failed verification and became unreadable.

[5] Verification is an optical measurement technique that digitally measures data matrix quality using multiple parameters as defined in established standards ISO/IEC 15415, AS9132, and AIM-DPM-1-2006.

Some tests had minimal effect on many of the submitted labels. Tests with minimal effect were discontinued prior to data matrices failing verification to allow resources to be focused on more discriminating tests.

Overview of Materials Submitted and Tests Conducted

Industry participation in this study was solicited via a sources sought notification posted from 25 Oct 2011 to 30 Nov 2011. The notification identified the types of tests to be conducted and limited each vendor's submission to a maximum of six labels types with 250 labels of each label type. The six label types could be specified for high or low surface energy[6] or CARC substrates. In order to minimize variability, companies were given tight tolerances on label submissions, data matrix dimensions, and were requested to encode the data matrices identically. See Appendix 3 for the sources sought notification and supplemental specifications.

Companies were provided a list of possible tests to encourage submission of labels thought to perform optimally in the simulated environments. The risk of this strategy is companies may submit labels optimized for tests in a laboratory and not the real environment. However, laboratory testing is intended to simulate a specific degrading influence of an environment and allow side by side comparison of multiple labels to an identical quantity of the "degrading influence" which allows label performance to be ranked and allows users of this report to select labels with suitable performance. Appendix 3 shows the list of possible tests provided to interested companies.

All tested labels were verified prior to any testing to baseline the mark quality and subsequently verified after each increment of testing until the testing ceased. Verification was performed using a Microscan UID DPM[7] Compliance verifier to the AIM-DPM-1-2006 standard.

The tests performed from the list of possible tests identified in Appendix 3 are shown below. Tests were selected based on three main factors:

1. Department of the Navy interest in the test.
2. Time and funding constraints.
3. Availability of equipment and materials.

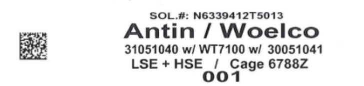
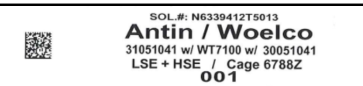
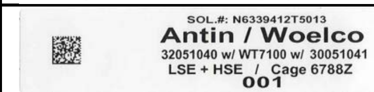
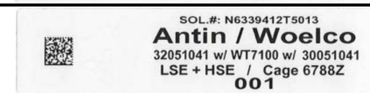
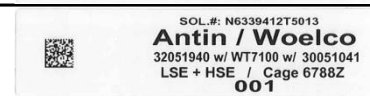
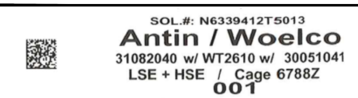
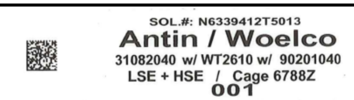
Some tests were damaging enough to cause most labels to experience adhesive or verification failure, allowing clear differentiation between labels. Other tests had less of an effect on the majority of labels and rankings within those tests indicate labels were still verifiable in many cases but showed statistically significant degradation. These "tests to failure" and "tests with limited effect" are shown below in Table 2. Appendix 4 discusses the statistical method chosen for analysis of test results. Details of each test method and in-depth data analysis of the results are given in respective appendices.

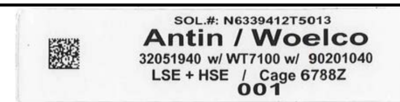
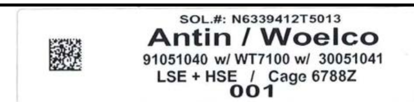
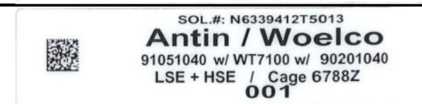
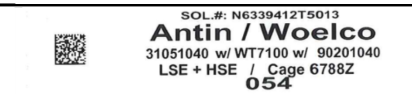
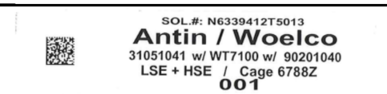
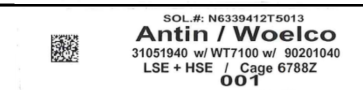
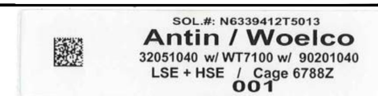
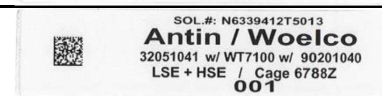
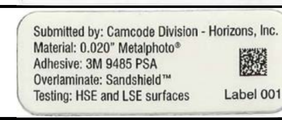
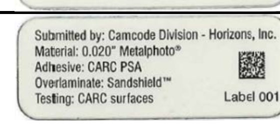
[6] Surface energy is a measure of the attractive forces a surface exerts. Plastics tend to have low surface energy (water beads and is not attracted to the surface). Uncoated metals and glass have high surface energy (water coats and is attracted to the surface). Surface energy also indicates the magnitude of attraction between adhesives and a surface. Special formulations of adhesives are required for high strength bonding to low surface energy materials.

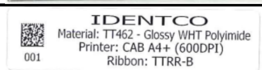
[7] Direct Part Marking

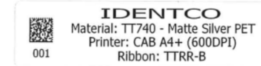
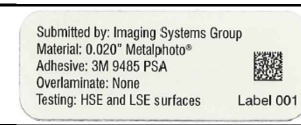
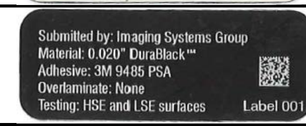
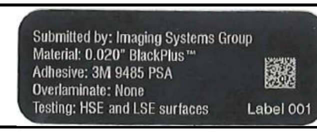
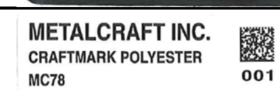
Table 1. Submitted label types

Note: Numerical designations of label types and the order of label types in the "Material ID" column have no correlation to performance in tests described in this report.

Material ID	Product	Label Material	Adhesive	Submitter	Description	Label
AB12	UV High Resist	Silver Polyester	Modified Acrylic	A2B Tracking Solutions	Label	
		Clear Polyester	Modified Acrylic		Laminate	
AB13	3M 7847	Acrylate	3M 9485	A2B Tracking Solutions	Label	
AN10	31051040	Polyester	Permanent Pressure-sensitive acrylic	ANTIN	Label	
	30051041	Polyester	FLEXcon L-10		Laminate	
AN11	31051041	Polyester	Permanent Pressure-sensitive acrylic	ANTIN	Label	
	30051041	Polyester	FLEXcon L-10		Laminate	
AN12	31051940	Polyester	Permanent Pressure-sensitive acrylic	ANTIN	Label	
	30051041	Polyester	FLEXcon L-10		Laminate	
AN13	32051040	Polyester	Permanent Pressure-sensitive acrylic	ANTIN	Label	
	30051041	Polyester	FLEXcon L-10		Laminate	
AN14	32051041	Polyester	Permanent Pressure-sensitive acrylic	ANTIN	Label	
	30051041	Polyester	FLEXcon L-10		Laminate	
AN15	32051940	Polyester	Permanent Pressure-sensitive acrylic	ANTIN	Label	
	30051041	Polyester	FLEXcon L-10		Laminate	
FC10	31051040	Polyester	Permanent Pressure-sensitive acrylic	FLEXCON	Label	
	30031040	Polyester	FLEXcon L-344		Laminate	
FC11	31082040	Polyester	Permanent Pressure-sensitive acrylic	FLEXCON	Label	
	30051041	Polyester	FLEXcon L-10		Laminate	
FC12	31082040	Polyester	Permanent Pressure-sensitive acrylic	FLEXCON	Label	
	90201040	Polyurethane	FLEXcon V-124		Laminate	

Material ID	Product	Label Material	Adhesive	Submitter	Description	Label
FC13	32051940	Polyester	Permanent Pressure-sensitive acrylic	FLEXCON	Label	
	90201040	Polyurethane	FLEXcon V-124		Laminate	
FC14	91051040	Polyimide	Permanent Pressure-sensitive acrylic	FLEXCON	Label	
	30051041	Polyester	FLEXcon L-10		Laminate	
FC15	91051040	Polyimide	Permanent Pressure-sensitive acrylic	FLEXCON	Label	
	90201040	Polyurethane	FLEXcon V-124		Laminate	
WC10	31051040	Polyester	Permanent Pressure-sensitive acrylic	WOELCO	Label	
	30031041	Polyester	FLEXcon L-10		Laminate	
WC11	31051040	Polyester	Permanent Pressure-sensitive acrylic	WOELCO	Label	
	90201040	Polyurethane	FLEXcon V-124		Laminate	
WC12	31051041	Polyester	Permanent Pressure-sensitive acrylic	WOELCO	Label	
	90201040	Polyurethane	FLEXcon V-124		Laminate	
WC13	31051940	Polyester	Permanent Pressure-sensitive acrylic	WOELCO	Label	
	90201040	Polyurethane	FLEXcon V-124		Laminate	
WC14	32051040	Polyester	Permanent Pressure-sensitive acrylic	WOELCO	Label	
	90201040	Polyurethane	FLEXcon V-124		Laminate	
WC15	32051041	Polyester	Permanent Pressure-sensitive acrylic	WOELCO	Label	
	90201040	Polyurethane	FLEXcon V-124		Laminate	
CA10	Metalphoto®	Photosensitive Anodized Aluminum with Laminate	3M 9485	Camcode	Label	
	SandShield™				Laminate	
CA11	Metalphoto®	Photosensitive Anodized Aluminum with Laminate	CARC Adhesive	Camcode	Label	
	SandShield™				Laminate	

Material ID	Product	Label Material	Adhesive	Submitter	Description	Label
CA12	DuraBlack® SandShield™	Multi-Layer Coated Anodized Aluminum with Laminate	3M 9485	Camcode	Label Laminate	
CA13	DuraBlack® SandShield™	Multi-Layer Coated Anodized Aluminum with Laminate	CARC Adhesive	Camcode	Label Laminate	
CA14	BlackPlus™ SandShield™	Exterior Grade Black Anodized Aluminum with Laminate	3M 9485	Camcode	Label Laminate	
CA15	BlackPlus™ SandShield™	Exterior Grade Black Anodized Aluminum with Laminate	CARC Adhesive	Camcode	Label Laminate	
CO12	Cable Marker	Thermoplastic	N/A	CodeSource	Cable Marker	
CO13	Cable Marker	Thermoplastic	N/A	CodeSource	Cable Marker	
ES11	B-423 3M 8671	Polyester Polyurethane	Permanent Acrylic Acrylic	EasySoft Corp	Label Laminate	
ES12	DuraBlack	Aluminum	3M 350	EasySoft Corp	Label	
ID10	Metal Plate	#4 Mechanical Polish 304 Stainless Steel	N/A	IDIntegration	Dot Peen Marking on metal plate	
IK10	TT462	Polyimide	Permanent Acrylic	Identco	Label	
IK11	TT700	Polyester	Permanent Acrylic	Identco	Label	
IK12	TT701	Polyester	Permanent Acrylic	Identco	Label	
IK13	TT705A	Polypropylene	Emulsion Acrylic	Identco	Label	

Material ID	Product	Label Material	Adhesive	Submitter	Description	Label
IK14	TT730	Polyester	Permanent Acrylic	Identco	Label	
IK15	TT740	Polyester	Permanent Acrylic	Identco	Label	
IM11	L3203158	White Gloss Polyester	High Performance Acrylic Adhesive	Intermec Technologies Corp	Label	
	L3261010	Clear Gloss Adhesive	Permanent Acrylic Adhesive		Laminate	
HO10	Metalphoto®	Photosensitive Anodized Aluminum	3M 9485	Imaging Systems Group (ISG)	Label	
HO11	Metalphoto®	Photosensitive Anodized Aluminum	CARC Adhesive	Imaging Systems Group (ISG)	Label	
HO12	DuraBlack®	Multi-Layer Coated Anodized Aluminum	3M 9485	Imaging Systems Group (ISG)	Label	
HO13	DuraBlack®	Multi-Layer Coated Anodized Aluminum with Water-Based Liquid Topcoat	3M 9485	Imaging Systems Group (ISG)	Label	
	FieldCoat™				Laminate	
HO14	BlackPlus™	Exterior Grade Black Anodized Aluminum	3M 9485	Imaging Systems Group (ISG)	Label	
ME10	Craftmark	Polyester	MC78 Permanent Acrylic	MetalCraft Inc.	Label	
FL10	mFOM Holder U07530RB-A1	Polyvinylidene Fluoride	Permanent Acrylic	Fleet Forces Command / Uticom	Label Holder	

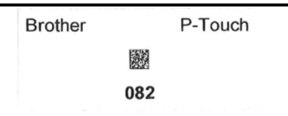
Material ID	Product	Label Material	Adhesive	Submitter	Description	Label
PO10	NSWC00005	Polyester	3M 350	Coast Label Company NSWC Corona	Label	
PT10	HG-2515PK	Polyethylene terephthalate (PET)	Acrylic Adhesive	Brother NSWC Corona	Label	

Table 2. Testing categories

"Tests to Failure" means at least one label became completely useless because of the test's degrading effects. "Tests with Limited Effect" means the test degraded the quality of the mark to some extent.

Tests to Failure	Tests with Limited Effect
Chipping	Solar
Pressure wash	Chemical - diesel
Adhesion – room temperature	Chemical - dilute acid
Adhesion – elevated temperature	Chemical - polyalphaolefin
Chemical– acetone	Chemical - salt water
Chemical - bleach	Chemical - clean lube protect
Chemical - hydraulic fluid	Chemical - detergent
Chemical - isopropyl alcohol	Chemical - antifreeze
Chemical - xylene	Chemical - WD-40

Data Discussion

Eighteen tests[8] were performed using multiple surfaces[9] with 47 label types[10] tested in triplicate or quadruplicate. Each test had multiple test increments and verification was conducted after each test increment. Verification measures ten parameters of interest at ten lighting angles. The ten parameters of interest are defined in ISO/IEC 15415 and AIM-DPM-1-2006. They are overall grade, unused error correction (UEC), fixed pattern damage, cell modulation, axial non-uniformity, grid non-uniformity, cell contrast, reference decode, minimum reflectance, and cell size.

Analysis of the data showed cell modulation and fixed pattern damage affected the overall grades the most. UEC however is the most useful parameter for analysis of damaging influence on the data matrix which would render it unreadable. A data matrix has information encoded along with error correction code. When the data matrix is damaged, often the information can still be decoded by using some fraction of the error correction code. A UEC score of 1 means none of the error correction code was required to decode the mark. UEC scores decrease to 0 as the level of damage increases. Given enough damage, the data matrix cannot be decoded and would have a UEC score of zero. See Appendix 5 for more details on UEC. This makes the UEC score a good indicator for the level of data matrix damage.

Variability in verification of barcodes has been an ongoing problem for the industry for many years. The problem remains despite extensive efforts at the national and international level to establish hardware, software, and testing procedures to remove the variability. Variability in these results was also noticed when different verifiers from the same manufacturer were tested as well as in results given by the same verifier. A limited discussion of verifier variability was undertaken in the original report. Further discussion and analysis is found in Appendix 4.

The "tests to failure" provided more direct data analysis. Groups of labels would cease to decode at various test increments and could be removed from further testing. Any labels that survived to the final test increment (in both "tests to failure" and "tests with limited effect") were compared using statistical analysis techniques, described in Appendix 4, where the difference between the initial and final UEC scores were compared to a statistically significant threshold.

[8] See Table 2.
[9] High Surface Energy (HSE) used 4"x4" glass plates and 1" wide glass plates for adhesion testing, Low Surface Energy (LSE) used 4"x4" polypropylene plates and 1" wide polypropylene plates for adhesion testing, chemical tests used glass microscope slides, chipping tests used 4"x4" galvanized steel plates, CARC adhesion tests were conducted with 1" wide CARC painted plates.
[10] See Table 1.

- Chemical tests – Labels were immersed in or coated with a chemical of interest and observed after 10 minutes of exposure and 7200 minutes of exposure. Data matrix degradation was evidenced by decreasing UEC score, laminate detachment, and/or adhesive failure. Labels were also examined for evidence of corrosion. Further detail on chemical testing can be found in Appendix 10.
- Room temperature adhesion test - The adhesion strength of labels attached to a given substrate was determined by peeling flexible labels at a fixed angle and specific speed and measuring the force to peel. Non-flexible labels were tested by shearing the labels from rigid plates and measuring the force to detach. Further detail on adhesion testing can be found in Appendix 11.
- Elevated temperature adhesion test - The adhesion strength of labels attached to a given substrate was measured at elevated temperature (110°F) by immersing the label in a heated water bath and testing adhesion strength as described in the adhesion test. Further detail on elevated temperature adhesion testing can be found in Appendix 11.
- Chipping test - Label resistance to chipping damage was tested using a method developed for the original report. The chipping test involves dropping a set quantity of gravel through a tube from a predetermined height onto the data matrix below. Further detail on chipping testing can be found in Appendix 8.
- Solar test - Label degradation induced by solar exposure was tested by placing labels outdoors in a California desert for 6 months. The total solar and total ultra violet radiation labels were exposed to over that period was measured. Contrast and UEC degradation were used to determine the effect of solar exposure on labels. Further detail on solar testing can be found in Appendix 12.
- Pressure wash test - Many military cleaning processes involve pressure washing. Labels adhered to surfaces cleaned by pressure washing will be exposed to this degrading influence. Label adhesive failure was measured for various pressure wash nozzle types and distances. Further detail on pressure wash testing can be found in Appendix 9.

Table 4 list all tested labels in the left most column and tests conducted along the top row. Table 3 is the aggregate chemical test results and each test has two columns; one column for UEC failure, the other with a letter "A", "L", and/or "C" to represent adhesive, laminate, and/or corrosion failure, respectively. At the intersection of a label and a test, a numerical value is given. The best score for a label is "100." The numerical scores in Table 3 and Table 4 are based on actual test results given in the appendices. A reading of the appendices will explain some scores are actual observed failures (numbers in black no cell shading), some scores are predictions of failure based on extrapolations of the data (numbers in red dot cell shading) and some scores indicate no statistically significant degradation in UEC was found during the test period (numbers in blue diagonal cell shading). Red numbers are only estimates and should not be confused with actual failure measurements. For example, the scores in the peel strength columns in Table 4 were determined by taking the highest adhesion peel value in lb/in (pounds force per inch) and multiplying by an appropriate factor to make it equal to 100. All other adhesion peel test results were multiplied by the same factor. Please refer to the respective appendices for full test details.

Table 3. Chemical test aggregate test results

Label	Acetone		Dilute Acid		Bleach		CLP		Detergent		Diesel		Anti Freeze		Hydraulic Fluid		IPA		PAO		Salt Water		WD-40		Xylene	
AB12	9	A	100		100		100		100		100		100		100		100		100		100		100		100	A
AB13	0	A	100		100		100	A	100		100		100		100		7	A	100		100		100		7	A
AN10	7	L	100		100		100		100		100		100		100		100		100		100		100		7	AL
AN11	7	AL	100		100		100		100		100		100		100		100		100		100		100	AL	7	AL
AN12	7		100		100		100		100		100		100		100		100		100		100		100		13	AL
AN13	7		100		100		100		100		100		100		100		100		100		100		100		7	AL
AN14	7		100		100		100		100		100		100		100		100		100		100		100		7	AL
AN15	7		100		100		100		100		100		100		100		100		100		100		100		7	AL
CA10	7	AL	100		100	A	100		100		100		100		48		100	L	100		100		100		48	AL
CA11	7	AL	100		100	A	100		100		100		100		41		100	L	100		100		100		41	AL
CA12	100	AL	100		100	A	37		100	A	100		100		100		100	L	100		100		100		41	AL
CA13	100	AL	100		100	A	100		100	A	100		100		100		100	L	100		100		100		100	AL
CA14	7	AL	100		7	ACL	100		100	A	100		100		100		100	L	100		100		100		100	AL
CA15	7	AL	100		27	ACL	100		100	A	100		100		63		15	AL	100		100		44		100	AL
CO12	41		100		12	C	100		100		100		100		100		100		100		100		100		100	
CO13	100		100		8	C	100		41		100		100		100		100		100		100		100		100	
ES11	7	AL	100		100		100		100		100		100		100		100	L	100		100		100		7	A
ES12	100	A	100		100	A	100		100	A	100		100		100		100		100		100		30		100	A
FC10	7	AL	100		100		100		100		100		100		100		100		100		100		100		7	AL
FC11	100	AL	100		100		100		100		100		100		100		100		100		100		100		100	AL
FC12	7	AL	100		100		100		100		100		100		100		59	L	100		100		100		7	AL
FC13	7	L	100		100		100		100		100		100		100		26	L	100		100		100		14	AL
FC14	7	L	100		100		100		100		100		100		100		100		100		100		100		7	AL
FC15	7	L	100		100		100		100		100		100		100		100		100		100		100		7	AL
FL10	0	AL	100		100		100		100		100		100		100		29	L	100		100		100		7	AL
HO10	100	A	100		7	AC	48		48	A	100		100		100		100		100		100		100		100	A

The table cells are shaded and text is color coded. Observed failures (no shading, black text); predicted failures (dot shading, red text); no degradation (diagonal shading, blue text).

Label	Acetone		Dilute Acid		Bleach		CLP		Detergent		Diesel		Anti Freeze		Hydraulic Fluid		IPA		PAO		Salt Water		WD-40		Xylene	
HO11	100	A	100		10	C	100		100	A	100		100		100		100	A	100		100		100		100	A
HO12	100	A	100		100		100		100		100		100		33		100		100		100		100		100	A
HO13	100	A	100		100	A	100		100	A	100		100		100		40		100		100		100		100	A
HO14	100	A	100		7	C	100		100		100		100		100		100		100		100		100		100	AL
ID10	30		100		16	C	100		100		100		100		100		100		100		100		100		20	
IK10	0		100		21		31		21		100		100		29		100		100		100		100		0	A
IK11	0		100		100		100		100		100		100		100		100		100		100		100		0	A
IK12	0		100		48		100		100		100		100		100		100		100		100		100		0	A
IK13	0		100		100		10		100		100		100		100		100		100		100		100		0	A
IK14	0		100		100		100		100		100		100		100		100		100		100		100		0	A
IK15	0		100		100		100		100		100		100		100		100		100		100		100		0	A
IM11	7	A	100		100		100		48		100		100		100		100		100		100		100		7	AL
ME10	45	L	100		100		41		100		100		100		100		100		100		100		100		23	AL
PO10	0		100		100		100		100		100		100		7		100		100		100		100		0	A
PT10	7	AL	100		100	A	100	A	100	A	100		100		100		100		100		100		100		7	AL
WC10	7	L	100		100		100		100		100		100		100		100	L	100		100		100		13	AL
WC11	0	L	100		100		100		100		100		100		100		31	L	100		100		100		7	A
WC12	0	L	100		100		100		100		100		100		100		100	L	100		100		100		7	A
WC13	0	L	100		100		100		100		100		100		100	A	100	L	100		100		100		7	A
WC14	0	L	100		100	A	100		100		100		100		100		100	L	100		100		100		7	A
WC15	0	L	100		100		100		100		100		100		100		100	L	100		100		100		7	A

The table cells are shaded and text is color coded. Observed failures (no shading, black text); predicted failures (dot shading, red text); no degradation (diagonal shading, blue text).

Table 4. Non-chemical aggregate test results

Label	Chipping	Solar HSE	Solar LSE	Pressure Wash HSE	Pressure Wash LSE	Peel HSE	Peel LSE	Peel CARC	Peel HSE 110F	Peel LSE 110F	Shear HSE	Shear LSE	Shear CARC	Shear HSE 110F	Shear LSE 110F
AB12	11	9	15	59	41	50	19	32	15	18					
AB13	11	100	100	44	48	34	26	9	3	14					
AN10	25	100	100	91	41	42	19		10	10					
AN11	25	100	100	91	33	77	43		39	30					
AN12	46	100	100	94	65	75	36	53	20	12					
AN13	25	100	100	94	33	34	13		8	8					
AN14	25	100	100	94	41	69	33		22	15					
AN15	46	100	100	94	86	78	33	57	22	15					
CA10	60	100	100	99	82						62	51		10	14
CA11	100		100	99	37						79	31	43	13	5
CA12	48	100	100	99	99						65	55		15	2
CA13	56		100	100	50						79	28	21	21	4
CA14	48	100	100	78	99						68	43		11	9
CA15	53		100	98	61						72	25	25	16	5
CO12	84	100													
CO13	60	5													
ES11	46		100	68	56	25	11		6	10					
ES12	25	100	100	96	87	61	37		8	20					
FC10	25	100	100	72	37	27	14		10	10					
FC11	11	100	100	75	33	51	23		13	24					
FC12	46	100	100	67	33	54	24		16	19					
FC13	50	100	100	94	66	75	24	58	23	10					
FC14	46	100	100	95	92	61	62	51	24	28					
FC15	50	100	100	91	95	47	58	47	25	27					

The table cells are shaded and text is color coded. Observed failures (no shading, black text); predicted failures (dot shading, red text); no degradation (diagonal shading, blue text).

Label	Chipping	Solar HSE	Solar LSE	Pressure Wash HSE	Pressure Wash LSE	Peel HSE	Peel LSE	Peel CARC	Peel HSE 110F	Peel LSE 110F	Shear HSE	Shear LSE	Shear CARC	Shear HSE 110F	Shear LSE 110F
FL10	11	100		92	32	52	31		17	22					
HO10	46	100	100	99	100						87	66		7	20
HO11	46		100	99	33						100	41	40	14	7
HO12	46	100	100	90	100						83	98		7	14
HO13	46	100	100	82	99						89	70		23	18
HO14	25	100	100	82	94						89	75		28	16
ID10	25	100													
IK10	11	100	10	77	17	32	5		10	6					
IK11	11	100	100	63	20	37	17		10	9					
IK12	11	100	100	55	17	29	15		5	13					
IK13	11	100	100	77	44	53	31		7	10					
IK14	25	100	100	77	21	47	15		9	10					
IK15	25	100	100	63	31	28	11		5	12					
IM11	25	100	100	79	33	62	34	42	20	26					
ME10	25	100	100	95	74	100	60		33	24					
PO10	4	100		48	32	38	23		12	8					
PT10	11	100	100	79	62	34	12		9	24					
WC10	25	100	100	79	33	40	19		10	11					
WC11	82	100	100	94	64	39	16		9	10					
WC12	53	100	100	89	44	82	36		32	25					
WC13	49	100	100	94	78	79	32	62	26	15					
WC14	49	100	100	93	67	30	19		8	10					
WC15	49	100	100	93	48	76	33		27	28					

The table cells are shaded and text is color coded. Observed failures (no shading, black text); predicted failures (dot shading, red text); no degradation (diagonal shading, blue text).

Conclusions

This report addresses, in a limited way, the performance aspect of labels. This report does not encompass all materials, all tests, or all environments. The need to limit the scope of testing was immediately clear for many reasons, among them the tens of thousands of available adhesives. Three main factors were used to limit the scope:

1. Department of the Navy interest
2. Time and funding constraints
3. Availability of equipment and materials

No "magic bullet" or "universal solution" was found to enable IUID implementation in all applications and environments. Decision makers may find the data collected in this study to be useful by determining the most relevant factors in their expected environments for data matrix degradation and selecting marking materials with resistance to those types of degradation. Weighing cost, schedule, and performance is important for optimal IUID implementation. This report only addresses the performance aspect of marking materials. Some general observations can be drawn from the data.

1. Solar degradation was minimal on most labels tested.
2. Pressure wash is a harsh cleaning method and most labels performed poorly in this test.
3. Chemical resistance of most labels was high. However, many labels performed poorly with exposure to organic solvents including acetone, xylene, and alcohol. Items cleaned with a "solvent wipe" will require labels with chemical resistance to organic solvents.
4. Adhesion test results of flexible labels can be divided into labels with adhesive strength higher or lower than duct tape at room temperature (about 2.5 lb/in on HSE). Some applications require very strong adhesive strength and others do not.
5. Rigid label adhesion was measured by shear strength testing and is not comparable to peel strength testing. However, rigid labels tended to perform better in pressure wash than flexible labels and label thickness and rigidity is related to the tendency for peel initiation.
6. Adhesives are weaker at elevated temperatures.

Perhaps the most valuable contribution the report makes to the community is an expanded body of tests and testing methodology designed to measure data matrix degradation. The necessary survey of established standard test procedures, identifying the utility and deficiencies of each, and the subsequent modifications to mitigate the weaknesses and adapting them to data matrices has been accomplished and documented. This establishes a body of knowledge that will enable future work to progress more meaningfully, on a shorter schedule, and at a reduced cost. Vendors may also wish to compare new product performance to label performance reported in this report.

Appendix 1 Acronyms

Acronym	Definition
ABS	Acrylonitrile Butadiene Styrene
AIM	Association for Automatic Identification and Mobility
ARL	Army Research Laboratories
ASCII	American Standard Code for Information
ASTM	American Society for Testing and Materials
CARC	Chemical agent resistant coating
CCD	Charge-Coupled Device
CLP	Clean Lube Protect (gun cleaner)
CTC	Calibration Test Card
DFARS	Defense Federal Acquisition Regulation Supplement
DoD	Department of Defense
DON	Department of the Navy
DoDD	Department of Defense Directive
DoDI	Department of Defense Instruction
DPM	Direct Part Marking
ECC	Error Correction Code also known as Error Checking and Correction
EOT	End of Transmission
FAR	Federal Acquisition Regulation
FISC	Fleet and Industrial Supply Center
GAO	Government Accountability Office
GFI	Ground Fault Interrupter
HSE	High Surface Energy
IPA	Isopropyl alcohol
ISO	International Organization for Standardization
IUID	Item Unique Identification
LSE	Low Surface Energy
MSDS	Material Safety Data Sheet
NSN	National Stock Number
NSWC	Naval Surface Warfare Center
OUSD (AT&L)	Office of the Under Secretary of Defense (Acquisition, Technology, and Logistics)
PAO	Polyalphaolefin
PET	Polyethylene Terephthalate
PSA	Pressure Sensitive Adhesive
RFI	Request for Information
RFP	Request for Proposal
SIM	Serialized Item Management
UEC	Unused Error Correction
UID	Unique Identification
UII	Unique Item Identifier
USMC	United States Marine Corps

Appendix 2 References

DFARS 252.211-7003	Item Identification and Valuation
DFARS 211.274	Item identification and Valuation requirements
DFARS 252.211-7003	Item Identification and Valuation
DFARS 252.211-7007	Reporting of Government-Furnished Property
DoD Instr. 4151.19	Serialized Item Management (SIM) for Materiel Maintenance
DoD Instr. 5000.02	Operation of the Defense Acquisition System
DoD Instr. 5000.64	Accountability and Management of DoD-Owned Equipment and Other Accountable Property
DoD Dir. 8320.03	Unique Identification (UID) Standards for a Net-Centric Department of Defense, March 23, 2007
DoD Instr. 8320.04	Item Unique Identification (IUID) Standards for Tangible Personal Property
(FAR) 15.201	Federal Acquisition Regulation, Contracting by Negotiation, Exchanges With Industry Before Receipt of Proposals
AIM-DPM-1-2006	AIM Direct Part Mark Quality Guideline released in December 2006
AS9132	Data Matrix Coding and Quality Requirements for Parts Marking
ASTM D3167	Standard Test Method for Floating Roller Peel Resistance of Adhesives
ASTM D2794	Standard Test Method for Resistance of Organic Coatings to the Effects of Rapid Deformation
ASTM D3170	Standard Test Method for Chipping Resistance of Coatings
ASTM D3330	Standard Test Method for Peel Adhesion of Pressure-Sensitive Tape
ASTM D4060	Standard Test Method for Abrasion Resistance of Organic Coatings by the Taber Abraser
FED-STD-191	Federal Standard: Textile Test Methods
ISO/IEC16022	Information Technology - Automatic Identification and Data Capture Techniques - Data Matrix Bar Code Symbology Specification
ISO/IEC 15415	Information Technology - Automatic Identification and Data Capture Techniques - Bar Code Print Quality Test Specification - Two-Dimensional Symbols
MIL-DTL-15024	Detail Specification: Plates, Tags, and Bands for Identification of Equipment, General Specification
MIL-HDBK-310	Military Handbook: Global Climatic Data for Developing Military Products
MIL-PRF-61002	Performance Specification: Pressure-Sensitive Adhesive Labels for Bar Coding
MIL-STD-130	Standard Practice: Identification Marking of U.S. Military Property
MIL-STD-13231	Standard Practice: Marking of Electronic Items
MIL-STD-810	Test Method Standard for Environmental Engineering Considerations and Laboratory Tests
USMC TM 4795-OR/1A	Organizational Corrosion Prevention and Control Procedures For USMC Ground Combat Equipment

Appendix 3 Request for Information

Sources Sought Notification

ITEM UNIQUE IDENTIFICATION MARKING PRODUCTS

REQUEST FOR INFORMATION (RFI) as defined in the Federal Acquisition Regulation (FAR) 15.201. The Fleet and Industrial Supply Center, San Diego, Regional Contracts Dept., Seal Beach Division, is conducting a market survey to obtain information on available Item Unique Identification (IUID) marking products. All interested sources may participate.

The IUID Center at the Naval Surface Warfare Center, Corona Division has been tasked by the Director of the Administrative/Fiscal Division in the Office of the Assistant Secretary of the Navy (Financial Management and Comptroller) to conduct a follow-on environmental survivability study of available IUID marking products and to provide technical performance data to the community.

The original study can be found at: www.acq.osd.mil/dpap/pdi/uid/docs/IUID_Environmental_Survivability_Testing_Report.pdf. The follow-on study will contain many of the tests from the original study. The follow-on study will expand beyond the scope of the original study to include direct part marking methods. Additional tests will be performed including UV exposure of printed materials.

Samples are to be provided at no charge. Samples will not be returned to the vendor after testing. Test results will be shared with the IUID community for consideration in their decision making processes. IUID implementation strategies and product selection may be influenced by the results of these environmental survivability studies resulting in the possibility of future contract awards.

Please contact the IUID Center for lists of the material properties that will be tested and an outline of the test plan. Sample quantity, data matrix details, and label or data plate size requirements will be provided. The IUID Center contact is Aaron Wiest at 951-273-4819 or at aaron.wiest@navy.mil.

In order to be considered for the testing, all samples must be received by the IUID Center no later than 10 December 2011. All samples shall be sent to:

If by shipper (e.g., UPS, FEDEX, etc.):

NAVAL SURFACE WARFARE CENTER CORONA DIVISION ATTN: IUID CENTER (PE11), BLDG. 519
1999 FOURTH STREET NORCO, CA 92860-1915

If by United States Postal Service (USPS):

NAVAL SURFACE WARFARE CENTER CORONA DIVISION ATTN: IUID CENTER (PE11), BLDG. 519 P. O. BOX 5000 CORONA, CA 92878-5000

As indicated above, this RFI is for testing and evaluation purposes only and is not to be construed as a Request for Proposal (RFP) or an Invitation/Request for Sealed Bids. The Government will not award a contract on the basis of this notice, nor pay respondents for any information that they submit in response to this RFI. Any information or samples submitted by respondents to this synopsis is strictly voluntary.

Additional Info:

Click here to get more information about FISC

Contracting Office Address:

N00244 FISC SAN DIEGO SEAL BEACH DETACHMENT 800 Seal Beach Blvd. Bldg 239 Seal Beach, CA

Supplemental Specifications

IUID Survivability Testing Material Requirements

Thank you for considering submitting materials for survivability testing. This document gives specifications of material size and IUID matrix requirements (content and cell size). We request at most 6 submissions from one company. Example 1 of a submission: Thermal transfer printed polyester label with over laminate. Example 2 of a submission: Laser engraved stainless steel plate with corrosion resistant overcoat.

This round of testing includes labels, data plates, protective coatings/covers, and direct part marking methods. We will conduct IUID matrix verification prior to testing using AIM-DPM-1-2006 or the latest version of this standard. Marks must pass acceptance criteria detailed in MIL-STD-130N 5.2.7.2b or they will not be tested. Testing will continue until the mark fails to verify or a particular test is determined to have limited effect on mark readability.

Each submission should include at least 250 samples.
Sample size restriction: 2-3 inches long, 0.5-0.75 inches wide, less than 0.1 inches thick.
Direct part marked materials must also follow the sample size restrictions.

If adhesive backed materials are sent, please indicate if the adhesive is intended for high surface energy (HSE) or low surface energy (LSE) substrates.

Submission must include material data e.g. adhesive type, label/data plate/direct part marked material info, printing or marking method as well as manufacturer and submitter contact information.

Specification for the Data Matrix barcode for testing purposes:

Module size:	0.008 < module size < 0.010 inch
Matrix size:	22 x 22
Quiet Zone	At least 2 modules wide on perimeter of data matrix

Content:	[)>r/s06g/s7LN41164g/s1PNAVYg/sSTESTINGr/sEOT
r/s	Record Separator {ASCII Chr (30)}
g/s	Group Separator {ASCII Chr (29)}
EOT	End of Transmission {ASCII Chr (4)}
Encoding: ASCII	

The data matrix should look like the example below (module size specified above)

Please include Human readable information that identifies your company, the label, and preferably sequential numbering 001-250 to identify each individual label.

IUID Survivability Testing Plan

Thank you for considering submitting materials for survivability testing. This document is intended to aid your company's technical experts in selecting IUID marking solutions that will perform optimally in various environments. We realize that laboratory tests may not accurately simulate every environment. However, there is benefit from a stable test plan for comparing results over time. If you feel that any of the tests have limited value or can be made significantly better with minor changes please let us know and we will seriously consider your input.

We intend to couple existing testing standards with IUID matrix verification at various time intervals. Results of the tests from the previous study performed in 2010 can be found at: www.acq.osd.mil/dpap/pdi/uid/docs/IUID_Environmental_Survivability_Testing_Report.pdf

We plan to repeat many of the tests found in the IUID Environmental Survivability Testing Report. Additionally, we plan to add UV exposure, sand blasting, pressure washing, and additional chemical resistance testing to the test protocol as time and funding permit. Adhesion testing at various temperatures will also be explored. We plan to test adhesion to additional low surface energy substrates including CARC.

Not all samples provided for the previous study were consumed. If vendors that participated in the previous study would like "left over" samples to be used for this study, please inform us by email.

Planned tests new in FY11:

Sand Blasting	MIL-STD-810 Method 510.5 Procedure II.
UV tolerance	MIL-STD-810 Method 505.5 Procedure II.
Peel test	Determine changes in adhesion strength using peel test as described in ASTM D3330 method F at various temperatures.

Pressure wash	Bombard label with water or washing solution to simulate pressure washing. Stop after set time or when label peels.

If mark readability is determined to be minimally affected by a given test, the test will be terminated and this will be noted in the report.

Appendix 4 Data Analysis and Verifier Variability

A simplified data analysis method is used for this round of testing. It is based on estimating the variability present in the test process and defining a threshold value above which degradation is significant. The estimation process and sources of variability are discussed below.

Variability comes from many sources. The manufacturing method used to make a material or adhesive may introduce inconsistencies. The marking method (printing, laser etching, engraving, etc.) may not be identical on each sample. Human error introduced in testing or variations in the test method can contribute to the variability. Additionally, location within a testing apparatus or sequencing on test equipment can cause variations.

Sources of variability should be identified and mitigated where possible. The specifications in Appendix 3 were one effort to minimize variability by requesting companies use similarly sized data matrices and labels. This was so labels printed with larger data matrices would not have an advantage over ones printed with smaller data matrices. In order to reduce error introduced experimentally, test procedures outlined in later appendices were closely followed. Additionally, labels were tested simultaneously so day to day variations of testing equipment would affect all labels in a given test together. Another effort to mitigate variability was testing multiple labels of each label type for each test and using ten different lighting angles on the verifier with the AIM-DPM-1-2006 standard. This not only provided for more statistically relevant data, but also represented the variation of lighting a data matrix might encounter in operational use.

Although it may seem reasonable to use the overall grade of the data matrix as the primary statistic of interest, it does not work well in practice. Overall grade is given as a letter grade (A through F) which does not lend itself to many useful quantitative statistical techniques. Additionally, data matrices may receive a grade of F for one parameter, making the overall grade an F and yet, the data matrix can still be read. For this report, data matrices were tested past the point of receiving an overall grade of F to a state of degradation where the encoded information could no longer be read by the verifier. Use of the terms "fail" or "failed" or "failure" in this document refer to the state of degradation where the data matrix could not be decoded by the verifier under any of the 10 lighting angles. UEC was found to give the best correlation with data matrix degradation. A UEC score of zero indicated the information in the data matrix was no longer readable. Accordingly, UEC was chosen as the verifier parameter of interest we would use to compare labels.

Variability is inherent in experimental tests. Often a large degree of variability is acceptable. For example, if a brownie recipe asked for the oven to be preheated to 359.3 degrees Fahrenheit, bakers would know something was off. Oven temperatures are usually given in 25 degree increments and most brownies are delicious despite the limitations of kitchen ovens. In experimental tests, limitations of test instruments, differences in test samples, and human factors all contribute to variability. Statistics allows us to quantify the variability and determine how to interpret test results in a meaningful way.

To quantify variability introduced by sample to sample differences, verifier limitations, and human factors, the UEC scores for initial verifications of labels were analyzed. Tests were performed using multiple surfaces with 47 label types tested in quadruplicate. Verification measures UEC at 10 lighting angles leading to 40 UEC measurements per label type per surface type per test. Averages of these 40 UEC measurements are given in the cells of Table 5. The bold column entitled "Average" is an average of these averages. Each cell is already an average of 40 UEC values and the average column is the average over the tests of the cell averages. Similarly, the bold column entitled "Standard Deviation" is the standard deviation of the average UEC values in the cells of Table 5. The average of UEC measurements over 10 lighting angles per label were statistically tested and found to be normally distributed. The standard deviation quantifies the variability of normally distributed samples.

In order to determine a threshold level of degradation greater than the variability of the measurements, a few assumptions had to be made. First, the variability of the verification UEC values of the labels initially was the same as the final variability. Second, it was assumed that the standard deviations of the individual label types were related (variability from the same sources). With these assumptions, a pooled standard deviation of all the initial verification values was calculated using the equation for pooled standard deviation shown in Equation 1.

$$\hat{\sigma} = \sqrt{\frac{\sum_{i=1}^{p}(n_i - 1){\sigma_i}^2}{\sum_{i=1}^{p}(n_i - 1)}}$$

Equation 1. Pooled standard deviation for a Normal distribution

Where $\hat{\sigma}$ is the pooled standard deviation, σ_i is the standard deviation of each label type, n_i is the number of tests used to calculate the standard deviation for each label type, and p is 47 for the number of label types tested.

Label degradation was measured by subtracting the average final UEC values ($\overline{UEC}_{final}$) from the average initial UEC values ($\overline{UEC}_{initial}$). Using the equation for error propagation and the first assumption listed above, it was determined that if Equation 2 was found true, then the measured degradation was large enough to be considered statistically significant.

$$\overline{UEC}_{final} - \overline{UEC}_{initial} > 1.645 * \sqrt{2}\hat{\sigma}$$

Equation 2. Statistical significance test for UEC degradation

Where $\hat{\sigma}$=0.048 and $1.645 * \sqrt{2}\hat{\sigma}$=.112.

Put more simply, if the UEC value drops by more than 0.112 during the testing, it is large enough to matter. 0.112 in UEC is like 25 degrees for your brownies!

Table 5. Averages of initial verification scores for each label type for each test

Label Types	Acetone	Bleach	CLP	Detergent	Chipping	Chipping Redo	Hydraulic Fluid	Isopropyl Alcohol	Solar HSE	Solar LSE	WD-40	Xylene	**Average**	**Standard Deviation**
AB12	0.8	0.925	0.8	0.85	0.875		0.85	0.895	0.974	0.995	0.875	0.825	0.879	0.0647
AB13	0.9	0.9	0.95	0.975	0.9		0.95	0.9	1	1	0.923	0.9	0.936	0.0409
AN10	1	0.975	0.9	0.975	1	1	0.993	0.975	0.975	0.898	0.9	0.975	0.964	0.0404
AN11	1	1	1	0.975	1	1	0.975	0.975	0.998	0.945	1	1	0.989	0.0177
AN12	1	1	1	0.975	1		1	1	0.993	0.92	1	1	0.99	0.0244
AN13	1	1	0.985	1	1		0.99	0.998	0.995	0.99	1	0.952	0.992	0.0141
AN14	0.998	0.975	1	1	1		1	1	0.998	0.983	0.95	1	0.991	0.0161
AN15	0.975	0.97	0.95	1	1	0.975	1	1	0.98	0.978	1	1	0.986	0.0167
CA10	1	0.998	1	1	1		1	1	1	1	1	1	1	0.0008
CA11	1	1	0.998	1	1		0.993	1		0.895	1	1	0.989	0.0329
CA12	0.838	0.895	0.898	0.773	0.736		0.873	0.8	0.648	0.808	0.86	0.885	0.819	0.0775
CA13	0.9	0.878	0.81	0.898	0.85		0.89	0.908		0.85	0.9	0.71	0.859	0.0608
CA14	0.888	0.67	0.718	0.775	0.808		0.903	0.808	0.665	0.578	0.673	0.74	0.748	0.0999
CA15	1	0.861	0.895	0.995	0.883		0.98	0.985		0.86	0.969	0.87	0.93	0.0604
CO12	0.858	0.9	0.775	0.55	0.874		0.504	0.725	0.819		0.798	0.625	0.743	0.1388
CO13	0.716	0.845	0.768	0.75	0.778		0.673	0.783	0.768		0.693	0.718	0.749	0.0505
ES11	0.988	0.98	0.945	0.955	0.921		0.995	0.915		0.634	0.978	0.83	0.914	0.1099
ES12	0.935	0.893	0.94	0.938	0.945		0.945	0.918	0.938	0.85	0.95	0.933	0.926	0.0298
FC10	1	1	0.998	0.995	0.975		1	1	0.988	0.983	1	1	0.994	0.0087
FC11	0.975	0.938	0.938	0.998	0.948	0.87	0.95	0.898	0.753	0.693	0.94	0.969	0.906	0.0926
FC12	0.985	1	0.998	0.995	0.895	0.995	0.98	0.988	0.91	0.885	0.988	0.955	0.964	0.0428
FC13	0.975	0.993	1	0.995	0.998	1	0.995	0.995	0.963	0.955	0.998	0.995	0.988	0.0153
FC14	0.925	0.975	0.968	0.998	0.975	0.965	0.947	0.95	0.908	0.95	0.95	1	0.959	0.0269
FC15	0.975	0.975	0.947	0.995	0.975	0.883	0.975	0.95	0.965	0.953	0.9	0.973	0.955	0.033
FL10	1	1	0.998	1			1	1			1	0.994	0.999	0.0023
HO10	1	0.975	1	1	0.975		1	1	0.975	1	1	1	0.993	0.0117
HO11	1	1	1	1	1		1	1		0.995	1	1	1	0.0016
HO12	0.945	0.923	0.998	0.965	0.975		0.973	0.925	0.915	0.79	0.993	0.943	0.94	0.0571
HO13	1	0.975	1	0.995	0.945		0.988	1	0.988	0.75	1	0.966	0.964	0.0732

Label Types	Acetone	Bleach	CLP	Detergent	Chipping	Chipping Redo	Hydraulic Fluid	Isopropyl Alcohol	Solar HSE	Solar LSE	WD-40	Xylene	**Average**	**Standard Deviation**
HO14	0.999	0.958	0.975	0.998	0.968		0.985	0.99	0.953	0.734	0.96	0.995	0.956	0.0755
ID10	0.505	0.69	0.52	0.375	0.528		0.498	0.543	0.465		0.528	0.475	0.513	0.0787
IK10	1	1	1	1	1		1	0.975	0.853	1	0.983	1	0.983	0.0441
IK11	1	1	1	1	1		1	0.975	0.875	1	1	1	0.986	0.0377
IK12	1	1	1	1	1		1	1	1	1	1	1	1	0
IK13	1	1	1	1	1		1	1	1	1	1	1	1	0
IK14	1	1	1	1	0.998		0.975	1	1	0.998	1	1	0.997	0.0075
IK15	1	1	1	0.975	1		1	1	0.95	0.97	1	1	0.99	0.0174
IM11	1	1	0.998	1	0.92		1	1	0.95	0.975	0.998	1	0.985	0.0269
ME10	1	1	1	1	0.975		1	1	0.9	0.925	1	1	0.982	0.0355
PO10	1	1	1	0.95			1	1			1	1	0.994	0.0177
PT10	0.998	0.898	1	0.989	0.993		1	1	0.968	0.973	0.995	0.898	0.974	0.0392
WC10	1	1	1	1	0.875	1	1	0.998	0.998	0.97	0.925	0.995	0.98	0.0398
WC11	1	1	1	1	0.95	1	1	1	0.995	0.973	1	1	0.993	0.0157
WC12	1	0.993	0.995	0.975	1	0.998	0.998	1	0.95	1	1	0.99	0.991	0.0149
WC13	1	1	0.998	1	1	1	0.998	1	0.973	0.993	1	0.985	0.995	0.0085
WC14	1	1	0.988	1	0.998	0.995	1	1	0.985	0.988	1	0.973	0.994	0.0088
WC15	1	0.975	1	1	0.995	1	0.995	0.998	0.96	0.948	0.993	0.998	0.988	0.0178

Appendix 5 Data Matrix Construction and Error Correction Code

A data matrix is comprised of a finder pattern, clocking pattern, data bytes and error correcting bytes called codewords. Figure 2 is color coded to make these parts of a data matrix easier to see. The blue L-shaped portion of the data matrix along the left and bottom is called the finder pattern. The alternating squares colored pink, white, pink, white along the top and right of the data matrix are called the clocking pattern. The finder and clocking patterns are used by scanners and verifiers to determine the orientation of the data matrix and the number of codewords among other things. The codewords are colored green and white in the center of Figure 2. Each byte is comprised of 8 bits. A bit is either a green or white square (module) in the data matrix shown in Figure 2. A green colored square is equal to 1 and a white colored square is equal to 0. 8 of these squares, or bits, each read as 0 or 1, form an 8 digit binary number called a byte. The smallest value of a byte is 00000000 equal to 0 in the decimal system and the largest value of a byte is 11111111 equal to 255 in the decimal system.

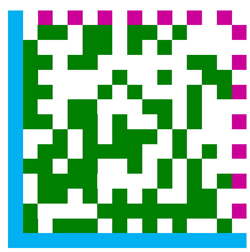


Figure 2. Data matrix comprised of finder pattern (bottom and left blue region), clocking pattern (top and right pink and white region) and data and error correcting bytes (center green and white region)

Because the perimeter of a data matrix contains the finder and clocking patterns, a 16 x 16 data matrix has 14 rows by 14 columns of data, equaling 196 bits of data. The 196 bits can be divided into 24 bytes with 4 excess bits. Figure 3 shows the composition of the eight bits into a byte and how the bytes in a 16 x 16 data matrix are constructed. The composition of data bytes and error correcting bytes in a 16 x 16 matrix is shown in Figure 3, where the 12 data bytes are shaded orange and the 12 error correcting bytes are shaded green.

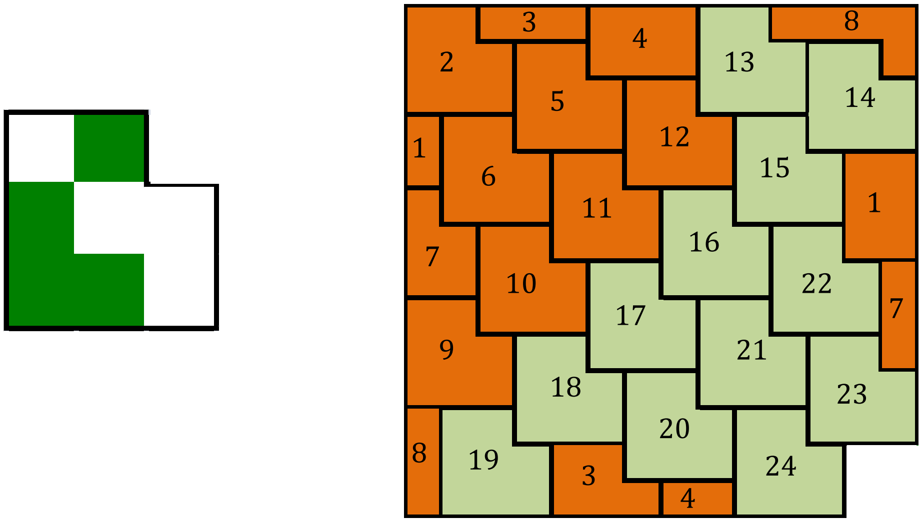


Figure 3. Left: The composition of 8 bits into a byte. Right: The composition of data bytes and error correcting bytes in a 16 x 16 data matrix

The data and error correcting bytes of a data matrix are mathematically linked using Reed-Solomon error correction. A more in-depth discussion of Reed-Solomon error correction can be found in ISO/IEC 16022. Data matrices are resistant to a certain degree of degradation because the error correction code allows the originally encoded data to be recovered even when some bytes have been damaged. A Microscan DPM verifier was tested by intentionally introducing errors into a data matrix shown in Table 6. The verifier gives a value of unused error correction (UEC). A UEC value of 1 means 100% of the error correction was unused. A value of zero means all the error correction was used to decode the data matrix or the data matrix could not be decoded because of too much degradation. When an entire data byte is damaged, as shown in row 2 of Table 6, 1/12 of the error correction is used to decode the data matrix, resulting in a UEC value of 0.92. However, when one or two bits in a data or error correcting byte are damaged, as seen in rows 3-5 of Table 6, 2/12 of the error correction is used to decode the data matrix. 6 bit errors across 6 bytes of data, seen in row 11 of Table 6, required all the error correction to decode the data matrix resulting in a UEC value of 0. One more damaged bit, seen in row 12 of Table 6, resulted in a failure to decode the data matrix. These results are consistent with the discussion of Reed-Solomon error correction in ISO/IEC 16022.

Table 6. UEC evaluation of Microscan DPM verifier

Data Matrix	Intentional Errors	UEC Value
	No damage	1
	1 complete data byte damaged	0.92
	1 data bit damaged	0.84
	1 error bit damaged	0.84
	2 bits in 1 data byte damaged	0.84
	2 data bits damaged	0.67
	1 data bit and 1 error bit damaged	0.67
	3 data bits damaged	0.50
	4 data bits damaged	0.34
	5 data bits damaged	0.17
	6 data bits damaged	0 - data matrix decoded
	7 data bits damaged	0 - data matrix did not decode

Appendix 6 Verifier Operation

Normalization is a setup procedure for the Microscan UID DPM Compliance verifier. It adjusts the processing of the image to account for variations in external lighting. If a verifier is moved or if the lighting of the environment changes throughout the testing period, this step is performed.

Verifier Setup

1.0 Normalization
- 1.1 Connect the verifier to a computer with HawkEye Normalization and UIDChecker software installed
- 1.2 Open HawkEye Normalization software
- 1.3 Enter the verifier's IP[11] address in the "Select Camera To Normalize" pop-up dialog box
- 1.4 Click on the "UID Verifier-Multifunction Light" radio button
- 1.5 Remove the Calibration Test Card (CTC) from its protective envelope and place it under the verifier so the solid black square image displays on the computer screen
- 1.6 When the dialog box "Please center one of the black squares on the calibration standard in center of the camera of field of view, then press the normalize button" displays, click "OK"
- 1.7 Adjust the CTC so the black square image is close to the center of the camera field of view
- 1.8 Click on the "Normalize" button
- 1.9 When the normalization process is completed, the HawkEye Normalization message window will display, click "OK"
- 1.10 Close HawkEye Normalization software
- 1.11 Remove the CTC from the verifier

2.0 Verifier Reflectance Calibration
- 2.1 Open the UIDChecker software
- 2.2 Click on the "Reader" menu, click "Reflectance Calibrate" from the dropdown menu
- 2.3 When the UID-COMPLIANCE-CHECKER message box displays, click "OK"
- 2.4 Place the CTC under the verifier so the data matrix is centered and displays on the computer screen
- 2.5 Enter the Contrast & Rmax values given on the CTC
- 2.6 Click on the "Calibrate" button
- 2.7 When the calibration is completed, all of the lighting angles displayed on the left panel should be highlighted green
- 2.8 Click the "Close" button
- 2.9 Remove the CTC and return the card to its protective envelope

Verification of Data Matrices

1.0 Click on the "Live Video (90)" button and use the AIM-DPM-1-2006 ten lighting angles

2.0 Center the data matrix under the verifier so the matrix aligns with the square alignment marks on the computer screen

3.0 Push one of the black buttons labeled as "IO TRIGGER" on the verifier

4.0 Remove the data matrix from the verifier

5.0 Repeat the sequence as necessary for other data matrices

---

[11] Internet Protocol (IP).

Appendix 7 Cleaning and Label Application

Cleaning

The cleaning and application procedures are based on a 3M process.
http://www.wrisupply.com/images/docs/add_file_1/5.1SubstrateSelectionandPreparationForGraphiocFilmApplication.pdf

Because new glass and polypropylene plates were used for most tests, cleaning was simplified. Microscope slides were used for chemical tests and metal electrical junction box covers were used for chipping tests, both of which were also initially fairly clean.

A 50% water 50% isopropyl alcohol mixture was used to clean the surfaces. Plates were wiped with the mixture and the plates were immediately wiped completely dry with clean absorbent paper towels. This process dissolves oils and atmospheric residues in the water-alcohol mixture and then absorbs them in the towel. Allowing the plates to air-dry re-deposits any contaminates dissolved in the water-alcohol mixture.

Label Application

Prior to application of a pressure sensitive adhesive backed label, the surface to be adhered to must be at least 50°F. The labels should be above manufacturer's specified application temperature for the label or the adhesive may become too firm to adhere readily below this temperature. The surface must be clean and dry prior to label application. Remove the liner with a metal spatula and position the label on the surface being careful not to touch the adhesive with your fingers or to allow the adhesive to become contaminated with dust, dirt, etc. Using firm even pressure, roll the entire surface of the label and as a final step burnish the edges. Greater pressure provides higher bond strength and allows the adhesive to "flow" into the tiny cracks and crevices between the adhesive and the surface. The adhesive bond will grow stronger with time, achieving final bond strength in the manufacturer's specified dwell time.

Appendix 8 Chipping Test

Test Procedure

1.0 Description:

The chipping test simulates debris impact a label could experience while in the field. A fixed volume of 1/8" and 3/4" pea gravel was dropped through a 4" diameter pipe from 50' onto a label placed 45° to the impact angle. The data matrix was verified after each testing increment and continued until the testing cycle was complete. The chipping test was developed as a hybridized test method of ASTM D3170 and ASTM D2794. Figure 4 shows the chipping tower setup.

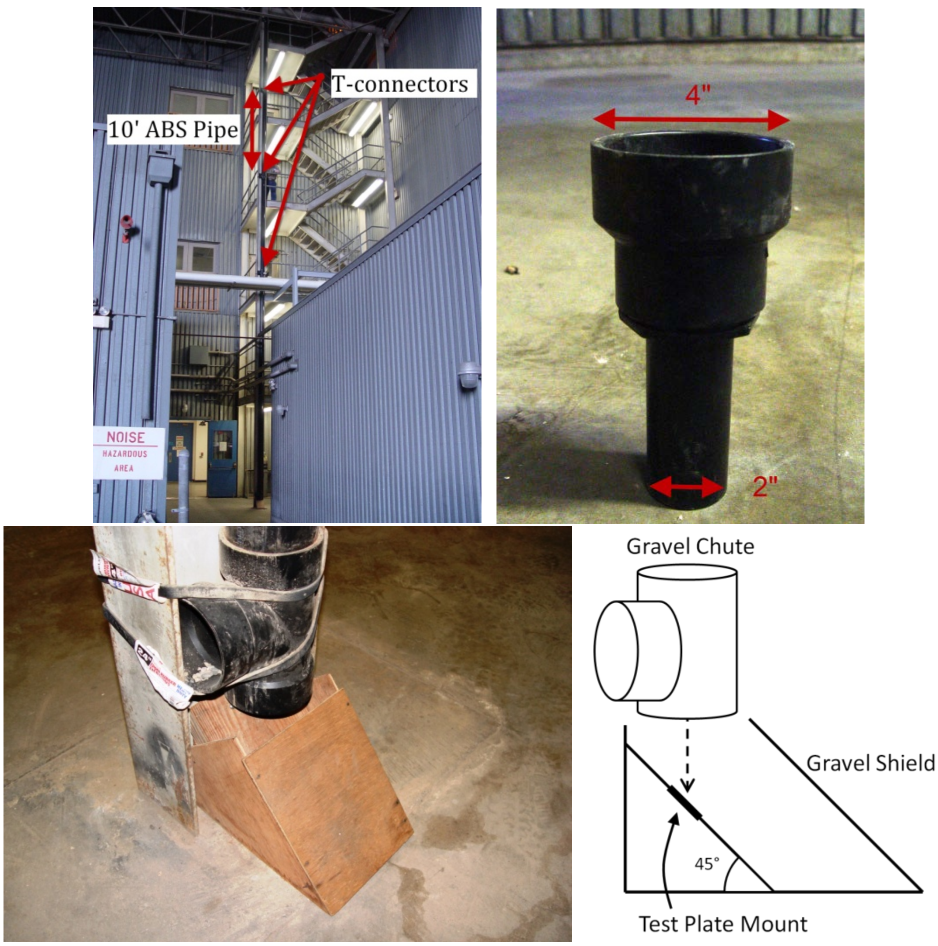


Figure 4. Views of the chipping tower, clockwise from top left: full tower, gravel collimator, side view diagram of gravel target, gravel target

- 1.1 Equipment, Fixtures, and Materials
  - 1.1.1 Pea gravel (size variation between 1/8" and 3/4")
  - 1.1.2 4" x 10' Acrylonitrile Butadiene Styrene (ABS) piping
  - 1.1.3 4" ABS T-connector
  - 1.1.4 4" to 2" ABS reducer coupling (gravel collimator)
  - 1.1.5 45° base data plate holder/ gravel collector
  - 1.1.6 Rubber tie down straps

1.1.7 4”x4” galvanized steel plates[12]

1.2 Procedural Steps

1.2.1 Label preparation

1.2.1.1 Clean the testing surface appropriately (see Appendix 7)

1.2.1.2 Adhere labels for testing to plate (see Appendix 7)

1.2.1.3 Verify the data matrix and record the results (see Appendix 6)

1.2.2 Tower preparation

1.2.2.1 Connect the pipes with T-connectors[13] and attach pipes to the testing location[14]. Ensure the pipes are vertically aligned

1.2.2.2 Attach plate in the label holder below pipe drop zone

1.2.2.3 Place the collimator at the top of the pipe at the recommended drop height and pour the gravel through for a better impact spread and to decrease gravel and pipe wall collisions

1.2.3 Testing instructions

i. 50’ drop with 500mL pea gravel

ii. 50’ drop with 1000mL pea gravel

iii. 50’ drop with 2000mL pea gravel

iv. 50’ drop with 3000mL pea gravel

1.2.3.1 Wipe dust and debris from label

1.2.3.2 Verify the data matrix and record the results after each increment

1.2.3.3 Proceed through gravel drops until the data matrix fails verification or the end of the test is reached

1.3 Reference Material

1.3.1 ASTM D 3170

1.3.2 ASTM D 2794

1.3.3 AIM-DPM-1-2006

Test Results

Results of the chipping test are shown in Table 7. If a label survived the entirety of the testing, it was subjected to a total of 6500mL of gravel dropped from 50 feet which impacts the plate at almost 40 miles per hour. This may be far beyond the required chipping resistance for many applications. Numerical values are milliliters (ml) of gravel dropped on label. Values less than or equal to 6500 indicate the increment of testing where the UEC=0 for that label. Values greater than 6500 are predictions of quantity of gravel required to make UEC=0 based on the slope of the (initial UEC score - final UEC score) line extrapolated to where UEC=0. It must be stressed that these are not measured numbers and may vary from the predicted value. All labels types showed degradation of (initial UEC score - final UEC score) value greater than 0.112 see Appendix 4. Results for FL10 were taken from the original report and results for PO10 were entered from unpublished data taken for the original report.

[12] Electrical junction box covers

[13] T-connectors limit pressure differentials in pipe. Do not glue pipes together for ease of disassembly and performing tests at various heights.

[14] Rubber straps work well because the pipes can be slid up and down to gain access to shorter gravel drop heights if desired.

Table 7. Chipping test results - Values less than or equal to 6500 indicate the increment of testing where the UEC=0 for that label. Values greater than 6500 are predictions of failure

Label Type	Total gravel [ml]
AB12	1500
AB13	1500
AN10	3500
AN11	3500
AN12	6500
AN13	3500
AN14	3500
AN15	6500
CA10	8442
CA11	14092
CA12	6764
CA13	7921
CA14	6751
CA15	7402
CO12	11801
CO13	8388
ES11	6500
ES12	3500
FC10	3500
FC11	1500
FC12	6500
FC13	7027
FC14	6500
FC15	7115
FL10	1500
HO10	6500
HO11	6500
HO12	6500
HO13	6500
HO14	3500
ID10	3500
IK10	1500
IK11	1500
IK12	1500
IK13	1500
IK14	3500
IK15	3500
IM11	3500

Label Type	Total gravel [ml]
ME10	3500
PO10	500
PT10	1500
WC10	3500
WC11	11556
WC12	7474
WC13	6952
WC14	6936
WC15	6952

Appendix 9 Pressure Wash Test

Test Procedure

1.0 Description:

Many military cleaning applications involve pressure washing. Labels attached to items cleaned in this manner would be exposed to pressure washing as well. The pressure wash specifications used for this test were taken from the United States Marine Corps Technical Manual, TM 4795-OR/1A. The expected failure mode for adhesive backed labels exposed to pressure washing is adhesive failure. Data matrix degradation was not observed. Photographs of pressure washing are shown in Figure 5. A 2 gallon per minute pressure washer limited to 1200 pounds per square inch (psi) as required by TM 4795-OR/1A was used for this test.

Figure 5. Views of a military wash rack in action.

1.1 Equipment, Fixtures, and Materials

- 1.1.1 TM 4795-OR/1A compliant electric pressure washer
- 1.1.2 Hose
- 1.1.3 Fresh water
- 1.1.4 Glass plates for HSE substrate
- 1.1.5 Polypropylene plates for LSE substrate

1.2 Procedural Steps

- 1.2.1 Label preparation
  - 1.2.1.1 Clean a test plate as described in Appendix 7
  - 1.2.1.2 Adhere labels to the test plate, roll and burnish as described in Appendix 7
  - 1.2.1.3 Secure label plates to a board or fixture prior to pressure washing
- 1.2.2 Testing instructions
  - 1.2.2.1 Using 25° nozzle, position nozzle 8" from data matrix, spray at 90° angle for 15 seconds
  - 1.2.2.2 Using 25° nozzle, position nozzle 8" from data matrix, spray edges of labels on plate at 45° angle for an additional 15 seconds (cumulative for all edges)
  - 1.2.2.3 Using 25° nozzle, position nozzle 1" from data matrix, spray edges of labels on plate at 45° angle for an additional 15 seconds (cumulative for all edges)
  - 1.2.2.4 Using 0° nozzle, position nozzle 8" from data matrix, spray at 90° angle for 15 seconds

1.2.2.5 Using 0° nozzle, position nozzle 8” from data matrix, spray edges of labels on plate at 45° angle for an additional 15 seconds (cumulative for all edges)

1.2.2.6 Using 0° nozzle, position nozzle 1” from data matrix, spray edges of labels on plate at 45° angle for an additional 60 seconds (cumulative for all edges)

1.3 Reference Material

1.3.1 USMC TM 4795-OR/1A

Test Results

Pressure wash test results for HSE and LSE substrates are given in Table 8 and Figure 6. Labels were tested in quadruplicate on each substrate. The number of labels of each label type lifting and/or detached at each increment was recorded. A scoring system was developed to quantify the survivability of labels. A label type with no detached or lifting labels for all 6 testing increments scores 100 points and a label type where all 4 labels detached after the first increment scores 0 points. Detachment failures deducted 8 times more points than lifting failures in order to ensure a label that peeled at the first increment but never detached would score higher than a label that detached in the last increment.

CA12, CA14, HO10, HO12, HO13, HO14, and FC15 had higher LSE pressure wash scores than HSE pressure wash scores. One would expect a correlation between peel or shear strength and pressure wash performance. Comparing the anomalous pressure wash failures (better label type performance on LSE substrates) to peel and shear results is interesting. HO12 showed higher shear strength on LSE and FC15 showed higher peel strength on LSE, but CA12, CA14, HO10, HO13, and HO14 had higher HSE shear strengths. Strong correlation would be expected between shear and peel strengths and pressure wash performance. A suitable explanation for the four anomalies has not been found. Problems with the scoring system or variability in pressure wash nozzle distances seem the most likely causes of the anomalies.

Label types CO12, CO13, and ID10 were not added to the testing results because they did not have adhesive backing and the pressure wash test measured adhesive failure. CO12, CO13, and ID10 were tested and showed no data matrix degradation after the 6 test increments. These labels could be used in pressure wash applications given a suitable method for affixing them.

Table 8. Pressure wash scores (max 100) for labels on HSE and LSE surfaces. No scores given for CO12, CO13, and ID10 because these labels were not adhesive backed

Label	HSE	LSE
AB12	58.9	40.6
AB13	44.3	47.9
AN10	90.6	40.6
AN11	90.6	32.8
AN12	93.8	64.6
AN13	93.8	33.3
AN14	93.8	40.6
AN15	93.8	86.5
CA10	99.5	81.8
CA11	99.5	37.0
CA12	99.5	99.0
CA13	100.0	50.0
CA14	78.1	99.5
CA15	97.9	60.9
CO12		
CO13		
ES11	68.2	56.3
ES12	95.8	87.0
FC10	71.9	37.0
FC11	75.0	33.3
FC12	67.2	33.3
FC13	93.8	66.1
FC14	94.8	91.7
FC15	91.1	94.8
FL10	92.2	32.3
HO10	99.0	100.0
HO11	99.5	33.3
HO12	90.1	100.0
HO13	82.3	99.0
HO14	82.3	94.3
ID10		
IK10	77.1	16.7
IK11	62.5	20.3
IK12	55.2	16.7
IK13	77.1	44.3
IK14	77.1	20.8
IK15	62.5	31.3
IM11	79.2	33.3

Label	HSE	LSE
ME10	94.8	74.5
PO10	47.9	31.8
PT10	78.6	62.0
WC10	79.2	33.3
WC11	93.8	64.1
WC12	89.1	44.3
WC13	93.8	78.1
WC14	93.2	67.2
WC15	93.2	47.9

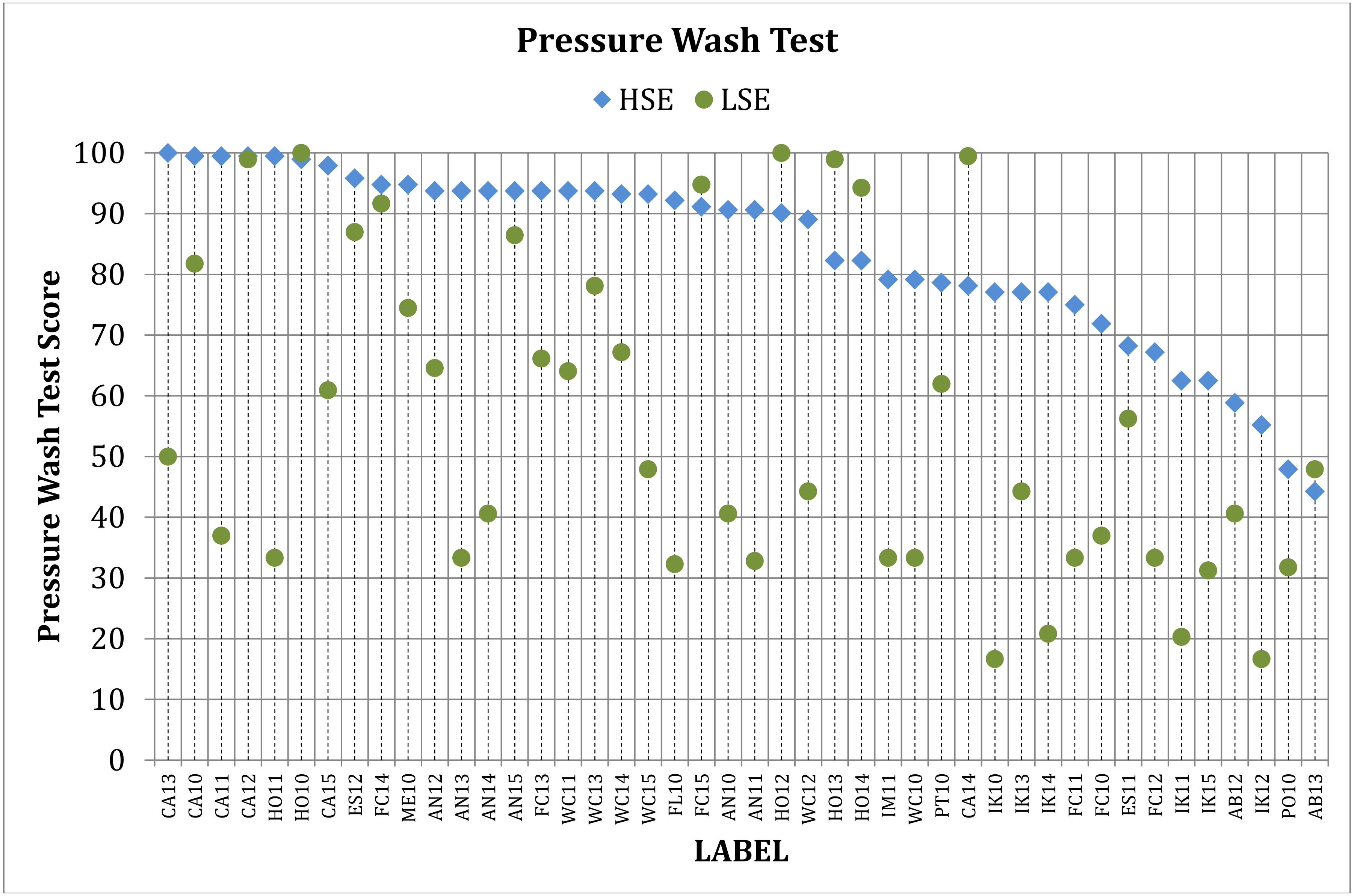


Figure 6. Plot of pressure wash scores by HSE substrate.

Appendix 10 Chemical Test

Test Procedure

1.0 Description:

The chemical test, shown in Figure 7, exposes labels to different chemicals that may be encountered in service. Acetone, dilute acid, bleach, gun cleaner (CLP), detergent, diesel, antifreeze, synthetic hydraulic fluid, isopropyl alcohol, polyalphaolefin (PAO), salt water, WD-40, and xylene were the chemicals tested. The labels were immersed for two different increments of 10±1 minutes and 7200±60 minutes (5 days±1hr).

Figure 7. Chemical test containers in the fume hood

- 1.1 Equipment, Fixtures, Materials, and Reagents
  - 1.1.1 Sealable glass container
  - 1.1.2 Sealable plastic bags
  - 1.1.3 Cotton wipes
  - 1.1.4 Microscope slides
  - 1.1.5 Reagents
    - 1.1.5.1 Acetone
    - 1.1.5.2 Dilute acid
    - 1.1.5.3 Bleach
    - 1.1.5.4 Gun cleaner (CLP)
    - 1.1.5.5 Detergent
    - 1.1.5.6 Diesel
    - 1.1.5.7 Antifreeze
    - 1.1.5.8 Synthetic hydraulic fluid
    - 1.1.5.9 Isopropyl alcohol (IPA)
    - 1.1.5.10 Polyalphaolefin (PAO)
    - 1.1.5.11 Salt water
    - 1.1.5.12 WD-40
    - 1.1.5.13 Xylene
- 1.2 Procedural Steps
  - 1.2.1 Safety note: Chemicals used in this procedure may be toxic, flammable, or corrosive. Avoid physical contact with the chemicals or inhalation of chemical vapors. Follow laboratory safety procedures and Material Safety Data Sheet (MSDS) documentation.
  - 1.2.2 Label preparation
    - 1.2.2.1 Clean the testing surface appropriately (see Appendix 7)
    - 1.2.2.2 Adhere labels for testing to plate (see Appendix 7)

1.2.2.3 Verify the data matrix and record the results (see Appendix 6)

1.2.3 Testing instructions

1.2.3.1 Insert four slides with labels into a sealable container, ensuring no contact between the slides

1.2.3.2 Mark the container with chemical name, rinse solvent, and label type

1.2.3.3 Expose labels to the test chemical to ensure the data matrix is fully immersed in the test solution

1.2.3.4 Seal container for a specified time (10±1 minutes then 7200±60 minutes)

1.2.3.5 After the specified exposure time, remove slides and allow excess chemical to drip into container. Wipe label with a Kimwipe to remove any excess chemical and to simulate a cleaning process.

1.2.3.6 Visually inspect labels and document results (e.g., smear, no change, peeling)

1.2.3.7 Rinse slides with appropriate solvent (e.g., water, IPA) to remove the test chemical and dry

1.2.3.8 Verify the data matrix and record the results

1.3 References

1.3.1 MIL-STD-810 Method 504

Chemical Details

1.1.5.1 Acetone: Industrial grade 100% acetone was used.
1.1.5.2 Dilute acid: Dilute acid immersion testing was intended to simulate an environment 100 times more acidic than acid rain. Acid rain has an approximate pH value of 4. To create a dilute acid solution with pH ~ 2, 9.3mL of 2N nitric acid and 6.0mL of 6N sulfuric acid were added to 3800mL of distilled water. The resulting dilute acid solution had a pH value of 1.84.
1.1.5.3 Bleach: Household bleach, available at most grocery stores, was used. Household bleach is approximately a 5% sodium hypochlorite solution.
1.1.5.4 Gun cleaner (CLP): Break Free CLP with national stock number (NSN) 9150-01-102-1473 was used.
1.1.5.5 Detergent: Palmolive dish detergent was used.
1.1.5.6 Diesel: Type 2 low sulfur diesel fuel available at gas stations in California was used.
1.1.5.7 Antifreeze: A 50% water 50% ethylene glycol commercially available antifreeze was used.
1.1.5.8 Synthetic hydraulic fluid: Royco 782 PRF-83282D synthetic hydraulic fluid was used.
1.1.5.9 Isopropyl alcohol: 99^{+}% 2-propanol was used.
1.1.5.10 Polyalphaolefin (PAO): PAO is a synthetic oil and is a component of many synthetic motor oils.
1.1.5.11 Salt water: Salt water immersion was intended to simulate salinity levels found in the ocean. Ocean water is about 35 parts per thousand sodium chloride. To simulate ocean water, 133.1g of 99.99% pure salt were added to 3800 mL water. The resulting salt water solution was 34 parts per thousand sodium chloride.
1.1.5.12 WD-40: The commercially available penetrating oil and water displacing spray sold as WD-40 was used for this test.
1.1.5.13 Xylene: 99% pure p-xylene was used for this test.

Test Results

A prescreen test was conducted on chemicals not expected to affect labels adversely. One label of each label type was immersed in dilute acid, diesel, antifreeze, isopropyl alcohol, PAO, and salt water. Visual observation confirmed the labels were unaffected after 1 week of exposure to these chemicals except in the case of isopropyl alcohol. Some labels immersed in isopropyl alcohol had detached from the microscope slides; laminates had detached in other cases. The isopropyl alcohol test was repeated following the procedural steps detailed in section 1.2. WD-40 and CLP tests were performed by spraying the labels and sealing them in sealable storage bags instead of immersing the labels in chemical contained in sealable beakers shown in Figure 7.

Multiple failure modes were observed for chemical exposure testing. UEC, laminate, adhesive, and corrosion failures are presented for each label type and chemical test in Table 9. UEC degradation and barcode failures were measured using the verifier. Table 9 has numerical values for the label types for each chemical tested. A value of 10 or 7200 indicates UEC=0 at the 10 or 7200 minute increment. Values greater than 7200 are predictions of failure time based on the slope of the (initial UEC score - final UEC score) line extrapolated to where UEC=0. It must be stressed that these are not measured numbers and may vary from the predicted value. Values of 99999 were entered when the (initial UEC score - final UEC score) value was not greater than 0.112 and therefore not larger than the variability present in the measurements (see Appendix 4). Adhesive failure resulted when the label detached from the slide. Laminate failure resulted when the laminate detached from the label or cracking or bubbling of laminate occurred. In some cases, laminate failure made the data matrix unreadable through the cracked or bubbled material. Laminates were removed after laminate failures were observed and the data matrix was verified after laminate removal. Corrosion failure also resulted in some cases where labels were degraded through interaction with the chemical. Notably, aluminum labels showed degradation after immersion in bleach.

There are far too many chemicals that may be encountered in military applications to test all of them in a reasonable amount of time within a reasonable budget. A method to roughly predict the effect of a chemical or mixture of chemicals on a label is described. However, the reader should note this is just an educated guess and chemical interactions can occur that increase degradation more than expected. In low risk situations, this method may suffice. Chemicals have similarities and can be grouped in families. Many solvents are combinations of chemicals. A rough estimate of how a solvent will affect a label can be determined by looking at how labels performed in chemicals similar to the constituent chemicals of the solvent. These “similar chemicals” would be in the same family of chemicals. Xylene, isopropyl alcohol, acetone, and diesel were chosen to represent families of chemicals. Xylene belongs to a family of chemicals called aromatics which includes benzene and toluene. Isopropyl alcohol also known as isopropanol and 2-propanol belongs to a family of chemicals called alcohols which include methanol and ethanol. Acetone belongs to a family of chemicals called ketones. Diesel is a blend of chemicals called alkanes which include propane, many oils, kerosene, and octane.

For example, a commercially available lacquer thinner contains:

- methanol - alcohol
- toluene - aromatic
- acetone and methyl ethyl ketone - ketones
- glycol ether and ethyl ester - not in a family of chemicals tested
- hexane - alkane

- acetic acid - an acid.

A label that performed well in isopropyl alcohol, xylene, acetone, diesel, and dilute acid would have a better chance of surviving exposure to lacquer thinner than labels that failed in one or more of the listed chemical exposure tests.

Table 9. Chemical tests - numerical values are observed or predicted failure times, 99999=no significant UEC degradation, A=adhesive failure, L=laminate failure, C=corrosion failure

Label Type	Acetone		Dilute Acid		Bleach		CLP		Detergent		Diesel		Anti Freeze		Hydraulic Fluid		IPA		PAO		Salt Water		WD-40		Xylene	
AB12	8533	A	99999		99999		99999		99999		99999		99999		99999		99999		99999		99999		99999		99999	A
AB13	10	A	99999		99999		99999	A	99999		99999		99999		99999		7200	A	99999		99999		99999		7200	A
AN10	7200	L	99999		99999		99999		99999		99999		99999		99999		99999		99999		99999		99999		7200	AL
AN11	7200	AL	99999		99999		99999		99999		99999		99999		99999		99999		99999		99999		99999	AL	7200	AL
AN12	7200		99999		99999		99999		99999		99999		99999		99999		99999		99999		99999		99999		13303	AL
AN13	7200		99999		99999		99999		99999		99999		99999		99999		99999		99999		99999		99999		7200	AL
AN14	7200		99999		99999		99999		99999		99999		99999		99999		99999		99999		99999		99999		7200	AL
AN15	7200		99999		99999		99999		99999		99999		99999		99999		99999		99999		99999		99999		7200	AL
CA10	7200	AL	99999		99999	A	99999		99999		99999		99999		48000		99999	L	99999		99999		99999		48000	AL
CA11	7200	AL	99999		99999	A	99999		99999		99999		99999		41426		99999	L	99999		99999		99999		41143	AL
CA12	99999	AL	99999		99999	A	36926		99999	A	99999		99999		99999		99999	L	99999		99999		99999		41110	AL
CA13	99999	AL	99999		99999	A	99999		99999	A	99999		99999		99999		99999	L	99999		99999		99999		99999	AL
CA14	7200	AL	99999		7200	ACL	99999		99999	A	99999		99999		99999		99999	L	99999		99999		99999		99999	AL
CA15	7200	AL	99999		26528	ACL	99999		99999	A	99999		99999		62720		14623	AL	99999		99999		44286		99999	AL
CO12	41160		99999		11945	C	99999		99999		99999		99999		99999		99999		99999		99999		99999		99999	
CO13	99999		99999		8139	C	99999		40755		99999		99999		99999		99999		99999		99999		99999		99999	
ES11	7200	AL	99999		99999		99999		99999		99999		99999		99999		99999	L	99999		99999		99999		7200	A
ES12	99999	A	99999		99999	A	99999		99999	A	99999		99999		99999		99999		99999		99999		29578		99999	A
FC10	7200	AL	99999		99999		99999		99999		99999		99999		99999		99999		99999		99999		99999		7200	AL
FC11	99999	AL	99999		99999		99999		99999		99999		99999		99999		99999		99999		99999		99999		99999	AL
FC12	7200	AL	99999		99999		99999		99999		99999		99999		99999		59250	L	99999		99999		99999		7200	AL
FC13	7200	L	99999		99999		99999		99999		99999		99999		99999		26051	L	99999		99999		99999		13979	AL
FC14	7200	L	99999		99999		99999		99999		99999		99999		99999		99999		99999		99999		99999		7200	AL

Label Type	Acetone		Dilute Acid		Bleach		CLP		Detergent		Diesel		Anti Freeze		Hydraulic Fluid		IPA		PAO		Salt Water		WD-40		Xylene	
FC15	7200	L	99999		99999		99999		99999		99999		99999		99999		99999		99999		99999		99999		7200	AL
FL10	10	AL	99999		99999		99999		99999		99999		99999		99999		28800	L	99999		99999		99999		7200	AL
HO10	99999	A	99999		7200	AC	48000		48000	A	99999		99999		99999		99999		99999		99999		99999		99999	A
HO11	99999	A	99999		10177	C	99999		99999	A	99999		99999		99999		99999	A	99999		99999		99999		99999	A
HO12	99999	A	99999		99999		99999		99999		99999		99999		32951		99999		99999		99999		99999		99999	A
HO13	99999	A	99999		99999	A	99999		99999	A	99999		99999		99999		40280		99999		99999		99999		99999	A
HO14	99999	A	99999		7200	C	99999		99999		99999		99999		99999		99999		99999		99999		99999		99999	AL
ID10	30300		99999		15771	C	99999		99999		99999		99999		99999		99999		99999		99999		99999		20118	
IK10	10		99999		20571		30968		20571		99999		99999		29239		99999		99999		99999		99999		10	A
IK11	10		99999		99999		99999		99999		99999		99999		99999		99999		99999		99999		99999		10	A
IK12	10		99999		48000		99999		99999		99999		99999		99999		99999		99999		99999		99999		10	A
IK13	10		99999		99999		9796		99999		99999		99999		99999		99999		99999		99999		99999		10	A
IK14	10		99999		99999		99999		99999		99999		99999		99999		99999		99999		99999		99999		10	A
IK15	10		99999		99999		99999		99999		99999		99999		99999		99999		99999		99999		99999		10	A
IM11	7200	A	99999		99999		99999		48000		99999		99999		99999		99999		99999		99999		99999		7200	AL
ME10	45354	L	99999		99999		41143		99999		99999		99999		99999		99999		99999		99999		99999		22677	AL
PO10	10		99999		99999		99999		99999		99999		99999		7200		99999		99999		99999		99999		10	A
PT10	7200	AL	99999		99999	A	99999	A	99999	A	99999		99999		99999		99999		99999		99999		99999		7200	AL
WC10	7200	L	99999		99999		99999		99999		99999		99999		99999		99999	L	99999		99999		99999		12967	AL
WC11	10	L	99999		99999		99999		99999		99999		99999		99999		31304	L	99999		99999		99999		7200	A
WC12	10	L	99999		99999		99999		99999		99999		99999		99999		99999	L	99999		99999		99999		7200	A
WC13	10	L	99999		99999		99999		99999		99999		99999		99999	A	99999	L	99999		99999		99999		7200	A
WC14	10	L	99999		99999	A	99999		99999		99999		99999		99999		99999	L	99999		99999		99999		7200	A
WC15	10	L	99999		99999		99999		99999		99999		99999		99999		99999	L	99999		99999		99999		7200	A

Appendix 11 Adhesion and Elevated Temperature Adhesion Test

Test Procedure

1.0 Description:

In the original "IUID Environmental Survivability Testing Report," labels were cyclically exposed to high and low temperatures expected in militarily relevant environments. After a predetermined amount of thermal exposure, labels were returned to room temperature and tested to determine if any changes in adhesion strength could be observed. Little variability in adhesion strength was found.

Individuals familiar with duct tape and other adhesive backed materials know on hot days the adhesive has lower adhesion strength and often becomes soft. The scope of the adhesion strength test method used for the original report did not capture this phenomenon.

The test method was altered for this report to allow testing of adhesives at elevated temperatures. Elevated temperature adhesion tests were performed by immersing labels in a thermally regulated bath of water. Adhesion testing in water was performed for several reasons:

1. Water has a high heat capacity and therefore changes temperature slowly.
2. The Navy operates in many environments where water is present.
3. An environmentally controllable chamber compatible with the adhesion tester was not available within the timeframe of this project.

The phenomenon of adhesives weakening at elevated temperatures was successfully observed using this method. However, there may also be an unaccounted for factor of adhesives weakening in the presence of hot water.

The adhesion test measures the force required to pull an adhered label from another surface at a constant rate. Two different methods of the adhesion test were used. Flexible labels were adhered to a plate and peeled at a set angle at a constant rate while measuring the force. The peel method is a variation of the method described in ASTM D3167 and uses the floating roller fixture called out in that standard. Rigid adhesive backed labels were sheared instead of peeled. A fixed surface area of adhesive was attached to a plate and the label was sheared off the plate at a constant rate. These tests were performed using an Instron model 5569 (see Figure 8).

Adhesion tests were performed on three surfaces: glass, polypropylene, and CARC. Glass and polypropylene were used in the report as HSE and LSE representative materials respectively. CARC was only tested at room temperature due to a miscommunication with the vendor.

CARC comes in many varieties including water-based and oil-based compositions with silica or polymeric flattening agent. The CARC composition, which many claim nothing sticks to, is made with the polymeric flattening agent. Army Research Laboratories (ARL) has conducted an extensive study on adhesives that adhere to the polymeric flattening agent CARC. The ARL study report is in draft and should be published within a year. An oil-based polymeric flattening agent CARC was ordered for testing for this report but adhesion strength results were surprisingly high. It was later discovered that an oil-based silica flattening agent CARC was provided instead. ARL shared that one can tell the flattening agent by scratching their fingernail across the CARC. Silica leaves a whitish streak while polymeric does not. Due to the silica flattening agent, the CARC samples tested for this report showed higher than expected adhesion strengths. However, all varieties of CARC have a textured surface and therefore hold in oils and dirt very well. The silica flattening agent CARC exhibited lower adhesion strengths after being contaminated. The cleaning method in Appendix 7 was not effective at cleaning the silica flattening agent CARC. However, a method shared by Randy Uveges at Camcode for cleaning CARC was effective. Duct tape applied to CARC and peeled off multiple times will remove much of the dirt trapped in the texture and improve label adhesion to CARC.

Figure 8. Left - Instron with heated water bath and clamped nylon strap. Right top - Air shear test. Right middle - Heated shear with added weights immersed in water to accommodate higher shear forces and unattached part of label bent to accommodate clamp. Right bottom - Heated peel test with visible orange thermocouple to monitor water temperature, floating roller peel fixture with white polypropylene test plate, and bottom fixed fixture epoxied to aluminum pot containing heated water.

1.1 Equipment, fixtures, and materials

1.1.1 GFI protected circuit

1.1.2 Suitable vessels for containing heated water (aluminum pots work well) with clamps and bottom fixed fixture as seen in Figure 9
1.1.3 Immersion heater
1.1.4 Tensile tester
1.1.5 Tension cable (duct tape works well)
1.1.6 Floating roller fixture for tensile tester (this fixture will only allow test plates 1" wide or less)
1.1.7 Sample grips for shear test
1.1.8 Nylon strap
1.1.9 Test specimens

1.2 Label preparation
1.2.1 Peel test (flexible labels)
1.2.1.1 Clean the testing surface appropriately (see Appendix 7)
1.2.1.2 Adhere labels for testing to plate (see Appendix 7) leaving approximately 0.5" of the label unattached
1.2.1.3 Verify the data matrix and record the results (see Appendix 6)
1.2.1.4 Attach a tension cable to the unattached portion of the label long enough to connect to the nylon strap shown in Figure 9
1.2.1.5 Let samples sit untouched at least 72 hours before testing
1.2.2 Shear test (rigid labels)
1.2.2.1 Clean the testing surface appropriately (see Appendix 7)
1.2.2.2 Adhere approximately 0.375 square inches of label for testing to plate (see Appendix 7)
1.2.2.3 Verify the data matrix and record the results (see Appendix 6)
1.2.2.4 Let samples sit untouched at least 72 hours before testing

1.3 Room temperature peel test
1.3.1 Measure label width
1.3.2 Feed tension cable through floating roller fixture
1.3.3 Clamp tension cable to a nylon strap shown in Figure 9
1.3.4 Make sure nylon strap is not taught
1.3.5 Perform peel test at an extension rate of 2"/min

1.4 Heated peel test
1.4.1 Maintain water bath temperature between 110-115°F
1.4.2 Wait at least 2 minutes before beginning peel test
1.4.3 Measure label width
1.4.4 Feed tension cable through floating roller fixture
1.4.5 Clamp tension cable to a nylon strap shown in Figure 9
1.4.6 Make sure nylon strap is not taught
1.4.7 Perform peel test at an extension rate of 2"/min

1.5 Room Temperature Shear Test
1.5.1 Measure adhered surface area
1.5.2 Clamp plate, clamp label
1.5.3 Ensure upper and lower clamps are aligned so label is sheared and not pulled at an angle
1.5.4 Perform shear test at an extension rate of 0.5"/min

1.6 Heated Shear Test
1.6.1 Maintain water bath temperature between 110-115°F
1.6.2 Wait at least 2 minutes before beginning shear test
1.6.3 Measure adhered surface area
1.6.4 Clamp plate, clamp label under water as shown in Figure 9

1.6.5 Ensure upper and lower clamps are aligned (it works well to attach label to a nylon strap with a clip and remove the slack after label is immersed)
1.6.6 Make sure nylon strap is not taught
1.6.7 Perform shear test at an extension rate of 0.5"/min

1.7 Reference Material
1.7.1 ASTM D 3167
1.7.2 MIL-HDBK-310

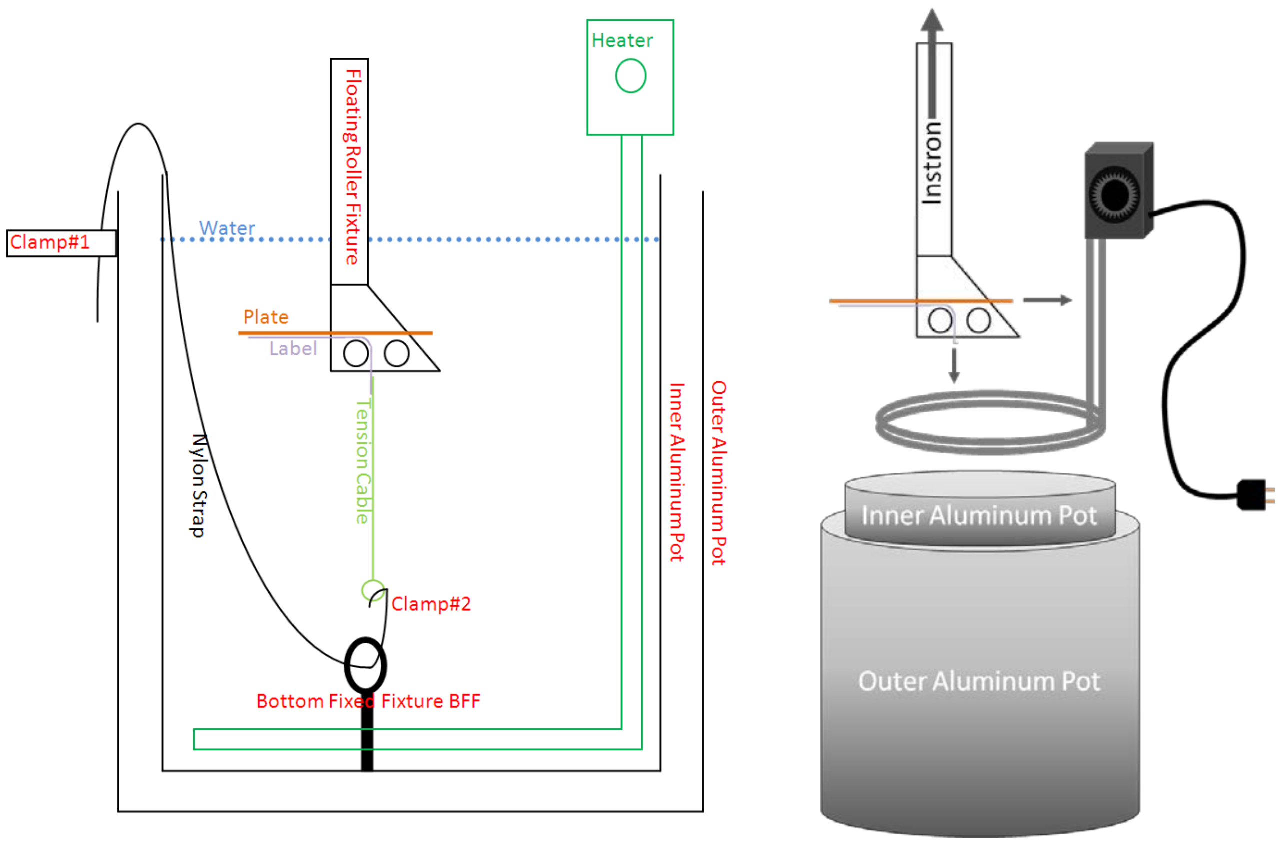


Figure 9. Sketch of heated peel setup. Left - inside water bath, Right - exterior sketch

Test Results

Duct Tape Adhesion

Duct tape[15] was used as an initial test material to determine if the heated peel test method described above would show weaker adhesive strength at elevated temperatures. Additionally, an extension rate test was performed using ASTM D3330 method F. The ASTM D3330 results at 2"/min are comparable to the ASTM D3167 results at 2"/min suggesting room temperature peel test results from the original report may be compared with the results contained in this report. The extension rate test data is found in Table 10.

[15] Gorilla brand duct tape was used for this testing.

Table 10. ASTM D3330 extension rate test of duct tape adhesion strength

Peel Rate [in/min]	Force [lb/in]
0.5	1.8
1	2.1
2	2.6
4	3.0
8	3.8
12	4.1

Duct tape adhesion strength results were puzzling. Duct tape exhibited the highest adhesion strength on CARC which was later attributed to the silica flattening agent. Moderate glass adhesion and lower adhesion strength on polypropylene were observed at room temperature as expected. However, elevated temperature peel tests of duct tape immersed in water showed the reverse trend. In some cases, the duct tape fell off glass plates after immersion in 110-115°F water without any applied force. Objects immersed in water feel lighter than ones in air due to an effect called the buoyant force. A correction for the buoyant force was applied to the data.

Figure 10 depicts a study of immersion time versus peel strength on glass and polypropylene plates. Figure 11 shows room temperature peel strength of duct tape on CARC, glass, and polypropylene plates. The average peel strength of duct tape on glass tested at 2"/min extension rate using the floating roller fixture was 2.5 lb/in which is similar to the value of 2.6 lb/in at a 2"/min extension rate measured using the ASTMD3330 method shown in Table 10. This suggests results from the two methods may be comparable.

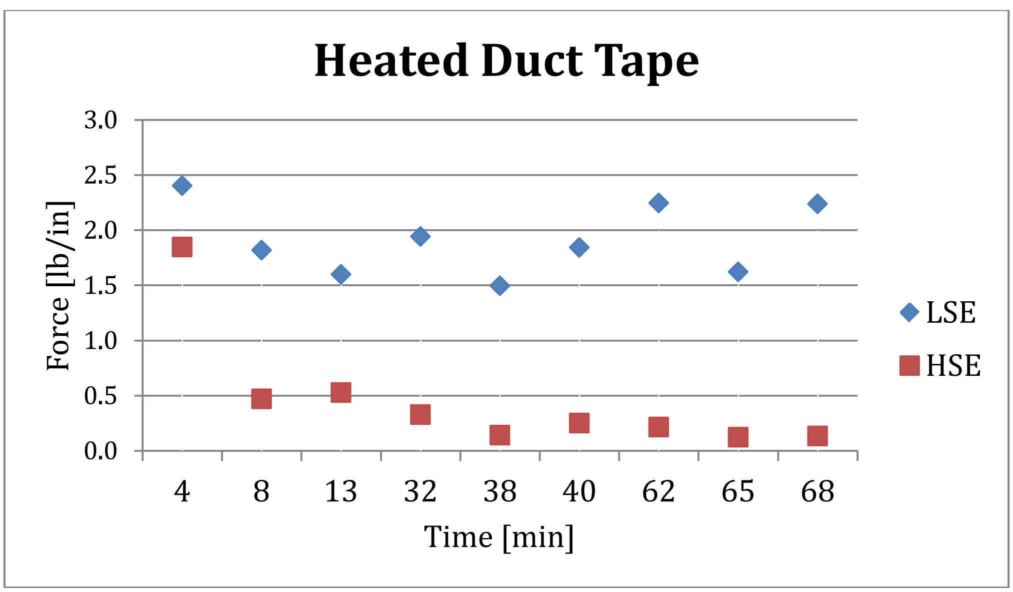


Figure 10. Duct tape immersion time vs. peel strength, one strip of tape tested at each time

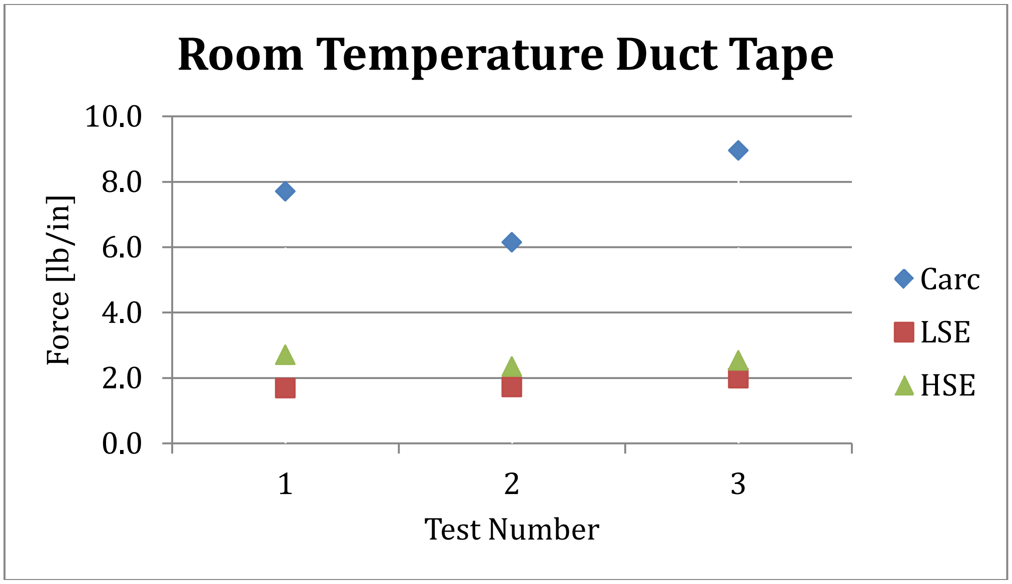


Figure 11. Room temperature adhesion strength of duct tape on multiple surfaces

Most of the labels tested in this report have an acrylic-based adhesive. In order to determine the appropriate immersion time for labels, an additional test of one of the reported label types was performed. After 2 min immersion, the variability in adhesion strengths of the tested label type was minimized. Accordingly, 2 min was selected as the minimum immersion time for labels.

Peel Tests

Peel tests were performed on flexible labels using the floating roller fixture. The peel test was conducted at a 2"/min peel rate. Results are normalized by the width of the label and given in lb/in[16]. Three peel tests were conducted for each flexible label type on each substrate (glass, polypropylene, and CARC) at room temperature and on glass and polypropylene at elevated temperature (110-115°F). Peel test results are summarized in Table 11 and graphed in Figure 12. Table entries and data points shown in the graph are averages of three data points.

Many vendors suggest a 72-hour dwell time for maximum adhesion to be attained. Labels were prepared for peel testing about one month prior to performing the tests by adhering labels to cleaned plates and attaching a strip of duct tape (tension cable referenced in 1.1.5) to feed through the floating roller fixture and attach to clamp #2. Some samples had high enough adhesion strength the attached duct tape tension cable slipped during testing. In heated peel tests where the duct tape adhesive weakened, the duct tape occasionally slipped off completely, usually at a force greater than 2 lb/in. Heated adhesion test results reported in Table 11 and Figure 12 greater than 2 lb/in may be higher than reported had the duct tape not slipped off. Additional test specimens of these labels were remade and allowed to dwell for 72 hours prior to testing. In some cases, the measured peel strength after 72 hours was significantly less than the peel strength measured after the one month dwell. The higher peel strength values were reported despite the duct tape tension cable slippage. With the exception of FC14 and FC15, label types had higher peel strength on HSE substrate compared to LSE substrate. The other anomalous result was PT10 which showed higher heated adhesion strength on LSE than room temperature adhesion. These anomalous results are highlighted yellow in Table 11.

[16] Units of lb/in are pounds force per inch width of the label.

It is interesting that none of the label types submitted for testing on CARC achieved peel strengths as high as duct tape. Comparison of Table 10 and Table 11 shows that duct tape had adhesion strength greater than 6 lb/in while vendor supplied labels had strengths less than 5 lb/in. This may be due to the thick layer of adhesive on duct tape penetrating into the silica flattening agent. The ARL report should give more detail and suggest optimal adhesives.

Table 11. Average peel strength of three tested labels reported in lb/in. Highlighted cells show unexpected results

	CARC	HSE		LSE	
Labels	**Air**	**110F**	**Air**	**110F**	**Air**
AB12	2.5	1.2	4.0	1.5	1.5
AB13	0.7	0.3	2.7	1.1	2.1
AN10		0.8	3.3	0.8	1.5
AN11		3.1	6.1	2.4	3.4
AN12	4.2	1.6	5.9	0.9	2.8
AN13		0.6	2.7	0.7	1.0
AN14		1.8	5.5	1.2	2.6
AN15	4.5	1.7	6.2	1.2	2.6
ES11		0.5	2.0	0.8	0.9
ES12		0.6	4.9	1.6	2.9
FC10		0.8	2.1	0.8	1.1
FC11		1.0	4.1	1.9	1.8
FC12		1.3	4.3	1.5	1.9
FC13	4.6	1.9	6.0	0.8	1.9
FC14	4.1	1.9	4.9	2.2	4.9
FC15	3.7	2.0	3.8	2.2	4.6
FL10		1.4	4.1	1.8	2.4
IK10		0.8	2.6	0.5	0.4
IK11		0.8	2.9	0.7	1.3
IK12		0.4	2.3	1.1	1.2
IK13		0.5	4.2	0.8	2.5
IK14		0.7	3.7	0.8	1.2
IK15		0.4	2.2	1.0	0.9
IM11	3.4	1.6	4.9	2.1	2.7
ME10		2.7	7.9	1.9	4.8
PO10		1.0	3.0	0.7	1.8
PT10		0.8	2.7	1.9	0.9
WC10		0.8	3.2	0.9	1.5
WC11		0.7	3.1	0.8	1.3
WC12		2.5	6.5	2.0	2.9
WC13	4.9	2.0	6.3	1.2	2.5
WC14		0.7	2.4	0.8	1.5
WC15		2.1	6.0	2.2	2.6

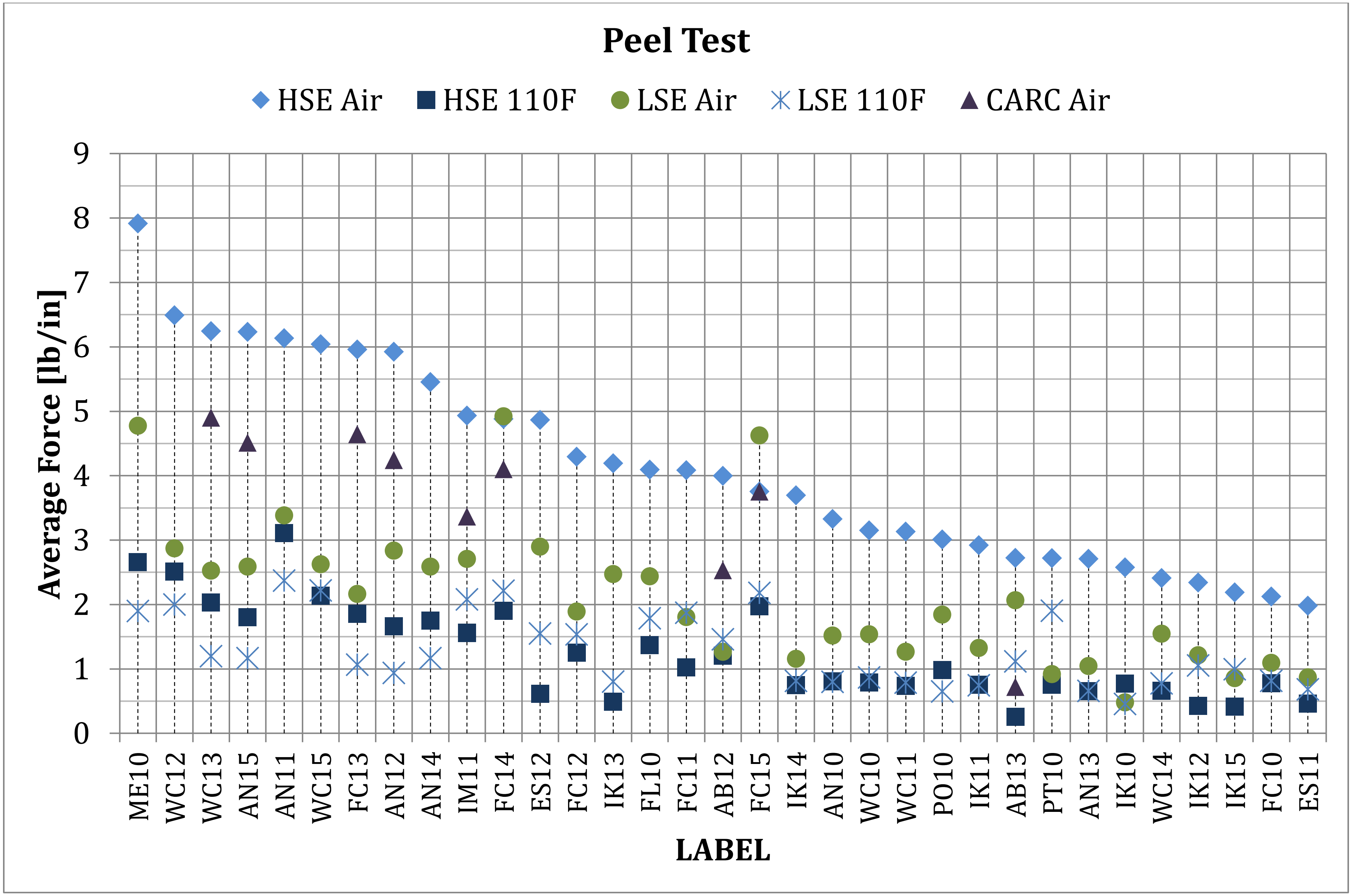


Figure 12. Average peel strength results by HSE substrate at room temperature.

Shear Tests

Shear tests were performed on rigid labels at a rate of 0.5"/min so as not to break the label. The results of shear tests are given in units[17] of lb/in^2. The force required to shear a data plate/label off the substrate is normalized by the surface area sticking to the substrate. These results cannot be compared to the peel test results and are only meaningfully compared to other shear test results. At least three shear tests were conducted for each flexible label type on each substrate (glass, polypropylene, and CARC) at room temperature and on glass and polypropylene at elevated temperature (110-115°F). Shear test results are summarized in Table 12 and graphed in Figure 13. More shear tests were conducted on labels where large variability was observed and the results were averaged. Table entries and data points shown in the graph are averages of three or more data points. High shear strength correlated well with pressure wash results, see Appendix 9. Rigid labels tended to perform better in pressure wash than flexible labels. Greater label thickness and label rigidity reduces the tendency of the label to start peeling.

Shear tests show trends similar to peel tests at room temperature with highest shear strength values measured on HSE substrate, followed by CARC followed by LSE. Heated shear tests also show lower strengths than room temperature tests as expected. HO12 has the anomalous result with the room temperature LSE shear strength appearing higher than the HSE test. This anomaly is highlighted in yellow in Table 12.

Table 12. Average shear strength of at least three tested labels reported in lb/in^2. Highlighted cells show unexpected results.

	CARC	HSE		LSE	
Label	**Air**	**110F**	**Air**	**110F**	**Air**
CA10		12.2	73.4	16.6	59.9
CA11	50.5	15.3	94.1	5.8	37.3
CA12		17.2	76.6	2.8	64.8
CA13	25.2	25.4	93.1	5.1	32.6
CA14		12.9	81.0	10.7	50.4
CA15	29.3	18.7	85.7	5.5	29.7
HO10		8.6	103.2	24.2	77.9
HO11	46.9	17.2	118.5	8.7	48.4
HO12		8.1	98.7	17.0	116.6
HO13		27.2	105.8	21.7	82.9
HO14		32.6	105.5	19.5	89.1

[17] Units of lb/in^2 are pound force per square inch.

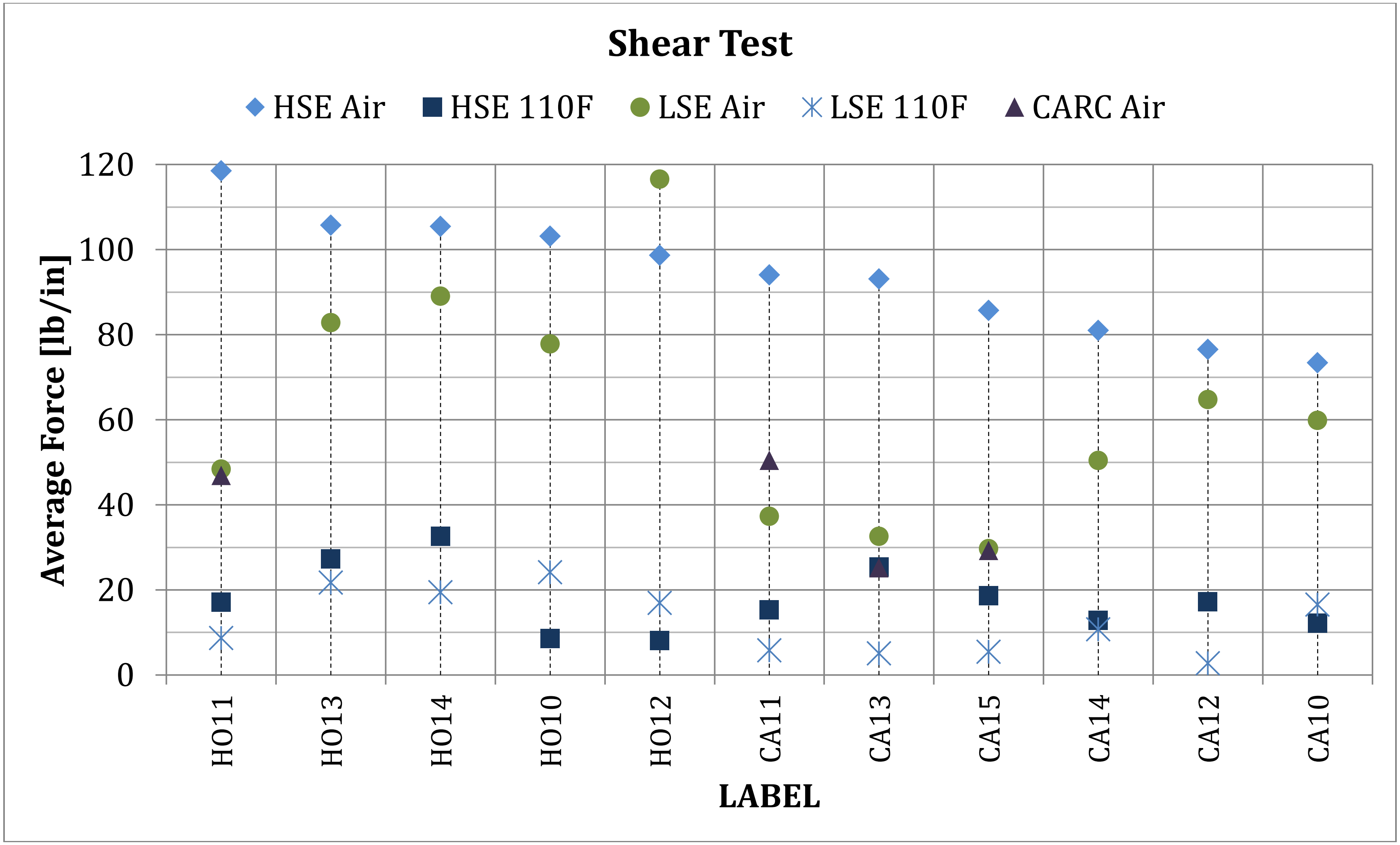


Figure 13. Average shear strength results by HSE substrate at room temperature.

Appendix 12 Solar Test

Test Procedure

1.0 Description:

Solar degradation is a potential failure mode for labels. There have been reports of laser-markable labels fading or bleaching after prolonged exposure to sunlight. MIL-STD-810G Method 505.5 is used to determine the effects of solar radiation on materiel. However, the section on limitations (1.3a) states, "This test method does not consider all of the effects related to the natural environment (see Annex A, paragraph 7.2) and, therefore, it is preferable to test materiel at appropriate natural sites." NSWC Corona is located in a California desert with ample solar radiation and the labels were exposed for 6 months to natural weather and solar radiation. The total solar and ultraviolet radiation were measured and are equivalent to approximately 45 cycles of accelerated procedure II testing called out in method 505.5. Labels were affixed to glass or polypropylene plates which were mounted on test boards and placed outside. A picture of the plates mounted on test boards is seen in Figure 14.

Figure 14. Labels attached to plates mounted on test boards for solar exposure testing

1.1 Equipment, Fixtures, and Materials

1.1.1 Solar radiation detector
1.1.2 Ultraviolet radiation detector
1.1.3 Mounted test plates
1.1.4 Sun

1.2 Procedural Steps
1.2.1 Label preparation
1.2.1.1 Clean a test plate as described in Appendix 7
1.2.1.2 Adhere labels to the test plate, roll and burnish as described in Appendix 7
1.2.1.3 Mount label plates to a board or fixture prior to solar exposure
1.2.2 Testing instructions
1.2.2.1 Place labels outside in location with unshaded sunlight

1.3 Reference Material.
1.3.1 MIL-STD-810G Method 505.5

Test Results

Labels were exposed to 4367 MJ/m^2 (megajoules per meter squared) of total solar radiation, 4.7% of which was in the ultraviolet spectrum, in the 6 month period they were outdoors (February - August 2012, Norco, CA). This is the amount of solar radiation 45 cycles of MIL-STD-810G Method 505.5 procedure II accelerated testing would have exposed the labels to. No label failures occurred in this time period but degradation in UEC score as well as label contrast was observed for some labels.

The only label with significant contrast degradation was CO13. UEC degradation was seen in three label types, CO13, AB12, and IK10. CO13 is not an adhesive backed label and was only tested by affixing it to a glass plate. AB12 showed UEC degradation while applied to both glass and polypropylene plates. IK10 showed UEC degradation only on the polypropylene plate. The reason IK10 only showed degradation on one type of surface is not understood. A table of test results and predicted failure times is found in Table 13. Numerical values are weeks of exposure and values of 999 indicate that no statistically significant degradation in UEC was noted during the 6 month solar exposure period.

Table 13. Solar exposure test. Values of 999 indicate no significant UEC degradation, other numbers are predicted weeks of exposure to UEC failure. No label failures in 26 weeks of solar exposure.

Label	HSE	LSE
AB12	85	148
AB13	999	999
AN10	999	999
AN11	999	999
AN12	999	999
AN13	999	999
AN14	999	999
AN15	999	999
CA10	999	999
CA11		999
CA12	999	999
CA13		999
CA14	999	999
CA15		999
CO12	999	
CO13	51	
ES11		999
ES12	999	999
FC10	999	999
FC11	999	999
FC12	999	999
FC13	999	999
FC14	999	999
FC15	999	999
FL10	999	
HO10	999	999
HO11		999
HO12	999	999
HO13	999	999
HO14	999	999
ID10	999	
IK10	999	103
IK11	999	999
IK12	999	999
IK13	999	999
IK14	999	999
IK15	999	999
IM11	999	999

Label	HSE	LSE
ME10	999	999
P010	999	
PT10	999	999
WC10	999	999
WC11	999	999
WC12	999	999
WC13	999	999
WC14	999	999
WC15	999	999