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Corrosion Inhibitive Hygroscopic Organic-Based Dust Palliatives

Final Report on Project F12-AR11

Sean W. Morefield, John K. Newman, Charles A. Weiss Jr., Catherine C. Thomas, and Philip G. Malone

November 2018

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and Control Program

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Corrosion Inhibitive Hygroscopic Organic-Based Dust Palliatives

Final Report on Project F12-AR11

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Final report

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3090 Defense Pentagon
Washington, DC 20301-3090

Under Project F12-AR11, "Corrosion Inhibitive Hygroscopic Organic-Based Dust Palliatives"

Abstract

Dense airborne dust caused by military ground vehicles is a large, multi-faceted problem for the Department of Defense. One costly aspect of the problem is that fugitive dust and small rocks made airborne by ground vehicles on unpaved military service roads increases erosive damage to vehicle coatings. The dust palliative products most widely used to stabilize the surfaces of unpaved roads are formulated using corrosive salts such as magnesium chloride. These are effective at reducing erosive coating degradation but they negate that benefit due to their inherent corrosiveness of exposed metal on vehicle undercarriages. This report documents the testing, demonstration, and validation of several soil-binding materials that effectively suppress fugitive dust while being less corrosive than the most widely used dust palliatives.

Based on laboratory and field test results, as well as data in the technical literature, a commercially available refined oil called Durasoil was found to be the most effective and least corrosive dust palliative of all materials and blends investigated. For purposes of calculating economic benefits, Durasoil was analyzed against magnesium chloride, which is the most widely used dust palliative. The projected return on investment of using Durasoil instead of magnesium chloride was 18.1.

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Preface

This project was performed for the Office of the Secretary of Defense under the Department of Defense Corrosion Prevention and Control (CPC) Program, Project F12-AR11, "Corrosion Inhibitive Hygroscopic Organic-Based Dust Palliatives." The proponent was the U.S. Army Office of the Assistant Chief of Staff for Installation Management (ACSIM) and the stakeholder was the U.S. Army Installation Management Command (IMCOM). The technical monitors were Daniel J. Dunmire (OUSD(AT&L)), Ismael Melendez (IMPW-E), and Valerie D. Hines (DAIM-ODF).

The work was performed by the Materials and Structures Branch of the Facilities Division (CEERD-CFM), U.S. Army Engineer Research and Development Center, Construction Engineering Research Laboratory (ERDC-CERL). At the time this report was prepared, Vicki L. Van Blaricum was Chief, CEERD-CFM; Donald K. Hicks was Chief, CEERD-CF; and Michael K. McInerney, CEERD-CFM, was the ERDC CPC Program Coordinator. The Deputy Director of ERDC-CERL was Dr. Kirankumar Topudurti and the Director was Dr. Lance D. Hansen.

The authors offer special thanks to Eugene (Gene) Arter, Engineering Technician, Pohakuloa Training Area Directorate of Public Works, and U.S. Army Pacific (USARPAC) personnel for their assistance in coordinating, financing, and executing this project.

The Commander of ERDC was COL Ivan P. Beckman was and the Director was Dr. David W. Pittman.

Unit Conversion Factors

Multiply	By	To Obtain
cubic yards (cu yd)	0.7645549	cubic meters
ft (ft)	0.3048	meters
degrees Fahrenheit	(F-32)/1.8	degrees Celsius
gallons (US liquid)	3.785412 E-03	cubic meters
inches (in.)	0.0254	meters
miles (US statute)	1,609.347	meters
miles per hour	0.44704	meters per second
mils	0.0254	millimeters
pounds (force) per square inch (psi)	6.894757	kilopascals
pounds (mass)	0.45359237	kilograms
square yards	0.8361274	square meters
tons (2,000 pounds, mass)	907.1847	kilograms

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1 Introduction

1.1 Problem statement

Dense airborne dust clouds caused by ground vehicles and aircraft, often referred to as *fugitive dus*t, are a large and multifaceted problem for the Department of Defense (DoD). Helicopter brownouts over untreated soil landing pads are an immediate safety problem in terms of flight operations, both in training areas and military missions. Fugitive dust emissions from unsurfaced roads and pads also present a respiratory hazard to nearby personnel and downwind communities, possibly posing the risk of future health problems.

To mitigate the safety and health risks associated with fugitive dust, engineers apply materials to stabilize or immobilize the surface of natural soils that are needed for operations. A common method for dust control is the application of water, the surface tension of which binds soil particles and agglomerates fines to prevent them from becoming airborne. A basic problem with this approach is that water evaporates quickly in warm and/or arid environments. Typically, hygroscopic compounds can be introduced with the water. These humectant products adsorb water from the air and retain it longer in the soil. However, some contain metal chlorides (e.g., calcium and magnesium chloride) and are highly corrosive to metals—especially aluminum, which is used to reduce the weight of ground vehicles and is the major structural metal used in aircraft. Humectants with metal chlorides are prohibited where aircraft operate, but they are used to stabilize soils where ground vehicle traffic produces fugitive dust.

Vehicle maintenance costs due to dust damage and corrosive dust-suppression materials are considerable, and they will continue to rise without improved technology solutions.

A U.S. General Accounting Office report (GAO July 2003), citing Timken and Thompson (2003), refers to a 1998 Army estimate that

> approximately $4B was spent on corrosion repair of helicopters. Based on past studies, the 2006 annual cost of corrosion to Army ground vehicles alone was estimated at $2.0 billion, compared to all DoD facilities and infrastructure corrosion costs which were estimated at $1.8 billion

> the following year. In addition, corrosion from dust control also has non-financial impacts. This includes reduction in system readiness and system sustainability.

Controlling fugitive dust is a critical necessity, but conventional techniques contribute to the high and increasing cost of corrosion control related to military vehicles, aircraft, and equipment. Therefore, DoD would greatly benefit from affordable soil-stabilization materials and methods that (1) possess water-retention and hygroscopic properties, (2) effectively suppress dust for the required amount of time, and (3) are less corrosive than currently available solutions.

1.2 Objectives

The project objective was to demonstrate and validate the performance of selected commercial and experimental dust control agents in terms of effectiveness and impacts on the corrosion of metals used in military ground vehicles and aircraft.

1.3 Approach

The site of the field work for this project was Pohakuloa Training Area (PTA), HI, which is subject to extreme corrosion problems due to

- the abundance of chlorides in the ocean air
- high ambient humidity
- aggressive, highly abrasive and corrosive soils formed by the weathering of volcanic soils.

This project encompassed four tasks:

1. Design and build the Keamuku Main Supply Route (KMSR) sub base, including grading, and sub-base stabilization using geogrid materials
2. Laboratory testing of the corrosion properties of dust palliative compounds in various soils on two types of steel
3. Measure the effectiveness of dust-stabilizing agents in the laboratory using the ERDC Dust Palliative Test (Newman and Rushing 2010), which simulates aircraft effects on ground surfaces
4. Field application and validation of selected dust stabilizers on the KMSR

The dust palliative materials were selected for application over the sub base upon evaluation of the laboratory test results. The compounds were applied to adjacent 750 ft sections of the selected supply road, which primarily accommodates wheeled-vehicle traffic.

1.4 Metrics

The overall metric for success of the tested dust palliatives was to be significantly less corrosive than commonly used soil stabilizers while being equally or more effective at dust suppression.

Corrosivity was evaluated by determining the corrosion rate of steel when exposed to moist soil containing each dust palliative. Corrosion rates were determined in the laboratory in accordance with ASTM G162, *Standard Practice for Conducting and Evaluating Laboratory Corrosions Tests in Soils*.

Dust-control capability was evaluated in the laboratory using the ERDC DPT (Newman and Rushing 2010).

Dust control capability was evaluated in the field using a commercial aerosol/dust monitor.

2 Technical Investigation

2.1 Technology overview

The general physical and chemical mechanisms of dust suppression are described by Gebhart, Denight, and Grau (1999).* There are a number of approaches to dust suppression that vary greatly depending on the environmental conditions, road surface mineralogy, and application cost. Six broad classes of palliative mechanisms are discussed in Gebhart, Denight, and Grau (1999). These are categorized in terms of physio-chemical mechanism and are primarily evaluated for their effectiveness in stabilizing the local soil type and surface characteristics, cost of application, and impact on the environment.

The lactobionic acid (LBA) formulations tested here belong to the organic non-bituminous class of dust palliatives. The Durasoil product is a type of refined oil that promotes adhesion among loose soil particles, and the tested calcium chloride treatment belongs to the water-attracting (i.e., humectant) class of stabilizers.

2.2 Road design/build

The road was designed and built by the 130th Engineer Brigade, stationed at Schofield Barracks, HI. The design complied with U.S. Army Corps of Engineers (USACE) Engineer Technical Letter ETL 1110-1-18, which provides guidance, basic criteria and information for the use of geogrids in the design and construction of pavements. A uniform road surface was required for the field testing of dust palliatives. The detailed road sub-base design is presented in Appendix A.

2.3 Laboratory corrosion testing

The experimental procedure for this testing was designed to duplicate contact between a metal surface and moist soils that contain dust-control agents. The goals were to characterize soils from two areas with specific dust problems and to determine and compare the corrosive effects of two

* This publication is also available as Army Environmental Command report SFIM-AEC-EQ-CR-99002.

compositionally different treated soils on an untreated steel surface. Details of the corrosion testing program are presented in Appendix B.

Two fine-grained soils that cause dust-control problems were selected for testing: Vicksburg (MS) loess and Keamuku (HI) andisol. The soils were characterized using D422, *Standard Test Method for Particle-Size Analysis of Soils*.

Two types of bare carbon steel were used in the testing: UNS G10180 mild steel (C1018) and UNS G10500 steel (C1050).

Six types of dust-control agents were tested: (1) a saturated magnesium chloride solution with a hygroscopic salt; (2) Durasoil*, a refined oil stabilizer; (3) a test solution containing chemically pure lactobionic acid (LBA); (4) a test solution containing a food-grade LBA; (5) a test solution containing potassium lactobionate and suspended calcium carbonate (K-LBa + $CaCO_3$); and (6) distilled water.

ASTM G162, *Standard Practice for Conducting and Evaluating Laboratory Corrosions Tests in Soils*, was used as the basic test procedure for evaluating the corrosive effects of the soil treated with dust palliatives. Three sample cups were used for each test, and each carried one cylindrical test specimen (i.e., coupon) of a selected metal. The procedure for uncoated samples was employed, and the tests were run in a partly saturated condition. The pH of each soil cup was measured using the procedure outlined in ASTM G 51, *Standard Test Method for Measuring pH of Soil for Use in Corrosion Testing*.

Control samples were prepared by adding 50 ml of distilled water to the test containers holding the steel coupons. The soil and water were not mixed. The procedure was designed to allow the samples to cycle from wet to dry as would occur in the field (see Appendix B under "Wet/dry cycling"). The coupons were in contact with the soil for a total of 864 hours.

The effects of corrosion were determined by cleaning the coupons and determining condition and mass loss at ten-day intervals or sooner if required. The cleaning and evaluation followed the guidelines in G1, *Standard Practice for Preparing, Cleaning, and Evaluating Corrosion*

* Durasoil is a registered trademark of Soilworks, LLC, Scottsdale, AZ.

Test Specimens. Data reduction followed the guidelines presented in ASTM G16, *Guide for Applying Statistics to Analysis of Corrosion Data*.

2.4 Laboratory dust-suppression testing

Laboratory testing of the dust palliatives was performed using the ERDC Dust Palliative Test (DPT) device to measure mass loss of soil under air impingement (Newman and Rushing 2010). Samples of the aggregate mixture used to construct the KMSR were employed in the testing.

Four materials were chosen for the laboratory study. Two were commercial products: a synthetic oil (Durasoil, or DS) and a humectant/natural polymer product (Xhesion Pro™, or XHP).* Also, two experimental materials were selected: a natural biopolymer blend called RhEPS (Newman et al. 2010); and an experimental humectant called calcium lactobionate (CLB). RhEPS and CLB were blended together as part of the testing. It was expected that the materials would be synergistic in action, with the biopolymer providing some adhesive qualities and the CLB providing some humectant capability.

The potassium lactobionate salts (K-LB) used in the corrosion testing proved to be difficult to scale up and disperse. Thus, the compound was not included in the laboratory or field dust-suppression studies. (CLB was tested instead because its general corrosivity is comparable to K-LB while its solubility is much higher, making CLB easier to disperse and apply in the field.

Magnesium chloride also was not selected for dust suppression testing because it is already known to be an effective dust suppressant. More importantly, in corrosion testing it was found to be highly corrosive to metals used in vehicles, thus making it unsuitable for applications requiring corrosion prevention or control properties.

2.5 Field application of dust palliatives

Based on the results of in-house laboratory testing, three compounds were selected for field application and dust-suppression testing: Durasoil, Xhesion Pro, and CLB. Two rates of application were chosen, 0.25 gsy and 0.5

* Xhesion Pro is a trademark of EnviroTech Services, Inc., Greeley, CO.

gsy.* RhEPS was not applied due to the lack of available quantities necessary for field testing. Magnesium chloride was not applied because of its highly corrosive properties (roughly ten times more corrosive, as measured in the lab.) Table 1 lists the materials tested, application rates, and the placement of the materials in the test area.

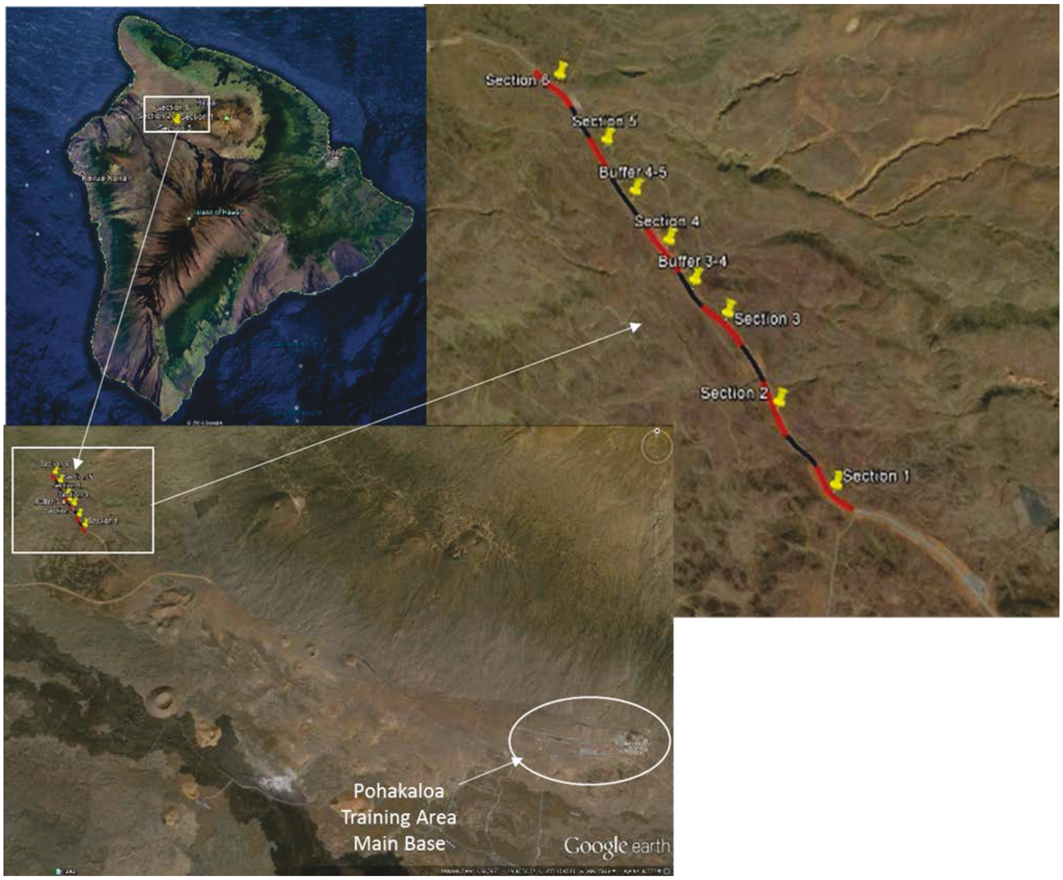
Table 1. Designations of test items, application rates, and locations of test sections and buffers.

Test Item	Application Rate (gsy)	Test Section	Start Distance (ft)	End Distance (ft)
Durasoil	0.25	1	0	750
Buffer			750	1250
Durasoil	0.5	2	1250	2000
Buffer			2000	2500
XHesion Pro	0.25	3	2500	3250
Buffer			3250	3750
XHesion Pro	0.5	4	3750	4500
Control	NA	Control	4500	5000
CLB	0.25	5	5000	5750
Buffer			5750	6250
CLB	0.5	6	6250	7000

This work was conducted on a section of the KMSR road at PTA. Figure 1 shows the area where the testing was performed and the layout of the test sections.

* gsy: gallons per square yard.

Figure 1. Google Earth image showing locations and test sections on the KMSR.



A length of the KMSR that had been reconstructed in 2012 and 2013 was chosen for the study (Figure 1). It ranges from at an average elevation of about 4,700 ft at Test Section 1 to 4,200 ft ending at Test Section 6. The temperatures range from 50–80 °F with occasional drops near 40 °F and highs near 85 °F. Rainfall is sparse, ranging 8–12 in. per year, but it generally comes in only three or four events per year. These large rain events often result in considerable washout damage to the local roads. The humidity in the test area ranges from near 30% to 100% daily. Often, thick fog develops in the KMSR area in the afternoons and overnight. These phenomena were expected to provide excellent conditions for the study of humectant and hygroscopic dust palliatives.

The test sections were measured on 3 September 2013 and the materials were placed on 4 and 5 September 2013. The control section was chosen near the middle of the test area. A Wolverine spray device manufactured by Midwest Industrial Supply was used to apply the materials (Figure 2).

Figure 2. Sprayer mounted on HUMVEE truck provided by the PTA fire department.

The spray device was calibrated by a trial-and-error process of adjusting the flow rate to 0.25 gsy at 3 miles per hour (mph), a speed that can be maintained by the High Mobility Multipurpose Wheeled Vehicle (HUMVEE) at near-idle. The interior nozzles were adjusted to provide double overlap of the spray pattern at the ground with approximately 6 in. of single spray on each side of the HUMVEE, covering a total width of about 8 ft. The width of the KMSR averaged about 24 ft. The middle of the road was sprayed first, then the sides were sprayed, overlapping approximately 6 in. with the middle to yield a total sprayed width of about 23 ft. The materials were applied at a rate of 0.25 gsy in three passes to provide complete coverage of the road. Each pass overlapped the other by approximately 6 in. The same pattern was utilized to achieve an application rate of 0.5 gsy except each pass was covered twice.

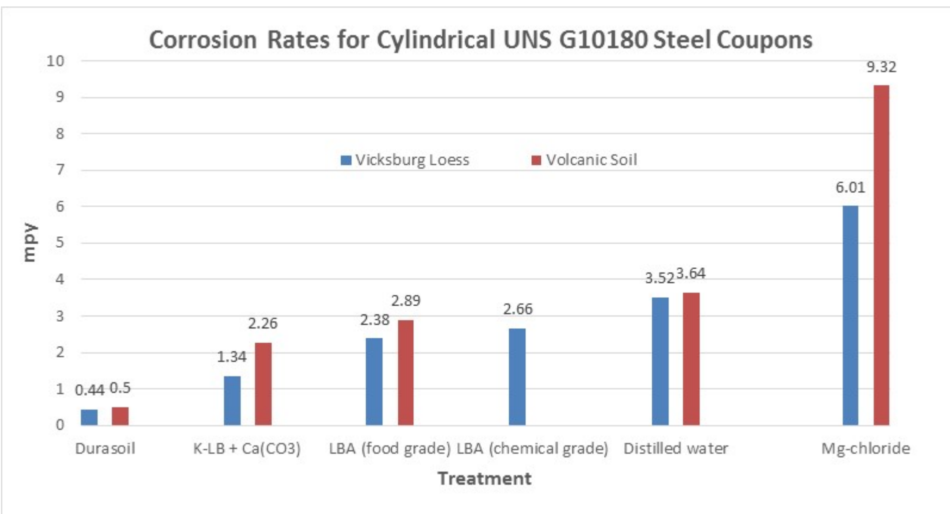
3 Discussion

3.1 Results

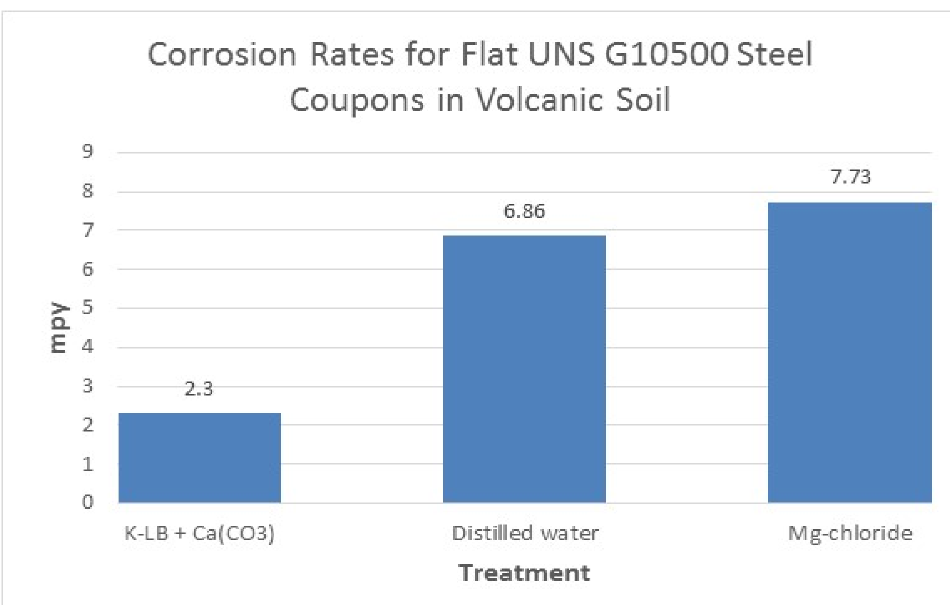
3.1.1 Laboratory corrosion testing

Details of the laboratory corrosion testing program are presented in Appendix B. The data from the corrosion tests on the G10180 steel cylindrical coupons are presented in Figure 3a. Results obtained from tests on the G10500 steel coupons are presented in Figure 3b.

Figure 3. Corrosion tests on the G10180 steel cylindrical coupons (a). Corrosion tests on the G10500 steel cylindrical coupons (b).



(a)



(b)

The corrosion rates for each soil treatment used on each soil are presented in ascending order. In both soil types, refined oil treatment has the lowest corrosion rate, followed by potassium lactobionate with calcium carbonate (K-LB + Ca(CO)3), then LBA and distilled water. The most corrosive treatment is magnesium chloride ($MgCl_2$). The corrosion rates are slightly higher in Keamuku andisol than in each corresponding treatment in Vicksburg loess. The difference may reflect the lower pH (i.e., higher acidity) of Keamuku andisol. The mineral composition of the Vicksburg loess also indicates that it would have a higher pH since it typically contains carbonates such as dolomite or possibly calcite. However, Keamuku andisol shows a higher corrosion rate even when the soil was treated with K-LB + $Ca(CO_3)$, a treatment that increased the pH in both soils.

The refined oil treatment (Durasoil) showed the lowest corrosion rate with pitting-type corrosion that was related to points on the coupon that came into contact with organic debris (decaying rootlets). The corrosion protection provided by the oil treatment was attributed to the oil effectively coating the steel surfaces. The oil coating was very nearly complete because the coupon was clean and dry when the oil was added to the test containers.

The LBA reduced the corrosion rate of steel but was not as effective as potassium salt. In both types of soil, LBA did reduce the corrosion rate of both types of steel when compared to samples that were exposed to distilled water. Testing with the G10180 steel indicated that there was no significant difference in performance between the chemically pure LBA or the less refined food-grade LBA.

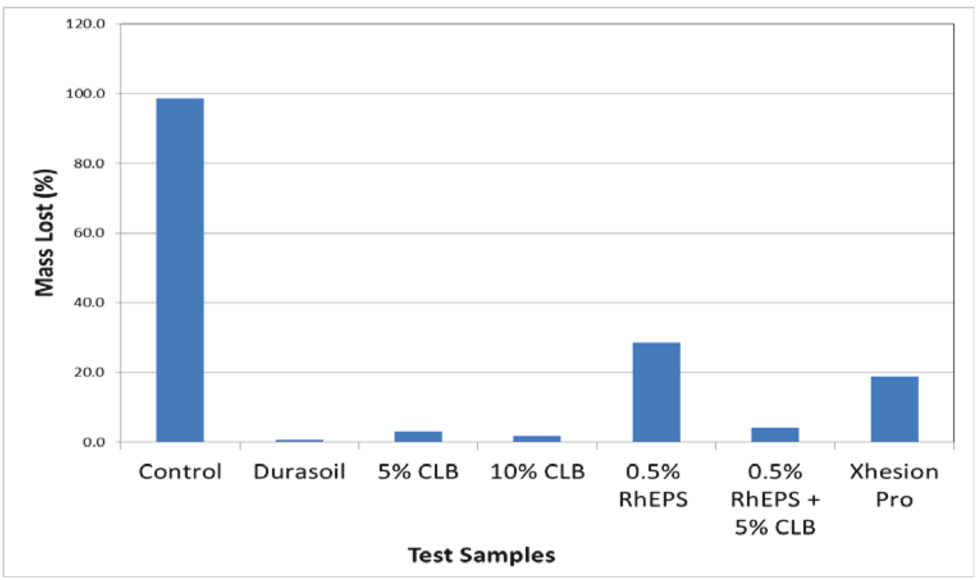
K-LB consistently lowered the corrosion rate for both types of steel in both soils. It outperformed all of the other water-based dust control treatments at the levels that were applied. Previous studies indicated that K-LB could be effective at far lower concentrations, but this study took advantage of the very high solubility of K-LB (>60% by weight) and used the higher concentration (44% by weight) that could be supplied with the same volume (50 ml) of liquid. Schmitt and Saleh (2000) provided data showing K-LB could be effective in reducing corrosion in brine-contaminated pipeline conditions at concentrations as low as 0.1%.

The magnesium chloride solution yielded the most significant surface-visible damage, followed by distilled water. The K-LB showed minimal damage, which corresponded well with the low corrosion rates measured in other tests.

3.1.2 Laboratory dust testing

Figure 4 displays the results of the DPT device for dust palliatives tested in the laboratory. The control sample performed as expected with near-complete mass loss of soil under air flow. Durasoil performed the best, followed by the 10% CLB solution, 5% CLB, 0.5% RhEPS/CLB, XHP, and 0.5% RhEPS.

Figure 4. Soil mass loss in the impingement test comparing various dust palliatives at 0.25 gsy.



3.1.3 Dust palliative performance field testing

The treated road sections were tested on 9 September 2013, four days after application (no rainfall was measured at the site during the interim) and again on 19 November 2013. The speed of the testing vehicle averaged 10 mph, and ranged from 8–12 mph. Dust was measured using a DustTrak II 8530 aerosol monitor* (Figure 5) that was mounted inside a test stand enclosure (Figure 6).

* DustTrak II 8530, TSI Inc., Shoreview, MN (http://www.tsi.com/dusttrak-ii-aerosol-monitor-8530).

Figure 5. DustTrak II monitoring device (manufacturer photograph).

Figure 6. Test stand with the dust monitor enclosure showing vertical blue sampling stack attached to the monitor inlet.

The DustTrak II uses an internal vacuum pump to draw air into a chamber that measures dust concentration using a light-scattering photometer. The device was used as a point measure placed at the center of the test sections and downwind approximately 5 ft from the edge of the vehicle path. Data were collected during 10 passes of the HUMVEE. An example of data from the control section is shown in Figure 7.

Figure 7. An example of the DustTrak II data from the control section showing the data from 10 passes of the HUMVEE.

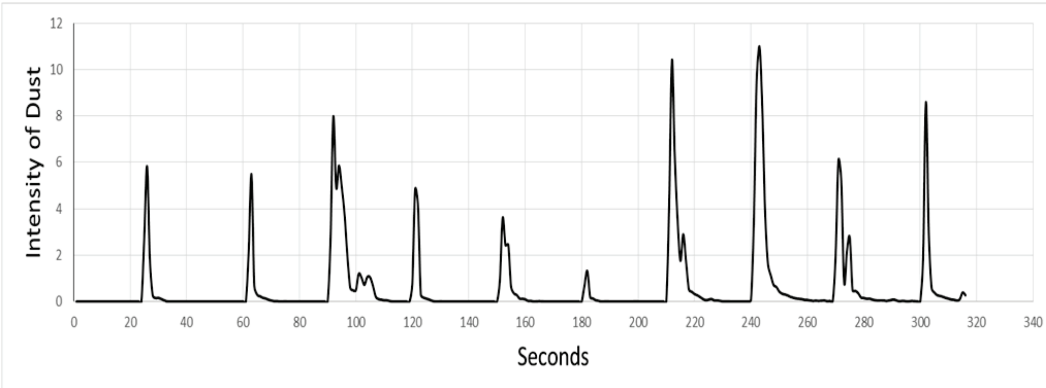
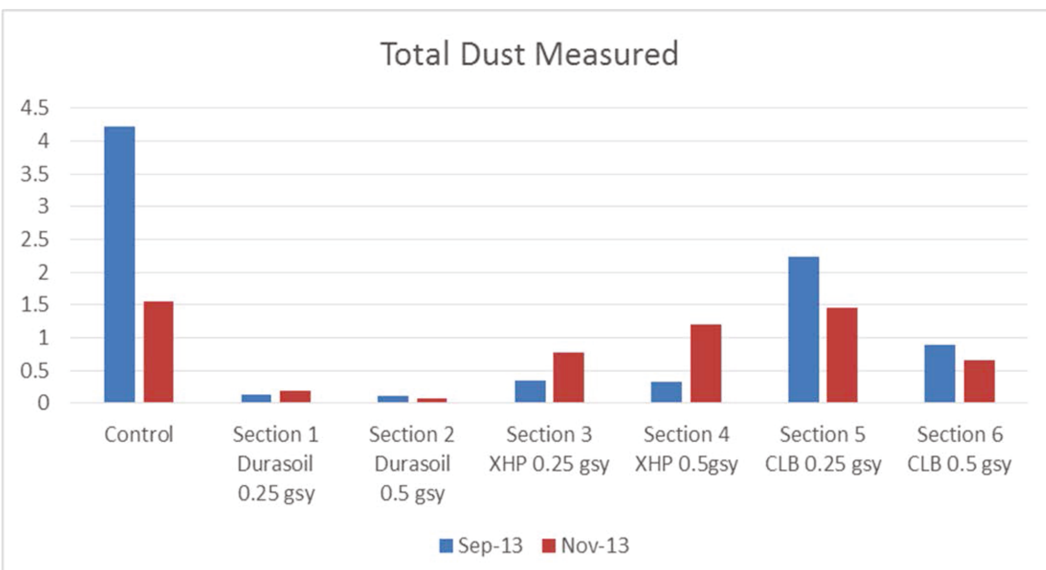


Figure 8 summarizes the testing conducted in September and November 2013. These data were generated by calculating the total area under the dust intensity versus time graphs for each roadway test section.

Figure 8. Summary of the total dust measured by the DustTrak II for September and November 2013.



Analysis of the data in Figure 8 shows that the results agree with expectations and laboratory testing. For the September 2013 data, the control section with no additive shows the highest level of measured dust, followed by Test Section 5 with CLB at 0.25 gsy. CLB 0.5 performed better than CLB 0.25 but not as well as either of the Xhesion Pro test sections. Durasoil outperformed all materials, with the 0.5 gsy application yielding the best results.

For the November 2013 data, the control section exhibited the highest dust levels followed by CLB 0.25. The CLB 0.5 exhibited lower dust than either Xhesion Pro test section, with Durasoil having the lowest dust levels of all the dust palliatives. The data clearly show that Durasoil provided the best overall dust abatement capability at the higher level of application (0.5 gsy), providing excellent performance even after three months of weathering and military vehicle traffic.

3.2 Lessons learned

It is difficult to predict how experimental products will scale up in production to meet the needs of medium-scale field testing. Therefore, prospective follow-on studies should include procedures for determining any application, operational, and performance implications of scaling up dust-control procedures using the tested materials.

Sufficient amounts of the RhEPS biopolymer were available for laboratory testing purposes. However, when attempting to procure it for field testing, the product was unavailable in the necessary quantities.

4 Economic Summary

This economic analysis compares use of the organic humectant Durasoil to conventional magnesium chloride dust palliatives.

4.1 Costs and assumptions

4.1.1 Alternative 1 (baseline scenario)

The most widely used conventional dust-suppression products include magnesium chloride ($MgCl_2$) as a stabilizing agent. Although it is corrosive to metals, it is widely accepted because it is inexpensive and is permitted by current facilities criteria (UFC 3-260-17). There are an estimated 100,000 miles of unpaved roads managed by the DoD according to Isaacson, Hurst, and Albertson (2001). Of those, approximately half are used and maintained by the Army. We assume that 1% of those roads in the Army inventory are resurfaced using a $MgCl_2$ solution. These roads are on average about 30 ft wide, which yields 8.8 million square yards of treated road surface. Note that this is a very conservative estimate; a 2016 unpublished presentation by IMCOM (Bonneau 2016) estimated their unpaved road inventory at 42 million square yards. The resulting cost of the baseline treatment is $6.6 million, based on a 2011 treatment price of $0.75 per square yard provided in the project management plan economic analysis for CPC Project F08-AR01, “Demonstration of Reactive Vitreous Coatings on Reinforcement Steel to Prevent Corrosion and Concrete Failure”) .

The indirect corrosion cost of using $MgCl_2$ is based on a University of Colorado report (Xi and Xie 2002) that cites the annual corrosion cost for vehicles traversing a roadway at $1,500 per ton of $MgCl_2$ applied to a paved road surface. Paved roads carry about a 100 times more traffic than unpaved roads, so the damage cost estimate is correspondingly reduced to $15 per ton. If applied at the rate of 0.50 gallons of $MgCl_2$ per square yard, the total yield would be 22,000 tons of application per year and the total annual corrosion damage cost would be $333,300.

4.1.2 Alternative 2 (demonstrated technology)

Durasoil, which returned the most favorable results in the lab and field tests, is used as the recommended alternative to $MgCl_2$. The same number of square yards of treated road are used as in the baseline scenario. The cost per square yard is $0.75, yielding a total annual cost of $6.6 million.

The cost avoidance is generated from the greatly reduced corrosion rate of Durasoil as compared to $MgCl_2$. The measured rate of corrosion for Durasoil applied to volcanic soils was 0.5 mils per year (mpy), and the rate for $MgCl_2$ was 9.32 mpy (see section 3.1.1, Figure 3). Also, based on the results presented in Figure 3, it is conservatively assumed that the relationship between corrosion rate and corrosion cost is linear. Durasoil was measured to be 95% less corrosive than $MgCl_2$, so it is assumed that the cost of corrosion associated with using Durasoil will likewise be 95% lower. This makes a strong case that the use of Durasoil will greatly reduce the cost of corrosion resulting from the use of $MgCl_2$ treatment for dust suppression.

4.2 Projected return on investment (ROI)

The analysis was based on methods prescribed in OMB Circular No. A-94 (1994). The ROI ratio calculated was 18.1 (Table 2). The slightly larger ROI, as compared to the one provided in the project management plan, is mainly a result of the greatly reduced corrosivity of Durasoil observed relative to $MgCl_2$, and the high indirect costs of that corrosion.

Table 2. Return on Investment calculation.

Return on Investment Calculation

Investment Required			500,000
Return on Investment Ratio	18.10	Percent	1810%
Net Present Value of Costs and Benefits/Savings	81,897,420	90,947,085	9,049,665

A Future Year	B Baseline Costs	C Baseline Benefits/Savings	D New System Costs	E New System Benefits/Savings	F Present Value of Costs	G Present Value of Savings	H Total Present Value
1	6,996,000		6,600,000	333,300	6,168,360	6,849,964	681,604
2	6,996,000		6,600,000	333,300	5,764,440	6,401,411	636,971
3	6,996,000		6,600,000	333,300	5,387,580	5,982,908	595,328
4	6,996,000		6,600,000	333,300	5,035,140	5,591,523	556,383
5	6,996,000		6,600,000	333,300	4,705,800	5,225,791	519,991
6	6,996,000		6,600,000	333,300	4,397,580	4,883,513	485,933
7	6,996,000		6,600,000	333,300	4,109,820	4,563,955	454,135
8	6,996,000		6,600,000	333,300	3,841,200	4,265,653	424,453
9	6,996,000		6,600,000	333,300	3,589,740	3,986,406	396,666
10	6,996,000		6,600,000	333,300	3,354,780	3,725,483	370,703
11	6,996,000		6,600,000	333,300	3,135,660	3,482,150	346,490
12	6,996,000		6,600,000	333,300	2,930,400	3,254,209	323,809
13	6,996,000		6,600,000	333,300	2,739,000	3,041,660	302,660
14	6,996,000		6,600,000	333,300	2,559,480	2,842,303	282,823
15	6,996,000		6,600,000	333,300	2,391,840	2,656,138	264,298
16	6,996,000		6,600,000	333,300	2,235,420	2,482,434	247,014
17	6,996,000		6,600,000	333,300	2,089,560	2,320,456	230,896
18	6,996,000		6,600,000	333,300	1,952,940	2,168,740	215,800
19	6,996,000		6,600,000	333,300	1,824,900	2,026,551	201,651
20	6,996,000		6,600,000	333,300	1,705,440	1,893,891	188,451
21	6,996,000		6,600,000	333,300	1,593,900	1,770,026	176,126
22	6,996,000		6,600,000	333,300	1,489,620	1,654,223	164,603
23	6,996,000		6,600,000	333,300	1,391,940	1,545,749	153,809
24	6,996,000		6,600,000	333,300	1,300,860	1,444,605	143,745
25	6,996,000		6,600,000	333,300	1,215,720	1,350,057	134,337
26	6,996,000		6,600,000	333,300	1,136,520	1,262,105	125,585
27	6,996,000		6,600,000	333,300	1,061,940	1,179,284	117,344
28	6,996,000		6,600,000	333,300	992,640	1,102,327	109,687
29	6,996,000		6,600,000	333,300	927,960	1,030,500	102,540
30	6,996,000		6,600,000	333,300	867,240	963,070	95,830

5 Conclusions and Recommendations

5.1 Conclusions

The authors offer the following conclusions on the reported demonstration/validation project:

1. Magnesium chloride, the most popular and widely used soil humectant for dust suppression on unsurfaced roads, is the most corrosive of the dust-control agents investigated.
2. Durasoil, a brand of refined oil, was found to be the least corrosive of all the materials tested and most effective at dust abatement in the field (section 3.1.3).
3. Lactobionic acid (LBA) is a useful organic humectant for dust control, but the application rate is limited by its relatively low water solubility, and it is less effective at inhibiting corrosion than the potassium salt of lactobionic acid (KLB).
4. Calcium lactobionate (CLB) is much more water soluble than KLB. As such, CLB is easier to apply in the field while providing similar corrosion inhibition.
5. The tested blends of Durasoil, XHesion Pro, and CLB were all effective at controlling dust in laboratory testing (see section 3.1.2).

5.2 Recommendations

5.2.1 Applicability

The tested blends of Durasoil and CLB can be used to suppress dust, and they significantly reduce the corrosion of wheeled vehicles as compared to corrosion caused by magnesium chlorides and calcium chlorides.

A general recommendation pertaining to applying this category of product is that users obtain the current Material Safety Data Sheets (MSDS) to evaluate possible impacts on human and environmental health, and to ensure regulatory compliance at the worksite.

5.2.2 Implementation

DoD implementation could be achieved by reviewing and amending Unified Facilities Criteria UFC 3-260-17, Dust Control for Roads, Airfields and

Adjacent Areas. Two content revisions are recommended for DoD consideration:

- Add *synthetic biopolymers* to the list of dust palliatives authorized by the UFC.
- For applications where vehicle or equipment corrosion is a consideration, users should obtain the product's MSDS or other manufacturer information to evaluate the product's potential for corroding metals, and select the least-corrosive material that will meet mission requirements.

5.2.3 Future work

Although dust palliatives encompass a range of mature technologies and materials, newly developed products that are formulated to minimize the corrosion of vehicles and aircraft may have environmental effects that are not initially well understood. Therefore, future studies may be advisable to gain technical knowledge of this category of materials. In particular, DoD should consider initiating studies of new product environmental impacts where applications are frequent and continued over the long term.

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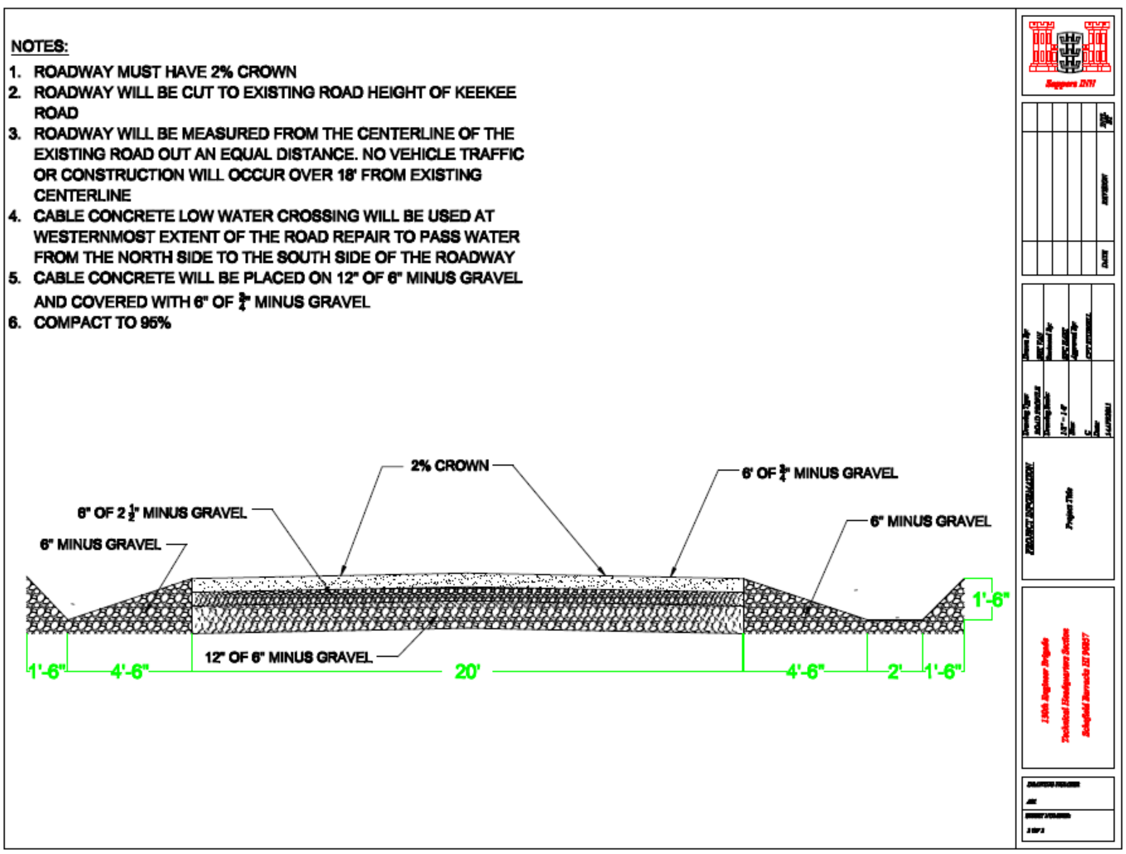
Appendix A: Supply Road Sub-Base Design

30% design

The road cross section was designed to support military vehicle traffic in soil consisting primarily of fine andisols, which are highly weathered volcanic ash and cinder deposits. The road bed profile required a deep bed of large aggregate (6 inch minus) confined by multiple layers of geotextile to limit migration under shear loading (Figure A1). The 30% design yielded specific information needed for material procurement and equipment and troop planning for construction and contracting.

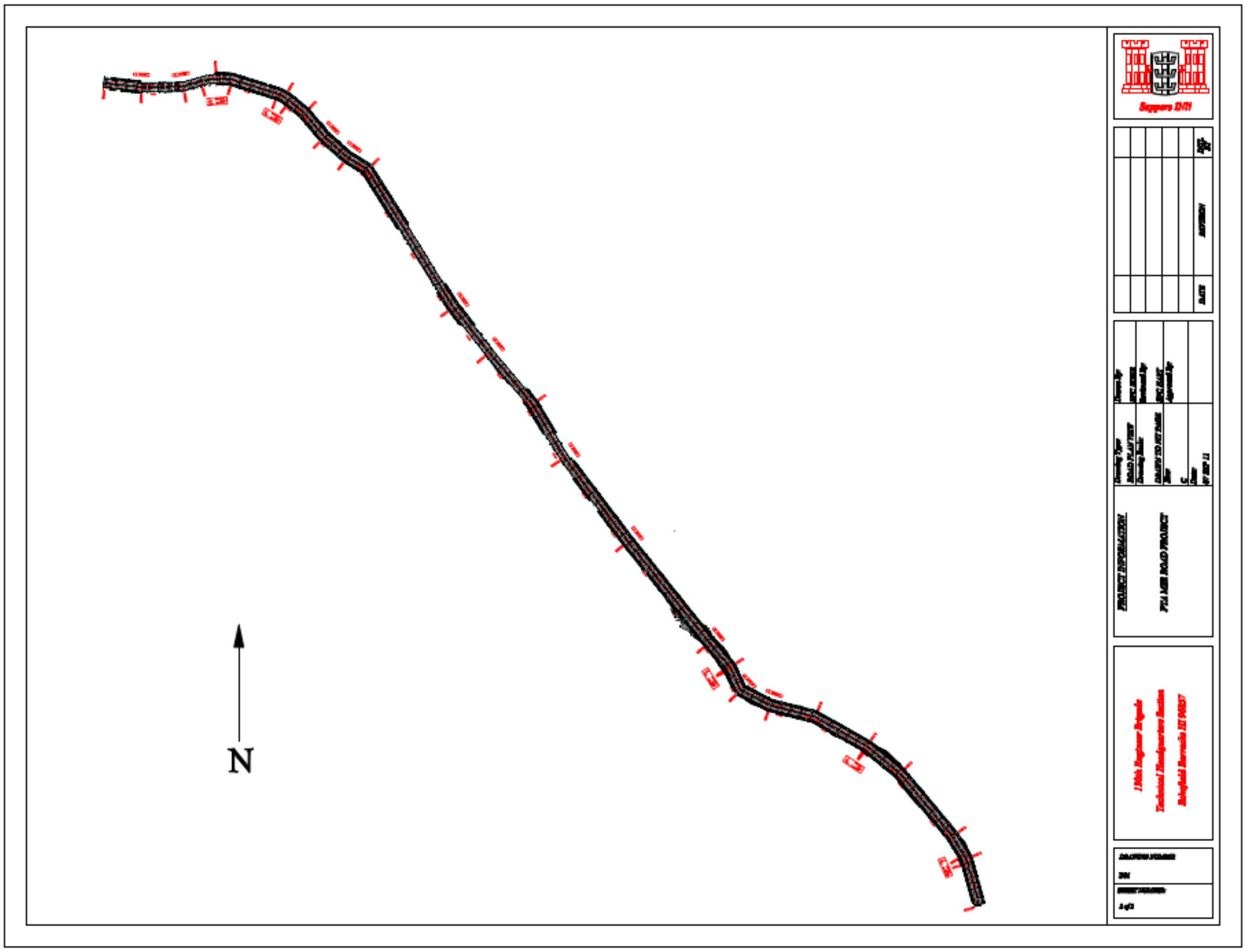
Figure A1. Roadbed profile.



95% design

The 95% design was completed by the 130th Engineer Brigade based in Schofield, HI. The design includes a full elevation profile for the full 2.5 mile section of road. Details of culverts, crossings, and drainage were developed Figure A2.

Figure A2. Details of culverts, crossings, and drainage.



Specific criteria for the coarse aggregate were developed as shown in Table A1.

Table A1. Coarse aggregate characterization final criteria.

Target Gradation - 150 mm (6-inch minus)	Target Gradation - 100 mm (4-inch minus)
Sieve Size % Passing	Sieve Size % Passing
150 mm 100%	100 mm 100%
100 mm 44 - 100%	75 mm 96 - 100%
50 mm 33 - 44%	50 mm 93 - 96%
19 mm 26 - 33%	38 mm 75 - 93%
12.5 mm 25% +/-	19 mm 60 - 75%
4.00 mm 12 - 26%	10 mm 53% +/-
2.36 mm 10% +/-	4.00 mm 36% +/-
0.600 mm 7% +/-	2.00 mm 21% +/-
	0.600 mm 7% +/-
Target Gradation - 38 mm (11/2-inch minus)	**Target Gradation – 19 mm (3/4-inch minus)**
Sieve Size % Passing	Sieve Size % Passing
1/2" 35 – 60%	Passing 1/4" 40-60%
3/4" 45 – 75%	Passing 3/4" 90-100%
3/8" 100% retained	Passing 3/8" 55-75%
1" 60 – 90%	Passing 7/8" 100%
1 1/2" 100%	

Geogrid requirements

The selected geogrids (Tensar brand) were created using select grades of polypropylene (PP) or copolymers that resist high, short-term dynamic loads or moderate loads over longer time periods. These products carry loads applied in any direction in the plane of the geogrid. When used in an unpaved road application, the TriAx has primary functions of reinforcement and stabilization and secondary functions of separation and filtration (when combined with unbound aggregate). A geogrid designed for use in a haul road will have apertures of sufficient size to allow "strike-through" of the specified aggregate. Additionally, it will have a structure of sufficient stiffness and integrity to confine the aggregate under repetitive loading over the life of the pavement. The geogrid is always placed either below or within the unbound aggregate base layer of a pavement. The composite section consisting of the geogrid and the reinforced aggregate is often referred to as a mechanically stabilized layer (MSL).

USACE ETL 1110-1-189 provides guidance, basic criteria and information for the use of geogrids in the design and construction of pavements. The

PTA training road contained both unreinforced and reinforced sections. The unreinforced bearing capacity factor (NC) is 2.8. The reinforced bearing capacity factor for the use of a geotextile separator and geogrid reinforcement is 5.8 (more than doubling by virtue of geogrid reinforcement). This assumes that the geotextile serves as a separation fabric with little reinforcement benefit.

In general, the geogrid benefits were more appreciable in sections with weak subgrades (CBR less than 6%) as compared to medium and stiff subgrade. The level of enhanced bearing capacity or CBR should be adjusted accordingly in order to more accurately account for the performance benefit associated with the inclusion of a geogrid. Increased bearing capacity results in reduced thickness of reinforced section. Similarly, effect of a geogrid can be modeled in PCASE by assigning higher CBR. A single layer of TriAx geogrid provides a 33% reduction compared to the unreinforced aggregate base thickness and two layers of TriAx geogrid provides a 50% reduction compared to the unreinforced aggregate base thickness.

Environmental compliance and construction

The completed environmental compliance checklist, as submitted, is included as Figure A3. The 2.5 mile section of road was constructed by the Army Reserve 85th Construction Battalion from 6 April through 6 May 2012.

Figure A3. Record of Environmental Consideration for KMSR reconstruction (continued to next page).

RECORD OF ENVIRONMENTAL CONSIDERATION (REC)

The DPW process owner office of this form is the Environmental Division

TO: Directorate of Public Works
ATTN: Environmental Division (IMPC-HI-PWE)
U.S. Army Garrison, Hawaii
Schofield Barracks, HI 96857-5013 (Stop 253)
Phone: 656-2878, ext. 1051, Fax: 656-1039

DATE: 16 August 2011

REC CHECKLIST
(Check before submitting)

- ☑ **Detailed Project Description**
- ☑ **Location Map and Plans**
- ☑ **Date of Proposed Action**
- ☑ **Reason for Categorical Exclusion**
- ☑ **Impact Analysis Checklist**

FROM: Eugene Arter
DPW/PTA Engineering Technician
Pohakuloa Training Area, Hi
808-969-2480

1. PROJECT TITLE: Rebuild Keamuku Main Supply Route and Keekee Trail, Pohakuloa Training Area (FEWR RK0005013)

2. DESCRIPTION OF PROPOSED ACTION ***(Provide detailed description of the proposed action and FEWR # if available. Attach location map and site plan, or other information that will help to clearly describe the proposal):***

The proposed action is to reconstruct/rebuild a portion of the Main Supply Route (MSR) and a portion of the Keekee Trail located in the Keamuku Parcel. These sections of trails were damaged during past heavy rainfall events. Work will include repairs to the existing roadway and installation of drainage features to prevent future damage during heavy rainfall events. The MSR trail repairs will extend for approximately 2.3 miles. Repair work will include increasing the width of the roadway to approximately 22-24 feet to bring it up to Army Standards for a MSR and to support the level of unit training anticipated in Keamuku. Drainage features would also be included to prevent future damage from torrential rainfall. Segments to be repaired are identified on the map attached. Designs for this repair project are not available yet and will be developed by the Construction Engineering Research Laboratory (CERL).

Dust palliatives will be used on approximately 2.5 miles of the MSR to test the effectiveness of a biopolymer in controlling fugitive dust emissions. Maintenance due to dust damage to vehicles and the corrosive salts used in most of the current dust control methods are costly to the Army. The biopolymer is a non-corrosive soil treatment that is composed of compounds that will (1) absorb water from the atmosphere; (2) function as a soil binder; and (3) retain water in the soil. It is hoped that this product would provide an economical, non-toxic, non-corrosive form of dust control. More details on the demonstration project are provided in the attached Project Management Plan.

3. ESTIMATED START DATE & DURATION OF PROPOSED ACTION: Spring 2012

4. IT HAS BEEN DETERMINED THAT THIS ACTION ***(Choose one)***:

☐ a. Is adequately covered in the following EA/EIS ***(Provide title and date of document)***:

IMPC-HI-PW Form 29, Jul 07 (This form replaces APVG-GW Form 29& 29A, Nov 04, which is obsolete)
This form is prescribed for use in DPW SOP APVG-GWV No. 327, SUBJECT: Environmental Analysis of 25th ID(L) & U.S. Army Hawaii Actions
(Under revision as of 20 July 2007) NOTE: This form consists of IMPC-HI-PW Form 29 & 29A Pg 1 of 2

Figure A3 (continued).

☑ b. Is categorically excluded under Appendix B, Section II, paragraph _(c)(3)_ of 32 CFR Part 651 for the following reason ***(See 32 CFR Part 651, Environmental Analysis of Army Actions, 29 Mar 02)***: (c)(3) road or trail construction and repair on existing rights-of-ways or on previously disturbed areas.

IMPC-HI-PW Form 29, Jul 07

Page 2 of 2

Figure A3 (continued).

5. POTENTIAL IMPACTS ON THE QUALITY OF THE ENVIRONMENT HAVE BEEN CONSIDERED AND ARE DOCUMENTED ON THE ATTACHED ENVIRONMENTAL CHECKLIST *(Complete Environmental Impact Analysis Checklist)*. IT HAS BEEN CONCLUDED THAT THIS ACTION IS NOT SEGMENTED AND NO EXTRAORDINARY CIRCUMSTANCES EXIST THAT WOULD PRECLUDE THE USE OF THE APPLICABLE CATEGORICAL EXCLUSION IDENTIFIED IN PARAGRAPH 4.b. ABOVE *(See Section 651.29 of 32 CFR, Part 651)*.

6. THIS REC DOES NOT RELIEVE THE PROPONENT FROM COMPLIANCE WITH OTHER APPLICABLE FEDERAL, STATE AND LOCAL ENVIRONMENTAL LAWS AND REGULATIONS; I.E. NATIONAL HISTORIC PRESERVATION ACT, ENDANGERED SPECIES ACT, CLEAN WATER ACT, ETC. *(Contact DPW Environmental Division for assistance on requirements)*.

7. THIS ACTION HAS BEEN COORDINATED WITH THE FOLLOWING OFFICES/AGENCIES:

Office	Name	Concur/ Non-con	Office	Name	Concur/ Non-con
PTA	Dr. Julie Taomia				

SUBMITTED BY THE PROPONENT:

ARTER.EUGENE.L.III.1260881589 16 August 2011

(Signature) (Date)

Eugene L. Arter, Lead Eng'r Tech, DPW, PTA 808-969-2480

(Typed or Printed Name and Title) (Telephone/Fax Number)

REVIEW AND CONCURRENCES *(For Environmental Division use)*:

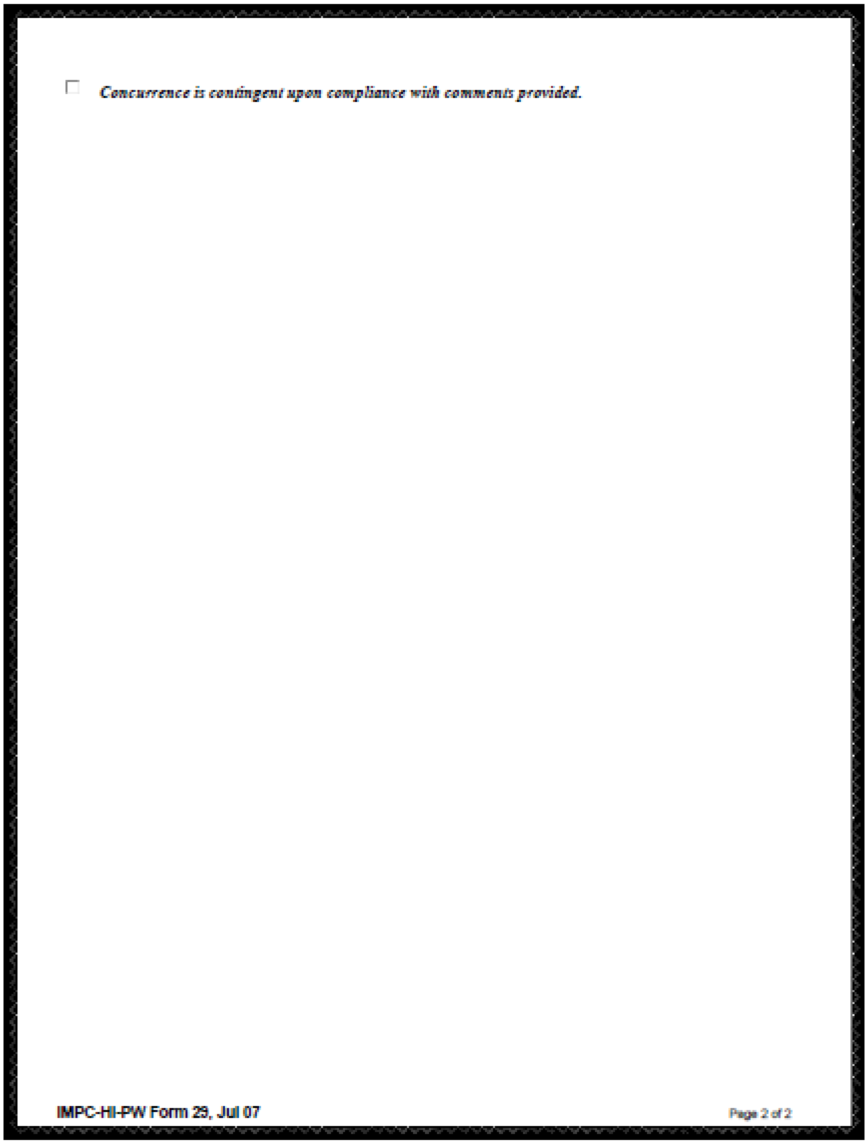
	YES	WITH CMNT	NO	
☐ (Natural Resources Program)	☐	☐	☐	(Date)
☐ (Cultural Resources Program)	☐	☐	☐	(Date)
☐ (Installation Restoration Program)	☐	☐	☐	(Date)
☐ (Water Quality Program)	☐	☐	☐	(Date)
☐ (Air Quality/Toxic Substances Control Act Program)	☐	☐	☐	(Date)
☐ (EMS/Recycling Program)	☐	☐	☐	(Date)
☐ (Hazardous Waste Program)	☐	☐	☐	(Date)
☐ (EPCRA Program)	☐	☐	☐	(Date)
☐ (Other environmental staff as required)	☐	☐	☐	(Date)

APPROVED BY:

(Environmental Coordinator) (Date)

IMPC-HI-PW Form 29, Jul 07 Page 2 of 2

Figure A3 (continued).



☐ ***Concurrence is contingent upon compliance with comments provided.***

IMPC-HI-PW Form 29, Jul 07

Page 2 of 2

Figure A3 (continued).

ENVIRONMENTAL IMPACT ANALYSIS CHECKLIST

PROPOSED ACTION: Rebuild Keamuku Main Supply Route and Keekee Trail, Pohakuloa Training Area

ENVIRONMENTAL IMPACT ANALYSIS ***(Consider both construction and operational impacts. Any "YES" or "MAY" answers need to be explained in the "Discussion" section at the end of this checklist.)***	**YES**	**NO**	**MAY**
1. AIR QUALITY			
a. Will the proposal cause air emissions such as smoke, dust, suspended particles, or air pollutants during construction or operations?	☑	☐	
2. WATER QUALITY			
a. Is there potential for accidental spills of hazardous or toxic substances?	☑		☐
3. TOPOGRAPHY AND SOILS			
a. Will there be alterations to topography, i.e. site grading that could potentially increase soil erosion?	☑	☐	
b. Will the construction area involve disturbance of one acre or more? *(If yes, your project requires a NOI Form C permit from the State Department of Health.)*	X		☐
4. NATURAL RESOURCES			
a. Will the proposal affect undeveloped areas, endangered or threatened species, or plant or animal critical habitat?	☐	X	☐
5. ARCHAEOLOGICAL/HISTORIC RESOURCES			
a. Will the proposal alter or destroy any archeological sites or buildings that are over 50 years old?	☐	X	☐
b. Will the proposal require any excavation, trenching, or grading activity?	X	☐	☐
6. LAND USE			
a. Will the proposal alter the present land use of an area?	☐	X	☐
b. Will the proposal result in a change in operations/activities occurring at the site or facility?	☐	X	☐
7. HAZARDOUS MATERIALS/WASTE OR TOXIC SUBSTANCES DISPOSAL			
a. Will the proposal result in alteration or disposal of existing facilities?	☐	X	☐
b. Will the proposal result in the use, treatment, storage, and/or disposal of hazardous materials or wastes?	☐	X	☐
8. NOISE ENVIRONMENT			
a. Will there be any changes to the numbers, types, and operations of aircraft, vehicles, or weapon systems that could affect noise levels?	☐	X	☐

IMPC-HI-PW Form 29A, Jul 07 Pg 1 of 2

Figure A3 (concluded).

ENVIRONMENTAL IMPACT ANALYSIS CHECKLIST

PROPOSED ACTION: Rebuild Keamuku Main Supply Route and Keekee Trail, Pohakuloa Training Area

ENVIRONMENTAL IMPACT ANALYSIS *(Consider both construction and operational impacts. Any "YES" or "MAY" answers need to be explained in the "Discussion" section at the end of this checklist.)*	YES	NO	MAY
9. TRAFFIC			
a. Will the proposal generate or increase vehicular traffic?	☐	☑	☐
b. Will there be a requirement to construct, reroute or alter roadways?	☐	☑	☐
10. UTILITIES SYSTEMS			
a. Will the proposal require electrical power, water, or wastewater disposal, or alterations to the existing utility systems or drainage system?	☐	☑	☐

DISCUSSION ***(Annotate items answered "YES" or "MAY" and provide a brief explanation of the potential impacts and mitigation measures to be implemented. Provide answers to the questions of how much, whom, where, when, and how? Contact the DPW Environmental Division at 656-2878 if assistance is needed.)***

1a. Fugitive dust will be generated during construction. Dust will be minimized by using best management practices.

2a. There is a potential for accidental spills from construction vehicles and equipment to occur. In the event that a spill should occur, the PTA Environmental Compliance Office shall be contacted.

3a, b. Grading will take place in order to repair and widen the trail and establish proper drainage. Soil and erosion best management practices (such as silt fences) shall be used to minimize run off of loose material.

5b. The trails and the 70 foot (35feet each side of center line of roadway) wide area of potential effect (APE) were surveyed for potential historic properties. No historic properties were identified within the construction footprint of either of the trails. Ranching features were identified within the 70 foot APE and will be cordoned off with construction fencing and be avoided during construction. These projects have been determined to fall within the scope of the Stryker Brigade Combat Team Programmatic Agreement, therefore archaeological and cultural monitors will be present during the construction phase of the project. The Army has determined, and the State Historic Preservation Division has concurred, that no historic properties will be affected by this project.

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Appendix B: Laboratory Corrosion Testing

General test plan

The experimental procedure used in this testing was designed to duplicate contact between a metal surface and moist soils that contain dust control agents. The goals were to characterize soils from two areas with specific dust problems and to determine the relative corrosive effects of two compositionally different treated soils on a bare steel surface. Two fine-grained soils that offer problems in dust control were selected for use in the test program and characterized using x-ray diffraction (XRD) and scanning electron microscopy (SEM). Six types of soil treatment were investigated. The dosages of the dust control agents were selected to approximate the average concentration that would be applied in the field.

ASTM G162, *Standard Practice for Conducting and Evaluating Laboratory Corrosion Tests in Soils*, was used as the basic test procedure for evaluating the corrosive effects of the dust-palliative treated soil. Three sample cups were used for each test and each carried one sample coupon for a selected metal. The procedure for uncoated samples was employed and the test were run in a partly saturated condition. The pH of each soil cup was measured using the procedure outline in ASTM G 51. The soils are all fine-grained dust producers and were characterized using ASTM D422, *Standard Test Method for Particle-Size Analysis of Soils*.

The effects of corrosion were determined by cleaning the coupons and determining condition and mass loss at 10-day intervals or sooner if required. The cleaning and evaluation followed the guidelines in ASTM G1 *Standard Practice for Preparing, Cleaning, and Evaluating Corrosion Test Specimens*. Data reduction followed the guidelines presented in ASTM G16 Guide for Applying Statistics to Analysis of Corrosion Data.

Materials investigated

Tests were conducted with two types of steel, each in its own type of coupon. Cylindrical coupons made from UNS G10180 mild steel (C1018) were used in the initial testing. The trends observed from the experiments with the cylinder or rod coupons were confirmed by conducting a separate series of tests with UNS G10500 steel (C1050) in the form of flat coupons.

UNS G10180 Steel Coupons. Three-inch long, quarter-inch diameter threaded-rod coupons of C1018 steel were furnished with glass bead blasted finish. The rods had an effective surface area of 2.45 sq in. (2.45 sq in. = 1580.6 sq mm or 15.8 sq cm).

UNS G10500 Steel Coupons. UNS G10500 steel flat coupons were furnished as 3 in. long, 1/2 in. wide rectangular plates that were 1/16 in. (1.6 mm) thick. With correction for the 0.25 in. (6.35-mm) mounting hole and the rounded corners, the flat coupons had a surface area of 3.34 sq in. (21.5 sq cm).

Characterization of soils investigated

SEM and EDX analysis

Specimens were examined using an FEI Nova NanoSEM 630 field emission SEM. This device has low-vacuum capabilities, making it ideal for examining nonconductive materials such as soils without special sample preparation or metallic coating. Imaging was performed at an accelerating voltage of 18 kV with a backscattered electron detector.

XRD analysis

A PANalytical X'Pert Pro X-Ray Diffractometer (XRD) equipped with a cobalt tube provided phase characterization of the material by examining the sample in reflection sample mode. Each sample was ground in a porcelain mortar and pestle until the sample passed through the number 325 sieve (0.044 mm). Analysis was performed on a reverse-pack powder sample.

Determination of soil pH

Soil pH was determined with a 1:1 soil suspension in distilled water. The pH determination followed the colorimetric strip technique discussed and validated for field agricultural use.

Soil treatments

Two soils, Vicksburg loess and the Keamuku andisol, were used in the corrosion testing. The coupons were placed in the soil-filled test containers and 50 ml of each of the test solutions was added to each of the containers. The weight of soil required to produce the volume needed to cover the corrosion surface of the coupon varied with the density of the soil. Each test container of Vicksburg loess contained approximately 200 g of soil. Each test container of the Keamuku andisol contained approximately 115 g of soil. Where sufficient soil was available, from each soil three identical sample containers that received each treatment were prepared. Distilled water was used as the control soil treatment.

A saturated magnesium chloride solution was used as the treatment with a hygroscopic salt. The solution was made up with reagent grade magnesium chloride hexahydrate ($MgCl_2(H_2O)_6$). The magnesium solution was prepared as a 30% solution and contained 28.6 g/100 ml. Fifty ml of the solution was added to each soil container, providing 14.3 g of $MgCl_2$ to each container.

Two grades of test solutions using lactobionic acid (LBA) were prepared; one was a chemically pure grade, and a second was a food-grade product. Each LBA solution was prepared as an 8% (by weight) solution in distilled water. This represents a saturated LBA solution.

The potassium lactobionate solution containing suspended calcium carbonate was prepared by dissolving 37.7 g of calcium lactobionate in 50 ml of distilled water and adding 6.9 g of potassium carbonate. The solution used in the soil treatment contained 44% potassium lactobionate by weight. Five grams of calcium carbonate was suspended in the 50 ml of solution. The suspension was stirred, and a 50 ml aliquot was added to each test container.

A similar volume (50 ml) of refined oil was added to the test containers. The oil was used with no additions just as it came from the container. No attempt was made to coat the test coupons with the oil. No additional water was added to the sample containers when the oil was added.

Control samples were prepared by adding 50 ml of distilled water to the test containers holding the steel coupons. No mixing of the soil and water was done.

Wet/dry cycling

The test containers were placed in a 100% humidity cabinet and maintained at 25 °C. After 96 hours, all the sample containers except for the refined oil samples and the distilled water controls were completely saturated. The LBA, K-LB, and magnesium chloride are all hygroscopic and collect moisture when in a high humidity environment. The samples were removed from the 100% humidity cabinet and left in the room at ambient temperature and humidity to dry out. After approximately 96 hours, inspections showed that the samples were moist but not saturated. The samples were returned to the 100% humidity cabinet for 96 hours. The procedure allowed the samples to cycle from wet to dry as would occur in a field setting. In the test series with the UNS G10180 steel, the coupons were in contact with the soil for 864 hours. In the test series with the UNS G10500 steel, the coupons were in contact with the soil for 360 hours.

Cleaning of coupons

The large amount of decaying organic material (largely fine roots) in the soil made it necessary to use commercial metal cleaners that contained industrial detergents and phosphoric and oxalic acids to remove the corrosion. The tar-like exudates from the roots acted to protect the corroded metal surfaces and leave the clean surfaces open to acid etching if conventional mineral acids were employed to remove the corrosion. Using detergents and organic acids in an ultra-sonic cleaner removed the residue and corrosion, leaving the uncorroded metal intact.

Results of characterization of the soils used in corrosion testing

Vicksburg loess is an aeolian sediment formed by the accumulation of wind-blown silt, typically in the 20–50 µm size range. Twenty percent or less is clay, and the balance is equal parts sand and silt that are loosely cemented by calcium carbonate. The soil sample was from the top of the soil column and contained an abundance of decaying rootlets and organic debris. A suspension of the Vicksburg loess in distilled water had a pH of 6.5-7.0. The mineral composition of the loess was confirmed by preparing an X-ray diffraction pattern from a sample of the soil used.

Volcanic soil from Keamuku Training Area, the Keamuku soil, is a weathered basalt lava (andisol) and consists primarily of fine grains of calcitic feldspar, non-crystalline (amorphous) minerals, such as allophone and imogolite, and glass fragments. Decaying plant fragments were abundant in the sample. A suspension of the Keamuku soil in distilled water had a pH of 6.0-6.5. The soil grains were typically irregular shapes with sharp edges, and the size varied widely. The abundance of very fine particles made the suspension of particulate matter in which 50% of particles have an aerodynamic diameter of less than 10 µm (PM10) a serious health concern. The mineral composition of the andisol was confirmed by preparing an X-ray diffraction pattern from a sample of the soil used.

Metals used in testing program

Four alloys that are used in military vehicles and aircraft have been selected as test metals. These metals contain different corrosion characteristics and represent the typical and most corrosion-prone components in military hardware.

Aluminum alloy (Al 2024 or ALCLAD). This is one of the best known of the high-strength aluminum alloys. With its high strength and excellent fatigue resistance, it is used to advantage on structures and parts where good strength-to-weight ratio is desired. It is readily machined to a high finish, readily formed in the annealed condition, and may be subsequently heat treated. Corrosion resistance is relatively low, 2024 is commonly used with an anodized finish or in clad form (ALCLAD) with a thin surface layer of high purity aluminum. Applications are: aircraft structural components, aircraft fittings, hardware, truck wheels and parts for the transportation industry. This alloy is one of the commonest aluminum alloys used on helicopters.

Copper (C10100 or CDA 101OFE). C10100 a high-copper alloy with excellent resistance to seawater corrosion and biofouling. The high-copper alloys are primarily used in applications that require enhanced mechanical performance, often at slightly elevated temperature, with good thermal or electrical conductivity (vehicle wiring).

Magnesium (M16410 or ZE41). This is a magnesium-zinc-zironium-rare earth alloy that is generally used for sand and permanent mold-casting. It is widely used for aircraft parts, machinery components and gearboxes.

Carbon steel (G10050). This alloy is a standard grade carbon steel. It is composed of (in weight percentage) 0.06% (max) carbon (C), 0.35%(max) manganese (Mn), 0.04%(max) phosphorus (P), 0.05%(max) sulfur (S), and the base metal iron (Fe). Other designations of G10050 include AISI 1005 and carbon steel C1005. Low carbon steel is the basic metal of choice for most deep drawn stampings and can be used to manufacture a vast variety of different parts for vehicles at a low cost per part.

Results of corrosion testing

The data from the corrosion tests on the G10180 steel cylindrical coupons are presented in Table B1. Additionally, results obtained from tests on the G10500 steel coupons are presented in Table B2. The corrosion rates for each soil treatment used on each soil is presented in order of increasing rates. In both soils, the ranking in terms of increasing corrosion rates is refined oil treatment with the least corrosion rate and then potassium lactobionate with calcium carbonate (K-LB + $Ca(CO)_3$), followed by lactobionic acid (LBA), and distilled water. The last and most corrosive treatment is magnesium chloride (Mg-chloride). The corrosion rates are slightly higher in the Keamuku andisol than for the corresponding treatment in the Vicksburg loess. The increase may reflect the lower pH noted in the Keamuku andisol. The mineral composition of the Vicksburg loess also indicates that it would have a higher pH, since it typically contains carbonates such as dolomite or possibly calcite. However, Keamuku andisol shows a higher corrosion rate, even when the soil is treated with K-LB + $Ca(CO_3)$, a treatment that should increase the pH in both soils.

Table B1. Corrosion rates for cylindrical UNS G10180 steel coupons in treated and untreated fine-grained soils.

Coupon No.	Soil Type	Treatment	CR µm/y (mpy)*	Average Corrosion Rate, µm/y (mpy)*
015	Loess	Refined Oil (Durasoil)	9.81 (0.386)	11.17 (0.440)
014	Loess	Refined Oil (Durasoil)	13.89 (0.547)	
017	Loess	Refined Oil (Durasoil)	9.81 (0.386)	
101	Loess	K-LB + $Ca(CO_3)$	49.86 (1.963)	34.05 (1.341)
102	Loess	K-LB + $Ca(CO_3)$	33.51 (1.319	
103	Loess	K-LB + $Ca(CO_3)$	18.80 (0.740)	
012	Loess	LBA (food grade)	67.84 (2.671)	60.48 (2.381)
013	Loess	LBA (food grade)	73.56 (2.896)	
016	Loess	LBA (food grade)	40.05 (1.577)	
020	Loess	LBA (chemical grade)	96.44 (3.797)	67.56 (2.660)
019	Loess	LBA (chemical grade)	53.94 (2.124)	
018	Loess	LBA (chemical grade)	52.31 (2.059)	
030	Loess	Distilled water	67.84 (2.671)	89.49 (3.523)
022	Loess	Distilled water	84.18 (3.314)	
028	Loess	Distilled water	80.09 (3.153)	
104	Loess	Distilled water	125.86 (4.955)	
021	Loess	$MgCl_2$	201.87 (7.948)	152.56 (6.006)
024	Loess	$MgCl_2$	106.25 (4.183)	
026	Loess	$MgCl_2$	149.57 (5.888)	
011	Volcanics	Refined Oil (Durasoil)	17.16 (0.676)	12.67 (0.499)
043	Volcanics	Refined Oil (Durasoil)	8.17 (0.322)	
036	Volcanics	K-LB + $Ca(CO_3)$	45.77 (1.802)	57.48 (2.263)
037	Volcanics	K-LB + $Ca(CO_3)$	67.02 (2.639)	
038	Volcanics	K-LB + $Ca(CO_3)$	59.66 (2.349)	
044	Volcanics	LBA (food grade)	66.20 (2.606)	73.28 (2.885)
047	Volcanics	LBA (food grade)	82.55 (3.250)	
050	Volcanics	LBA (food grade)	71.10 (2.779)	
042	Volcanics	Distilled water	85.82 (3.379)	100.53 (3.644)
048	Volcanics	Distilled water	103.80(4.086)	
049	Volcanics	Distilled water	111.97 (4.408)	
035	Volcanics	Distilled water	68.65 (2.703)	
041	Volcanics	$MgCl_2$	246.01 (9.685)	236.74 (9.321)
045	Volcanics	$MgCl_2$	192.88 (7.594)	
046	Volcanics	$MgCl_2$	271.34 (10.683)	

*1 mpy = 0.0254 mm/y = 25.4 µm/y

Table B2. Corrosion rates for flat UNS G10500 steel coupons in treated and untreated fine-grained soils.

Coupon No.	Soil Type	Treatment	Corrosion Rate, µm/y (mpy)*	Average Corrosion Rate, µm/y (mpy)*
024	Volcanics	K-LB + $Ca(CO_3)$	54.03 (2.127)	58.29 (2.295)
021	Volcanics	K-LB + $Ca(CO_3)$	62.56 (2.463)	
022	Volcanics	Distilled water	226.07 (8.900)	174.17 (6.857)
019	Volcanics	Distilled water	122.28 (4.814)	
023	Volcanics	$MgCl_2$	199.05 (7.837)	196.21 (7.725)
020	Volcanics	$MgCl_2$	193.37 (7.613)	
* 1 mpy = 0.0254 mm/y = 25.4 µm/y				

The refined oil treatment showed the lowest corrosion rate and pit-type corrosion that was related to points on the coupon that came in contact with organic debris (decaying rootlets). The corrosion protection that the oil treatment produced was due to the oil coating the surface of the steel. The oil coating of the steel was very nearly complete, since the coupon was clean and dry when the oil was added to the test containers.

Both LBA and K-LBA are hygroscopic organic compounds derived from the oxidation of lactose. LBA is a commonly used humectant that is included in skin treatments and cosmetics to retain moisture in the skin and is used as a preservative in transplanted living tissue. LBA is not typically used as a corrosion inhibitor; but amide compounds made from LBA (lactobionic acid cocosamide, lactobionic acid tallowamide, and lactobionic acid oleyamide) have been used in non-corroding machining fluids and as corrosion inhibitors in gas transmission lines. The results from the current tests indicate that LBA (the acid form) reduced the corrosion rate of steel but was not as effective as its potassium salt. In both types of soil, LBA did reduce the corrosion rate of both types of steel compared to samples that were exposed to distilled water. Testing with the G10180 steel indicated that there was no significant difference in performance between the chemically pure LBA or the less refined food-grade LBA.

K-LB consistently lowered the corrosion rate for both types of steel in both soils. It outperformed all of the other water-based dust control treatments at the levels that were applied. Previous studies indicated that K-LB could be effective at far lower concentrations, but this study took advantage of the very high solubility of K-LB (>60% by wt.) and used the higher concentration (44% by wt.) that could be supplied with the same volume (50 ml) of liquid. Schmitt and Saleh (2000) provided data showing K-LB could be effective in reducing corrosion in brine-contaminated pipeline conditions at concentrations as low as 0.1%.

Observations of the surface condition of the coupons following testing also indicated similar trends in corrosion rate and damage observed for the soil treatments investigated. Figure 5 shows G10500 steel coupons tested in distilled water, Mg-chloride solution, and K-LB treated soil after only 48 hours of exposure. As anticipated, the Mg-chloride solution yielded the most significant surface damage followed by distilled water. The K-LB showed minimal damage, which corresponded well with the low corrosion rates measured in other tests.

The testing indicates that magnesium chloride is consistently the most corrosive dust control agent investigated. Magnesium chloride has been widely recognized as causing serious corrosion on vehicles traveling on roads treated with the salt and has been shown to have lasting effects on the ground water and surface water in the area of the treated soil. The original environmental impact statement prepared for the Keamuku Training Area indicated that magnesium chloride would be used for dust control and stated that the salt contamination may require that the vehicles using the treated roads be washed frequently to prevent salt corrosion. The data developed in this study indicate that magnesium chloride could be a particularly difficult corrosion problem in the Keamuku Training Area soil.

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14. ABSTRACT

Dense airborne dust caused by military ground vehicles is a large, multifaceted problem for the Department of Defense. One costly aspect of the problem is that fugitive dust and small rocks made airborne by ground vehicles on unpaved military service roads increases erosive damage to vehicle coatings. The dust palliative products most widely used to stabilize the surfaces of unpaved roads are formulated using corrosive salts such as magnesium chloride. These are effective at reducing erosive coating degradation but they negate that benefit due to their inherent corrosiveness of exposed metal on vehicle undercarriages. This report documents the testing, demonstration, and validation of several soil-binding materials that effectively suppress fugitive dust while being less corrosive than the most widely used dust palliatives.

Based on laboratory and field test results, as well as data in the technical literature, a commercially available refined oil called Durasoil was found to be the most effective and least corrosive dust palliative of all materials and blends investigated. For purposes of calculating economic benefits, Durasoil was analyzed against magnesium chloride, which is the most widely used dust palliative. The projected return on investment of using Durasoil instead of magnesium chloride was 18.1

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