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Corrosion and Performance of Dust Palliatives: Laboratory and Field Studies

Lulu Edwards, Charles A. Weiss Jr., J. Kent Newman,
Fred A. Nichols Jr., L. Rodgers Coffing, and Quint Mason

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Corrosion and Performance of Dust Palliatives: Laboratory and Field Studies

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Abstract

This report details laboratory and field experiments on BioPreferred® dust suppressants to assess performance and corrosion characteristics. Numerous bio-based dust suppressant products are marketed, but little data are available to assess performance for dust abatement and corrosion of common metals. A laboratory study used an air impingement device and the Portable *In-Situ* Wind EROsion Laboratory (PI-SWERL) to simulate wind speeds similar to those in field conditions for rotary wing aircraft. Laboratory corrosion studies used metal coupons imbedded in soil treated with dust palliative. Field trials were conducted using ground vehicle traffic to minimize cost and lower safety concerns while increasing surface wear from repetitive traffic. These studies clearly show that bio-based products demonstrate low corrosion potential with similar dust abatement performance to synthetic-based agents.

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Preface

This study was conducted for the Defense Logistics Agency under the project, “Noncorrosive Dust Control for Military Applications,” MIPRS Co4001600975 and SC04001900452. The technical monitor was Ms. Iris (Maria) Garcia Labuda, Hazardous Minimization and Green Products Branch.

The work was performed by the Concrete and Materials Branch (GMC) and the Airfields and Pavement Branch (GMA) of the Engineering Systems and Materials Division (GM), U.S. Army Engineer Research and Development Center (ERDC), Geotechnical and Structures Laboratory (GSL). At the time of publication, Dr. Jameson Shannon was Chief, GMC; Ms. Anna M. Jordan was Chief, GMA; Mr. Justin S. Strickler was Chief, GM; and Ms. Pamela G. Kinnebrew, GZT, was the Technical Director for the Military Engineering business area. The Deputy Director of ERDC-GSL was Mr. Charles W. Ertle II, and the Director was Mr. Bartley P. Durst.

COL Teresa A. Schlosser was the Commander of ERDC, and Dr. David W. Pittman was the Director.

1 Introduction

1.1 Background

Fugitive dust emissions from ground and airborne mechanical assets are a significant problem for the Department of Defense (DoD). From a safety standpoint, rotary wing brownouts (Figure 1) are a significant concern, and inhalation from repeated exposure to siliceous and other fine dust may pose delayed health problems for personnel.

Maintenance costs due to dust damage to vehicles and aircraft and the corrosive salts used to control dust on roads may be significant. In addition, fugitive dust transported by wind from Army/DoD installations may pose health concerns for nearby residents, both civilian and military.

Airborne dust is reduced by binding fine soil particles into larger particles that cannot become airborne. Numerous materials have been used as binder -- including portland cement, petroleum-based hydrocarbons, organic binders, and liquids with high surface tension. A common form of dust control is the application of water. Water performs well because its high surface tension creates binding forces between fine soil particles.

Unfortunately, water has a high vapor pressure and evaporates quickly at warmer temperatures. Hygroscopic materials (e.g., cellulose, polyacrylamide, and superabsorbers like polyacrylic acid) that bind water and soil can be used to suppress the evaporation of water from soil. Humectants added to the soil are effective at absorbing water from the air in climates with an average relative humidity above about 30%.

The use of humectants alone or in combination with hygroscopic materials is an effective form of dust control. Historically, this has been accomplished by using metal chlorides such as calcium and magnesium chlorides; however, these materials are extremely corrosive to metals, especially aluminum. Aluminum is being increasingly used in ground vehicles to reduce weight and is the major structural component of many aircraft. The salts also are highly water-soluble and leach from the soil during surface runoff, limiting their effectiveness and increasing salts in the watershed. Although metal chlorides are in widespread use as a dust mitigant, they are not used when corrosion and/or environmental factors may be an issue. They are not allowed at airfield

facilities due to the potential for corrosion of aluminum on aircraft. Organic humectants (e.g., polysaccharide, glycerol, and hydroxyl acids) are also available but, like salts, may suffer from leaching and biodegradation, which limit the long-term effectiveness. However, the corrosion characteristics of the commercial agents that employ these materials in their formulations are largely untested.

Current commercially available noncorrosive materials include acrylic polymers, synthetic fluids, and organic oils (may be petroleum or biological sources). These may be applied topically or blended into soil as an admixture. The acrylic polymers provide strong bonds between the soil particles. These materials are best employed by blending them with native soil at a specific depth as soil stabilizers for long-lasting dust control but the method is expensive due to the required mixing. The synthetic fluids and organic oils are hydrocarbons that act in similar fashion to water, yet the binding forces are much weaker. These are best applied topically in most cases. This weaker bonding is advantageous in that the soil surface may be regraded and recompact as damage to the surface occurs from traffic. Although reapplication will be necessary, the synthetic fluids and organic oils provide immediate, non-corrosive dust control to the soil surface through topical application and at a lower cost as mixing is not required. The U.S. Army Engineer Research and Development Center (ERDC) has conducted extensive dust abatement treatment and palliative distribution equipment research, development, evaluations, and DoD manual updates since 2002. This work includes laboratory evaluations of commercial-off-the-shelf (COTS) dust palliatives, development of expeditionary palliative distribution systems, and field evaluations of dust palliatives on helipads and lines-of-communications. These studies have demonstrated that even though the mechanisms of dust formation for roads and helipads are different, the mitigation strategies are similar. Thus, studies of road-dust palliatives provide valuable information that applies to dust mitigation for aviation. However, for aviation, consideration of the corrosive properties of dust palliatives is necessary for safety and maintenance.

Currently, little information exists on the corrosive nature of many commercial dust agents and their effects on common metals used in military aircraft. In addition, no field or laboratory testing standards exist for selection of dust agents based on application type, soil type, climate, cost, and/or effectiveness. This study will assess the effectiveness of bio-based dust suppressants and provide the basis for assessing commercial dust control products based on their ability to mitigate dust and limit corrosion.

1.2 Previous work

Oldham et al. (1977) evaluated a variety of materials as soil stabilizers (including acids, asphalt, cement, lime, resins, salts, silicates, and others) as a function of soil type (silt, loess, clay, and sand). The performance criteria were the compressive strengths of the materials after stabilization. They found that cement, lime, and asphalt proved to be the best materials. Other materials, such as sodium silicate, were effective on silts; lignin was effective on clays and silts; and both phosphoric acid (or phosphorous pentoxide) and aniline furfural resin were effective on clays.

Billman and Arya (1988) used a wind tunnel to evaluate fugitive dust emissions from storage piles. Gebhart et al. (1999) coalesced data into a dichotomous key that allowed the user to select the most appropriate or environmentally acceptable dust control product based on variables such as climate, underlying soil types and textures, trafficked surface and aggregate materials characteristics, vehicle type, anticipated traffic volumes, and length of service required. Bolander and Yamada (1999) developed a dust palliative selection and application guide, including a flow chart to assist in selecting the correct palliative. They based their selection on vehicle speed, number of wheels per vehicle, number of vehicles, vehicle weight, particle size distribution (gradation) of the surface material, restraint of the surface fines (compaction, cohesiveness/bonding, and durability), and surface moisture (humidity, amount of precipitation, precipitation, and amount of evaporation).

Kolias et al. (2005) reported data from both the laboratory as well as the field using Class C Fly ash in conjunction with portland cement as an effective way to stabilize soils exposed to construction traffic. Graber et al. (2006) discussed the potential of four types of ameliorants as soil stabilizers: gypsum and gypsiferous materials, synthetic organic polymers, organic matter waste materials, and fly ash.

Orts et al. (2007) showed that the use of polyacrylamide copolymers to stabilize sediments could reduce runoff of irrigation water by 90%. Liu et al. (2011) introduced a new organic polymer termed STW as an effective slope stabilizer for clayey soils.

In his master's thesis, Eckhoff (2012) introduced a test method, UAF-DUSTM (University of Alaska Fairbanks Dust Monitor) that was developed to provide a consistent test method for determining the

effectiveness and longevity of dust palliative applications. The instrument is portable (one suitcase-sized case and one toolbox) and straps onto the back of any all-terrain vehicle (ATV). Dust lofted from the back tire of a moving ATV is continuously drawn through a laser that measures the opacity of the dust-laden air stream. Opacity is converted into concentration values, resulting in an accurate comparison of the palliative's effectiveness every approximately 9 m (30 ft) along the measured section (Barnes and Connor 2017). Etyemezian and coworkers developed the PI-SWERL (Portable *In-Situ* Wind EROsion Laboratory), a portable testing device that can be used to determine the potential for soil wind erosion and dust suspension (Dust-Quant 2011). Because the device is portable, it can be used in the laboratory and field to evaluate performance. A rotating ring enclosed in a chamber generates wind shear close to the surface that can create aerosol dust and initiate saltation (Etyemezian et al. 2007). To simulate saltation using this method, the ring speed is gradually ramped up until the moment significant transport is detected (Qian et al. 2019).

Lekha, Ravi Shankar, and Sarang (2013) reported the effectiveness of Zycosoil as a soil amendment to improve the engineering properties of lateritic and clay soils in India. Gebhart (2013) gave current information regarding the selection of technologies and chemical products for controlling dust on unpaved roads, landing strips, and helipads. Chen et al. (2015) reported that both xanthan gum and guar gum are effective in enhancing the moisture retention capacity of soil, improving the dust resistance, and increasing the surface strength of mine tailings beyond that of water wetting. Jones (2017) developed a guide introducing a new process for selecting an appropriate chemical treatment category for a specific set of unpaved road conditions using ranked potential performance. Kunz et al. (2018) evaluated road-dust suppressants by using dust particulate monitors combined with visual observations and road surface conditions over a 19-month period.

Several dust control investigations have also been conducted by the ERDC previously. In a series of reports, Tingle et al. (2004); Rushing et al. (2005); Rushing et al. (2006); and Rushing and Tingle (2006) evaluated potential chemical dust palliatives for mitigating fugitive dust in military operations. The products were compared in laboratory testing and several field trials. The results of these efforts were compiled to provide assistance for selecting and applying chemical dust palliatives for use on helipads, roads, airfields, and

base camps. Rushing and Tingle (2006) provided a compilation of these efforts for the military engineer in the form of a field handbook. Studies by Newman and Rushing (2009) showed the application of field dust monitors in full-scale applications, and Newman and Rushing (2010) detailed the construction and testing of a laboratory air-impingement device for testing dust suppression. Edwards et al. (2010) evaluated several products in a semi-operational environment to evaluate dust suppression. One of the most recent documents delineating dust control for military applications on Army, Navy, and Air Force installations is UFC 3-260-17, *O&M Manual: Standard Practice for Dust Control on Roads, Airfields, Base Camps, and Adjacent Areas* (USACE 2018), which provides guidance for dust control materials and methods that are used successfully on roads, airfields, base camps, and areas adjacent to these structures to reduce airborne dust.

1.3 Objectives

The ERDC was tasked by the Defense Logistics Agency - Aviation (DLA Aviation) to evaluate green, noncorrosive, high-performing dust palliatives for developing updates and changes to dust manuals and field manuals used by the Army and the DoD. The project focused on selecting and evaluating materials, procedures, and protocols for products, particularly green (bio-based) and/or noncorrosive dust palliatives.

Specific technical objectives were to:

1. Perform a market survey and literature review.
2. Select dust palliatives and corrosion metals for laboratory testing based on expected performance and environmental corrosion. This was a joint effort between DLA Aviation and ERDC Airfields and Pavement Branch (APB) personnel.
3. Develop and explore laboratory testing techniques that correlate with field experiments. This would allow for improved screening of materials in the laboratory to reduce costs associated with field tests.
4. Conduct field and laboratory experiments on select noncorrosive dust palliatives to evaluate performance.
5. Conduct laboratory experiments on the corrosive nature of dust palliatives.
6. Incorporate findings by working with DLA to update Army/DOD manuals and establish National Stock Numbers (NSNs) as necessary for field equipment and palliatives.

2 Properties of Dust Palliatives

2.1 Selection of dust palliative products

Dust palliatives chosen for this project met one of the following criteria:

- have been recently used in military projects (purchase data provided by DLA for 2017-2018),
- are USDA BioPreferred® or certified bio-based (<https://www.biopreferred.gov/BioPreferred/faces/catalog/Catalog.xhtml> 2018), and
- are uncertified new bio-based products (as of 2018).

Certified bio-based products must contain at least 85% bio-based components and obtain certification from the United States Department of Agriculture (USDA). This project also focused on comparing known, proven products with previously untested bio-preferred or bio-based products. Please note that the following dust control products may be referred to as products or palliatives in the following chapters.

2.2 Dust palliative product descriptions

The product descriptions in this section were obtained from information supplied by the manufacturer or product supplier. As such, their descriptions may include promotional information. More information is available from the manufacturer or in the product literature.

2.2.1 Water

Water is often used as a temporary and cost-efficient dust control solution. As soon as the water evaporates, it is no longer effective. Potable water was used as the control for the laboratory testing described in the report.

2.2.2 BioSoyl Plus and BioSoyl Plus NP

BioSoyl Plus, a new product made by Midwest Industrial Supply Inc., is a soy-based dust suppressant. BioSoyl Plus NP is similar to BioSoyl Plus but has an enhanced resin binder for longevity. The products have 100% bio-based content and can be applied neat or can be diluted prior to application with 1-5 parts water to 1 part concentrate. According to the manufacturer, the recommended storage temperature of the

concentrate is 40-130°F, and the recommended application temperature is greater than 40°F. There is no curing time required for this product, and the treated surface can be exposed to traffic after the product has penetrated the soil. After application, the product is expected to last up to 6 months without reapplication, depending on the application rate and site conditions. These products are not on the USDA BioPreferred® or certified bio-based product list.

2.2.3 Durasoil®

Durasoil® is a synthetic organic fluid made by Soilworks LLC. Durasoil® does not require dilution and is applied neat. The recommended storage temperature is less than 300°F, and the recommended application temperature is greater than 5°F. No curing time is required for this product, and traffic may be applied after the product has penetrated the soil. After application, the product is expected to last up to 16 months. This product is not on the USDA BioPreferred® or certified bio-based product list.

2.2.4 DustKill

DustKill (made by DustKill) is a soybean-derived oil specifically formulated to penetrate and bond the loose dust particles of a roadway, creating a dust-free environment. The product has a 100% bio-based content and can be applied neat. The recommended application rates include 80, 60, and 40 square feet per gallon, with 60 being the most efficient. The recommended storage temperature is between 0 and 130°F, but the product must be applied above 60°F due to high viscosity at lower temperatures. While a defined curing time is not mandatory, the manufacturer recommends at least 12 hr to allow for penetration before allowing vehicle traffic. After application, the product is expected to last up to 1 yr, depending on the application rate. This product is not on the USDA BioPreferred® or certified bio-based product list.

2.2.5 DustPly Plus C

DustPly Plus C is an engineered blend of polymeric binder and natural additives made by Willamette Valley Company. The product has a 100% bio-based content and can be applied neat or diluted. According to the manufacturer, the required storage temperature is 40 to 140°F, and the recommended application temperature is greater than 40°F. The product is effective only 1 hr after product application. Depending on the application rate and the traffic condition, the product should stay

effective for 3 to 6 months. This product is not on the USDA BioPreferred® or certified bio-based product list.

2.2.6 EnviroKleen 2800 (EK2800)

EnviroKleen 2800 (EK2800), a blend of synthetic isoalkane and polymeric binders, is made by Midwest Industrial Supply Inc. EnviroKleen 2800 does not require dilution and is applied neat. The recommended storage temperature is -50 to 150°F, and the recommended application temperature is greater than 40°F. No curing time is required for this product, and traffic may be applied after the product has penetrated the soil. After application, the product results in long-term performance and is expected to last up to 1 yr without reapplication, depending on the application rate and site conditions. EnviroKleen 2800 can be effective for the effective life of the surface as it can be rewetted to extend its use. This product is not on the USDA BioPreferred® or certified bio-based product list.

2.2.7 EK35

EK35, a blend of synthetic isoalkane and binders, is made by Midwest Industrial Supply Inc. EK35 does not require dilution and is applied neat. The recommended storage temperature is -50 to 150°F, and the recommended application temperature is greater than 40°F. There is no curing time required for this product, and traffic may be applied after the product has penetrated the soil. After application, the product is expected to last up to 1 yr, depending on the application rate. EK35 can be effective for the effective life of the surface as it can be rewetted to extend its use. This product is not on the USDA BioPreferred® or certified bio-based product list.

2.2.8 GRT9000

GRT9000 is a polymeric binder marketed by Global Road Technologies. Using *in-situ* or imported materials, GRT9000 is used to create a hard, semi-flexible, and water-impermeable pavement. GRT9000 polymer soil-stabilized pavements display high bearing and tensile resistance and pose a cost-effective alternative to traditional bound pavements such as asphalt and concrete for a laid pavement, saving from 50-70%. The product is typically applied at a 1:1 dilution with water. This product is not on the USDA BioPreferred® or certified bio-based product list.

2.2.9 Knockout Dust Control

Knockout Dust Control is a USDA-certified 99% bio-based material marketed by Hamilton Manufacturing Inc. This product is a humectant. No curing time is required for this product, and traffic may be applied after the product has penetrated the surface. The material can be re-activated with water and is noncorrosive. The storage temperature is -38 to 130°F, and the application temperature is 40 to 130°F. Depending on traffic, soil type, and grading techniques, the material should typically provide dust control for a few months without reactivation. The product is typically applied at a 1:4 dilution with water. This product is on the USDA BioPreferred® or certified bio-based product list.

2.2.10 Magnesium chloride

Magnesium chloride is the chemical compound MgCl_2 and its various hydrates $\text{MgCl}_2(\text{H}_2\text{O})_x$. It is available from several suppliers. These salts are ionic halides and are highly soluble in water. The hydrated magnesium chloride can be extracted from brine or seawater. MgCl_2 is highly deliquescent and, as such, adsorbs water from the air, resisting evaporation. However, because it causes metals to corrode, it is not recommended for use in areas proximal to aircraft use. MgCl_2 is typically applied at a 35% concentration and may be packaged in totes already mixed or in powder form to be mixed on site. This product is not on the USDA BioPreferred® or certified bio-based product list.

2.2.11 SandTec 9006

SandTec 9006, manufactured by Arrmaz Custom Chemicals Inc., is a USDA-certified 100% bio-based material that is a bio-degradable, bio-renewable blend of aliphatic alcohols in an aqueous solution. The product is applied neat. According to the manufacturer, the recommended storage temperature is -50 to 150°F, and the recommended application temperature is greater than 40°F. No curing time is required for this product. After application, the product is expected to last up to 1 yr, depending on the application rate. This product is on the USDA BioPreferred® or certified bio-based product list.

2.2.12 Soiltac®

Soiltac® is a liquid copolymer emulsion product made by Soilworks LLC. Soiltac® requires a dilution of 3 parts water to 1 part product. According to

the manufacturer, the recommended storage temperature is greater than 32°F, and the recommended application temperature is also greater than 32°F. The recommended curing time is approximately 24 hr. After a topical application, the manufacturer estimates the product to last up to 2 yr. This product is not on the USDA BioPreferred® or certified bio-based product list.

2.2.13 Triple Tac

Triple Tac was designed as a natural glue (guar gum food additive) for the hydroseeding industry and dust control industry and is marketed by Hamilton Manufacturing Inc. It creates a crust, binding the soil particles together. The storage temperature is -30 to 130°F, and the application temperature is 40 to 130°F. The typical curing time is 1 to 2 hr, depending on weather, soil type, and moisture content. Use of this material for trafficking is not recommended. It is intended as a material to keep dust from stockpiles or to keep bare soil in place. This product is not on the USDA BioPreferred® or certified bio-based product list.

2.2.14 X-Hesion Pro™

X-Hesion Pro™ is a USDA-certified 96% bio-based product of agriculturally derived, complex organic polymer made by Envirotech Services Inc. X-Hesion Pro™ acts as a strong humectant, stabilizing surfaces with binders and agglomeration of dust particulates through the adsorption of water. It may be diluted with water depending on conditions. It does not require curing time and is most easily applied at a temperature above 40°F. This product is on the USDA BioPreferred® or certified bio-based product list.

2.2.15 Soykill

Soykill is a soy-based uncertified USDA bio-based dust suppressant marketed by SoySolv Inc. Due to the proprietary nature of the material, information on the product could not be obtained. This product is on the USDA BioPreferred® or certified bio-based product list.

3 Laboratory Testing of Dust Palliatives

Each palliative was evaluated in the laboratory to verify the manufacturer's recommended application rates. Two different types of laboratory testing were conducted, air impingement testing and tests using the PI-SWERL device. The first test method, air impingement testing, was developed during previous dust abatement evaluations at ERDC and refined during the last round of testing in 2009. For a complete description of the testing apparatus, protocols, and history, refer to previous testing reports (Newman and Rushing [2010] and Edwards et al. [2010]). Also, note that these applied products are used in a military expeditionary scenario. They are applied with no further treatment or application of water. Some of these products may perform better when they are rewet. The second test method used the PI-SWERL device.

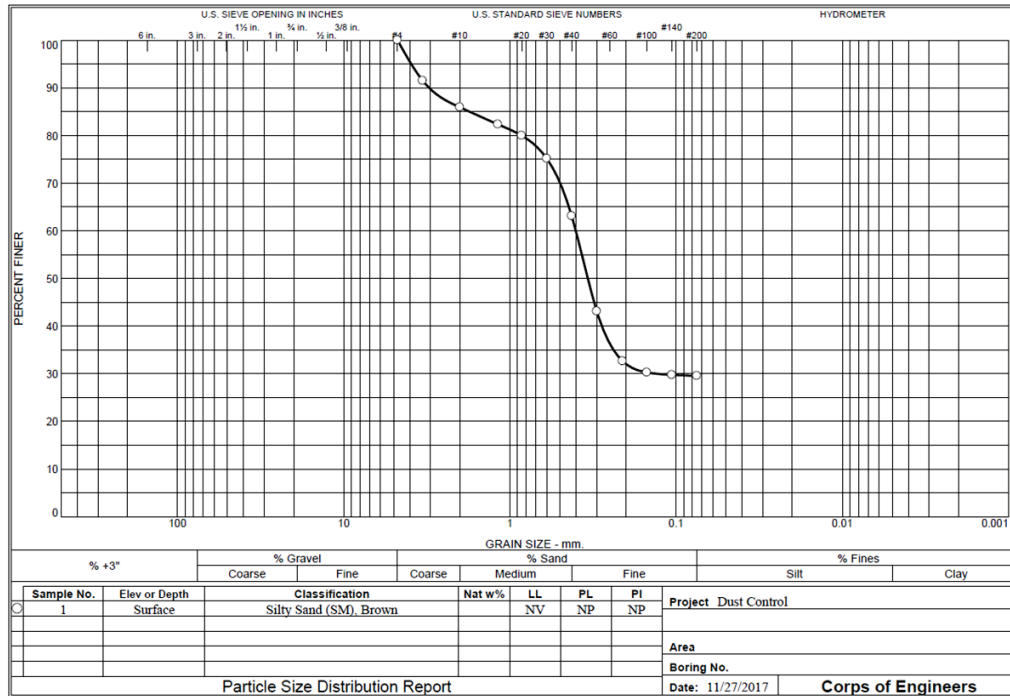
3.1 Test specimen preparation

For evaluation of the durability of the dust control products, test specimens were prepared in 6-in. by 6-in. by 2-in.-deep square plexiglass molds. The soil was classified as silty sand (SM) according to the Unified Soil Classification System (USCS; ASTM 2017). The material was processed prior to testing by removing all moisture in an oven at 230°F and then a No. 10 sieve was used to remove any large soil grains. The grain size distribution curve is shown in Figure 1. The SM was placed into the plexiglass containers, which were then placed on a vibratory table for 30 sec; additional SM was added as necessary. The SM surface was struck off level with the mold surface with a metal straightedge to provide a flat surface for the dust palliative application.

3.2 Dust palliative application

All test specimens were sprayed with a topical application of the dust palliative at application rates of 0.4, 0.8, or 1.2 gal per square yard (gsy) in a manner similar to field application. Three test specimens were tested for each application rate in the product application device (Figure 2). The test specimens were placed into a galvanized steel stock tank to collect overspray (Figure 3). The dust palliative was prepared by diluting and mixing, as applicable, and poured into an aluminum canister. Photographs of the samples after application of the dust palliative as well as after air impingement are given in the Appendix (Figures A1-A24).

Figure 1. Soil gradation used to prepare laboratory samples.



The canister was equipped with a ball valve and plastic wide-fan spray nozzle, the same type used in field sprayers. The top of the canister had a port for attaching an air hose to pressurize the canister to 2-3 psi and to achieve the necessary fan width from the spray nozzle. This system required calibration for each dust palliative because viscosity differences require pressure adjustments to obtain equal flow rates. The canister was mounted onto a carriage attached to a motorized transfer mechanism. Uniform displacement rates were achieved by using a rack-and-pinion system powered by a variable-speed direct current (DC) motor. Travel speeds were adjusted by using a rheostat and dial gauge to obtain calibration for achieving the desired application rates, based on both speed and volumetric output.

Figure 2. Spraying apparatus.

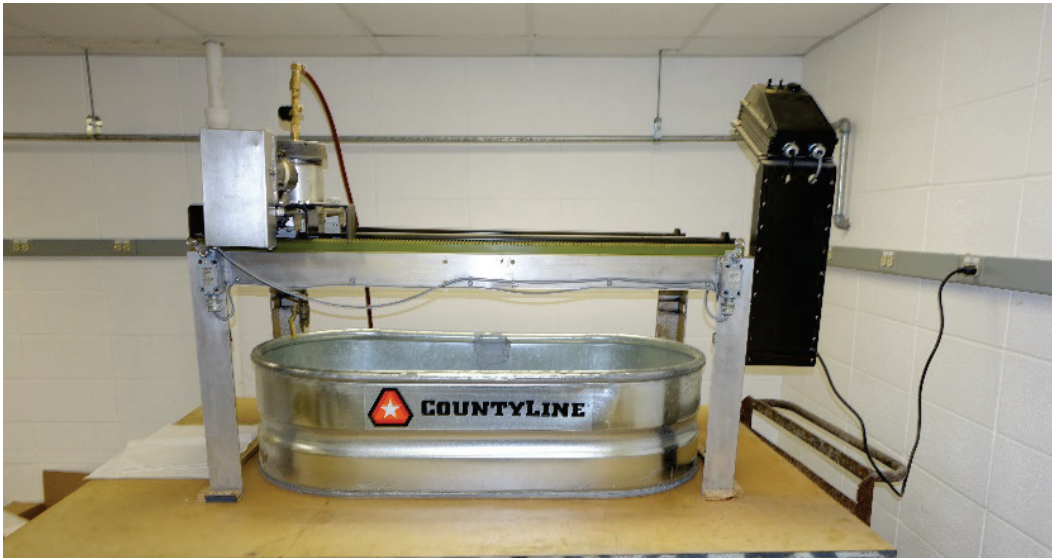


Figure 3. Spraying product.



3.3 Curing

The soil samples in the plexiglass containers were sprayed and allowed to cure for 24 hr in an oven at 120°F. The soil samples (Figure 4) were weighed for the initial weight prior to the air impingement testing.

Figure 4. Cured soil samples.



3.4 Air impingement testing

Test specimens were tested in a sealed chamber designed to simulate wind velocities encountered near aircraft (Newman and Rushing 2009). The chamber was 4 ft long, 1 ft wide, and 2 ft tall (Figure 5). The wind chamber was sealed from external air to prevent dust from escaping during testing. Air velocities of 150 mph were generated by an electric fan motor and transmitted through a 3-in. PVC pipe to a rectangular aperture 4.5 in. wide and 0.5 in. in height (Figure 5, right). A return air duct circulated air from the testing chamber to the electric fan to equilibrate pressure. Air blasts were initiated 1 in. above the test specimen at an angle of 20° from horizontal and lasted for 30 sec. During the air impingement test, 300 g of 20-30 mesh size Ottawa sand was injected into the air stream to initiate saltation. Dust concentrations within the testing chamber were recorded

by using a Haz-Dust™ EPAM-5000 Environmental Particulate Air Monitor and lasted for 120 sec. The sand injection increased surface scour and was intended to simulate saltation, as displaced soil and sand particles impart additional abrasion to the ground surface. Figure 6 shows an example of the soil samples after the air impingement test.

Figure 5. Air impingement wind chamber.

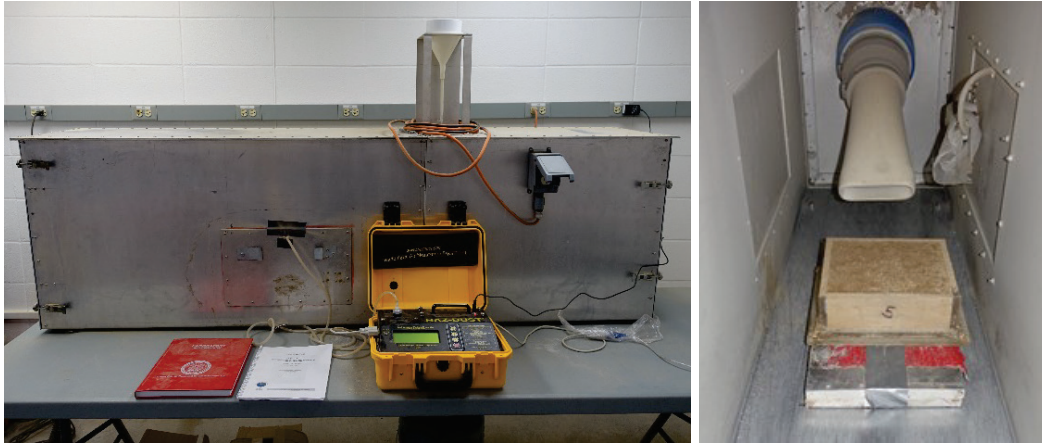


Figure 6. Example soil samples after wind chamber test with water as the dust agent.

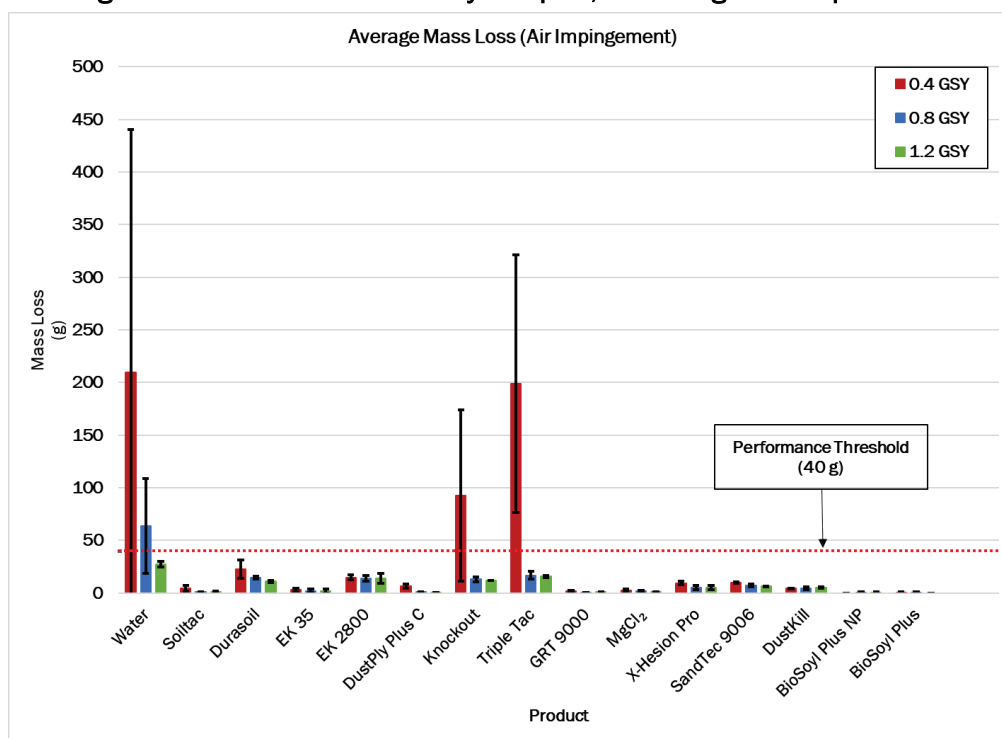


3.4.1 Surface erosion

Test specimens were evaluated on their ability to resist surface erosion during the testing sequence. Quantification of soil loss under this test method was achieved by weighing test specimens before and after they were subjected to the air impingement test. The mass of soil displaced from the test specimen was considered an indication of anticipated performance for dust mitigation. Dust palliatives that prevented surface erosion were expected to perform well in field conditions. Products with little resistance to wind erosion would disintegrate rapidly during the test. This method was used to determine the relative effectiveness of dust palliatives and to identify quantities of palliative necessary to provide acceptable levels of dust mitigation. The test specimens were compared to soil sprayed with only water (after drying) as a baseline.

Erosion potential data indicating the soil mass lost during air impingement testing are shown graphically in Figure 7. Data presented here are the average and standard deviation at 95% confidence level of the mass loss for the three test specimens for each application rate tested. The total range of mass loss was from zero (negligible loss) to approximately 200 g. In general, an increase in dust palliative applied to the surface lowered the total amount of material loss for all samples. Samples with 0.8 gsy of product performed better than for those with 0.4 gsy, but there was no significant change when 1.2 gsy was used compared to 0.8 gsy. Two samples (Knockout and Triple Tac) performed similarly to water at 0.4 gsy. Samples exhibiting maximum mass loss of less than 40 g were rated as good performers in this laboratory test, based on previous testing experience. Photographs of the test specimens after the application of dust palliatives and after air impingement testing are located in the Appendix (See Figures A1-A24).

Figure 7. Mass loss of laboratory samples, indicating erosion potential.



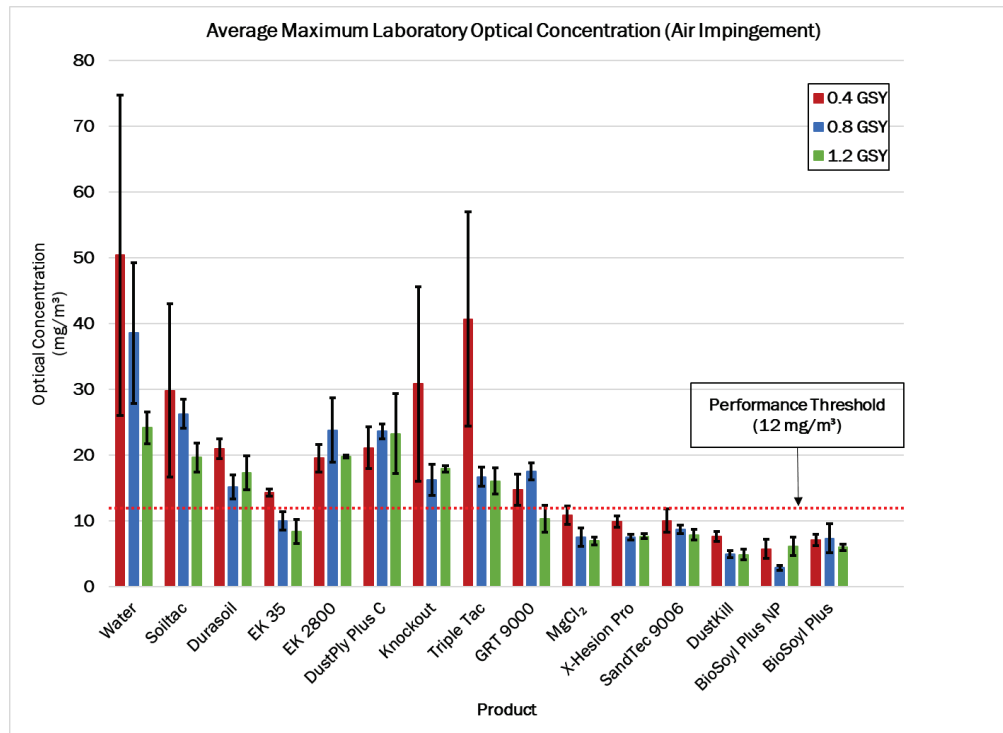
3.4.2 Optical dust concentration

Dust concentrations (mg/m^3) within the testing chamber were recorded by using a Haz-Dust™ EPAM-5000 Environmental Particulate Air Monitor. The device uses optical techniques to record dust concentrations in the air. The monitor can detect dust particles from 0 to 100 micrometers in size at concentrations up to $200 \text{ mg}/\text{m}^3$. Measurements were recorded at 1-sec intervals and stored on the dust monitor's internal computer. Data were collected during the 30 sec of air impingement and 120 sec of wait time to observe the rate of settling of dust within the testing chamber. Dust concentrations reported in this document are the maximum values obtained by the sensor during testing, normalized by subtracting the initial dust concentration.

Dust concentration maximum values for the dust palliatives tested are shown graphically in Figure 8. The data presented here are the average of the maximum values of three test specimens. The range of materials was compared against water as the control. In general, an increase in material applied to the surface lowered the total amount of dust emitted for all samples. The 0.8-gsy samples performed better than the 0.4-gsy samples, but the 1.2 gsy samples provided no significant increase in

performance. Samples exhibiting maximum dust concentrations of less than 12 mg/m³ were rated as good performers in this laboratory test.

Figure 8. Results from the testing chamber using the Haz-Dust EPAM-5000.



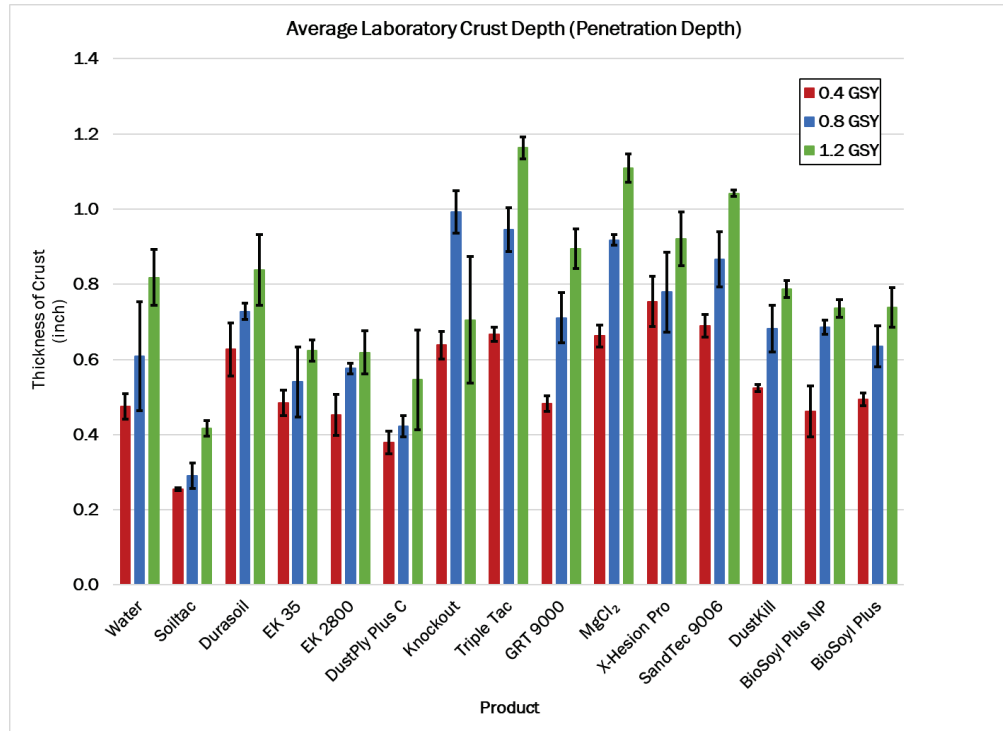
3.5 Penetration depth

Previous dust abatement studies indicated that penetration depth is a crucial indicator of performance on helipads constructed for military aircraft. In Rushing et al. (2006), a penetration depth of at least 1 in. was recommended for polymer emulsion products to minimize foreign object debris (FOD) potential. A similar conclusion was discussed in Edwards et al. (2010), in which the 1-in. depth was recommended for all products to ensure successful dust suppression and FOD prevention.

For each test specimen tested, the maximum penetration depth was recorded. The averages of the maximum penetration depths for the three test specimens are shown graphically in Figure 9 as a function of application rates of 0.4, 0.8, and 1.2 gsy. Error bars are also included to show the variability for the group of three samples. As expected, higher application rates resulted in increases in penetration depth for all samples. Note that these penetration depth data values were not used in the selection of

products for field testing because of the difference between soil types in the laboratory and field and the testing was not conducted with helipads.

Figure 9. Average crust penetration depths for laboratory samples.



3.6 PI-SWERL testing

Measurements were made using the PI-SWERL by using the DustTrak™ attached to the PI-SWERL monitor to measure airborne dust concentrations. A step test was chosen as the measurement type, which means a set ring speed was held for a period of time, and incrementally increased until it reached a set speed. The setting used was the H5000 and is shown graphically in Figure 10. The StepMass is the total mass of dust (in µg) that was in suspension since the start of a specific target speed (RPM) value (3,000, 4,000, and 5000 rpm). The total mass of dust is the summation of all the dust collected from start to finish in the test, which includes the dust measured during the ramp to the specified speed (RPM) and the dust measured at that present speed. For the purposes of this study, testing was conducted for a range of wind speeds produced by rotary wing aircraft. Conversion of the speed of the instrument as a function of the rotational speed, x (in RPM) to MPH is given by

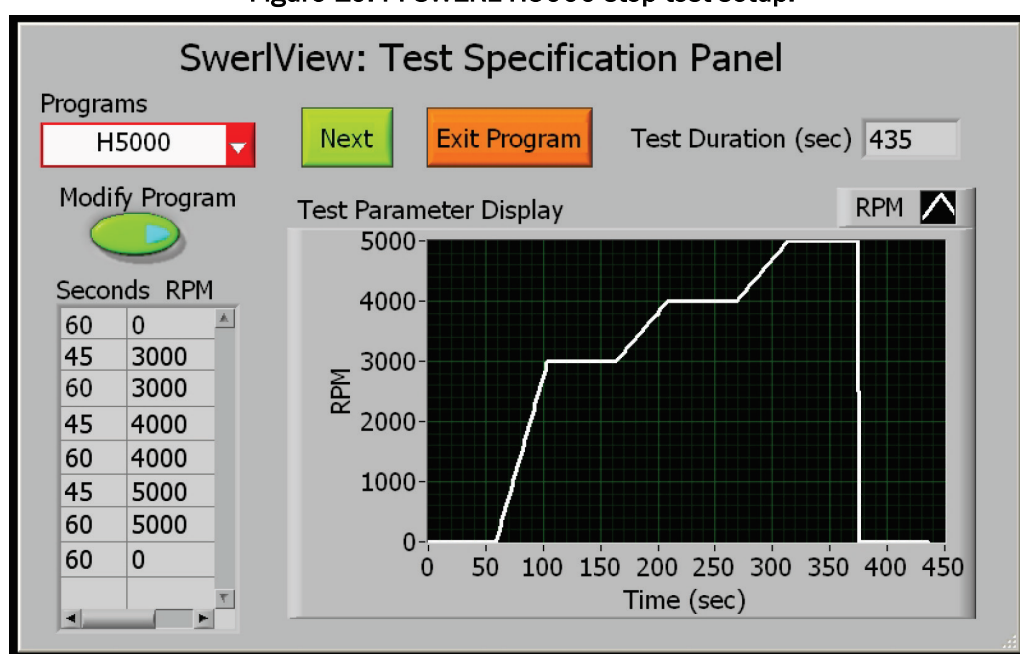
$$\text{Speed (mph)} = x \times \pi / 12 \text{ in.} \times 60 \text{ min/hr} / 12 \text{ ft/in.} / 5,280 \text{ mile/ft}$$

For the speeds used in our studies (i.e., 3,000, [107.1 mph]; 4,000 [142.8 mph]; and 5,000 [179.5 mph] RPM), the wind shear (τ) is shown in Table 1.

Table 1. Rotational speeds used in the study and conversion to linear speed and wind shear at the edge of the plate at the stated RPM.

Rotational Speeds (RPM)	Speed (MPH)	Wind Shear
3,000	107.1	0.34
4,000	142.8	0.54
5,000	178.5	0.76

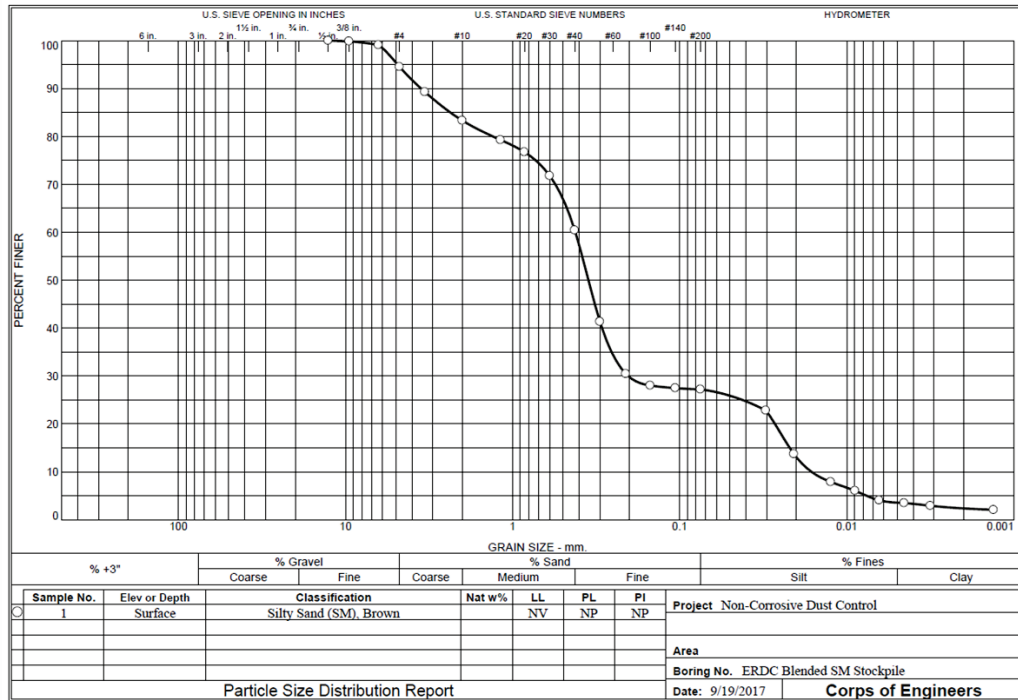
Figure 10. PI-SWERL H5000 step test setup.



Laboratory samples were prepared in a similar fashion to the previous laboratory testing but in a 15-in.-diam circular pan that was 3 in. deep. The soil was sieved using a No. 10 sieve, discarding any material retained on the sieve. The gradation curve for the soil is given in Figure 11. The SM soil in the circular pan was also placed on the vibratory table with the rheostat set to 30 and vibrated for 30 sec, adding SM as necessary to remain flush with the surface. This was done to provide a consistent sample for each laboratory test. The surface of the pan was leveled off with a metal straightedge. The dust control products were prepared according to the manufacturers' directions.

The products used in the field were prepared in the same way as applied in the field and sprayed with the same setup as the prior testing (Figure 12, see section 3.2). After spraying, the pans were placed in the oven at a temperature of 120°F for 24 hr. The PI-SWERL was then placed on the sample in the circular pan to evaluate the different products.

Figure 11. Gradation curve for soil used for PI-SWERL testing.



PI-SWERL testing was available during and after the field trials, so only the products used in the field trial are reported. A significant advantage to the PI-SWERL device is the ability to use it in both the laboratory and the field, providing a significant capability to the research team's testing regimen. The data comparisons from the laboratory and field show good correlation, providing a solid basis for future studies. Figure 13 shows the laboratory PI-SWERL results for the dust products used in the field test compared to water as a control. This comparison provides some context as to how well the products perform relative to water after drying. In Figure 14, water values are removed, showing the relative performance of the products against one another. It should be noted that Durasoil® was tested at 0.4 gsy, the same application rate used for the buffers in the field between product test items. It should also be noted that the large error bars for EK35 may be related to sample preparation (cracks in the sample surface).

Figure 12. Laboratory testing with the PI-SWERL.

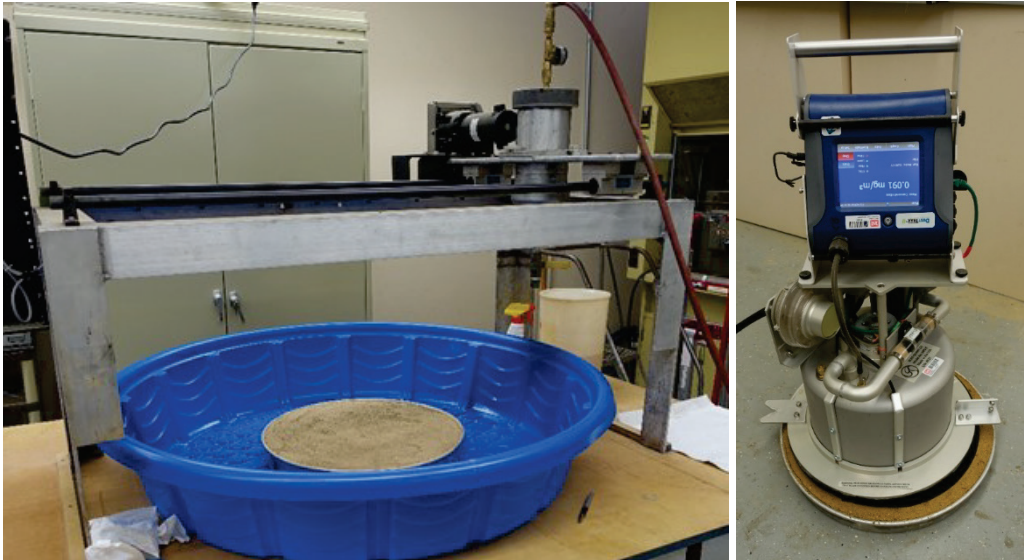


Figure 13. PI-SWERL laboratory data of dust palliatives used in the field testing, showing water as a control.

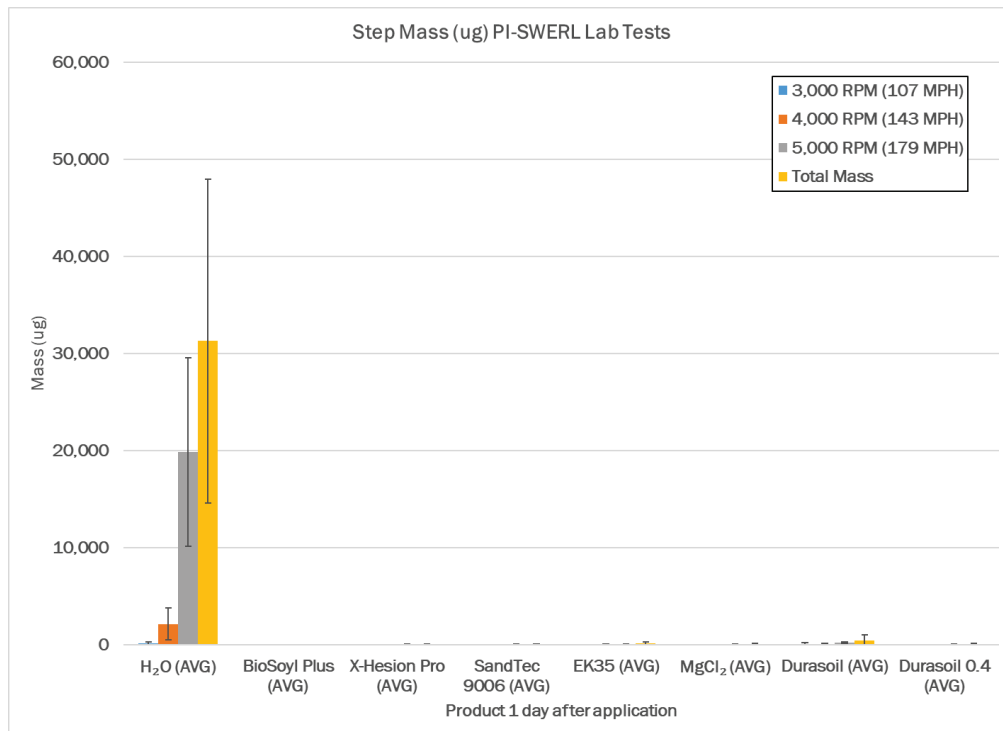
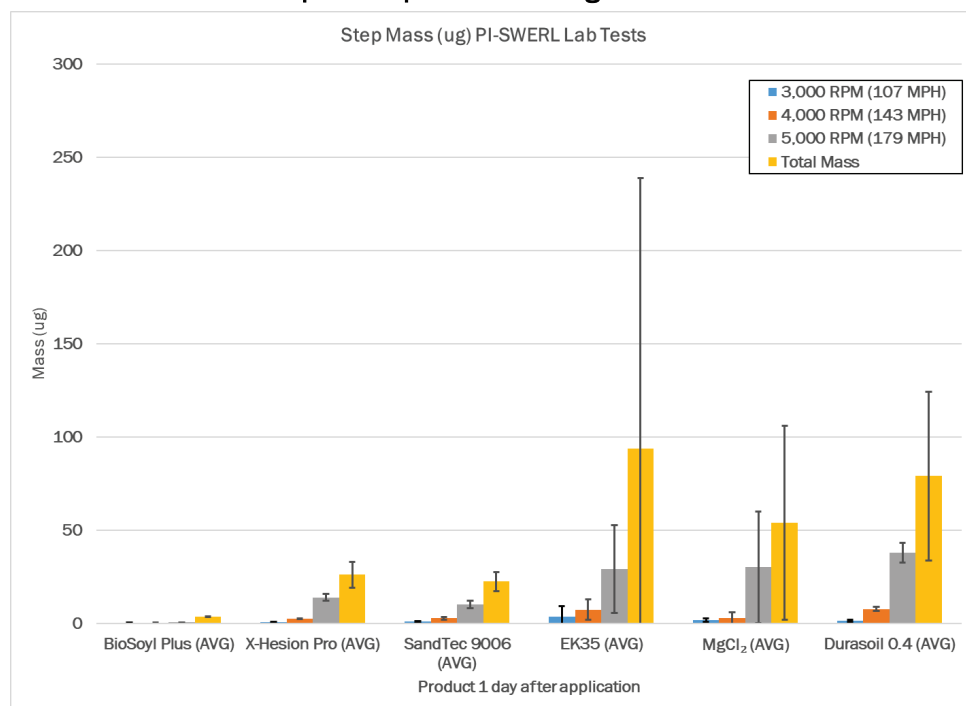


Figure 14. PI-SWERL laboratory data of used in the field testing with water removed to show the product performance against each other.



3.7 Discussion of laboratory testing

The air impingement laboratory testing was used to provide the basis for the selection of products to be used in the field trials. Samples exhibiting laboratory performance less than 40-g erosion potential and 12-mg maximum dust in the air impingement were initially selected. Selecting the palliative application rate was a balance between performance and logistical considerations. Because an application rate of 0.8 gsy performed significantly better than 0.4 gsy, and 1.2 gsy provided no apparent significant increase in performance, 0.8 gsy was used for the selections and field trials.

Using the erosion potential, maximum dust concentration from air impingement, and application rate of 0.8 gsy, the the list of products was downselected to EK35, MgCl₂, X-Hesion Pro™, SandTec 9006, DustKill, BioSoyl NP, and BioSoyl Plus. EK35, MgCl₂, X-Hesion Pro™, and SandTec 9006 were chosen based on performance characteristics, with BioSoyl Plus being chosen for its performance characteristics and soy-based components. DustKill and BioSoyl NP were not chosen based on a combination of slightly lower performance characteristics than BioSoyl Plus in the erosion test and limitations in the number of field test sections to five, based on cost and site characteristics.

4 Corrosion Testing

4.1 Corrosion coupons

Corrosion studies included coupons of four metals (Table 2). The coupons were 1/8-in. thick x 1 in. wide x 3 in. long with a 3/8-in.-diam hole located 3/8 in. from the end. The tolerances were ± 0.031 in. The vendor pre-weighed, individually packed, and stamped with an individual serial number each coupon.

Table 2. Metal coupons.

Material	Surface Finish	Location on Aircraft
Magnesium ZE41A	Cast finish	Transmission housing
Aluminum 2024-T3	Smooth finish	Outer skin
Aluminum 7075-T6	Smooth finish	Frames
High-strength steel 4340	Smooth finish	Landing gears

4.2 Corrosion testing

A plywood box (24 in. wide x 48 in. long x 8 in. deep) was designed with five rectangular compartments (24 in. x 9 in.) and used to hold the corrosion coupons. Drilled holes in the side of the plywood box held the wooden dowels on which the corrosion coupons were hung (Figure 15).

The SM for the corrosion test containers was not sieved since the container was larger. The dust palliatives for the corrosion testing were applied at 1.2-gsy concentration, as it is the highest concentration tested in the laboratory and, thus, the worst-case scenario.

Each dust palliative was sprayed three times at a rate of 0.4 gsy to achieve a total of 1.2 gsy concentration into two of the compartments of the corrosion test containers (Figure 16). A plywood board was used to shield the neighboring test compartments to prevent contamination. Each 0.4-gsy spray was allowed to soak into the SM before proceeding to the next application. After 3 passes were completed, the SM and dust palliative combination was allowed to cure for 24 hr before the corrosion testing was started. For each dust palliative, 12 coupons were tested, with 6 in each compartment. Initial weights for the metal coupons were measured before being carefully placed into the soil. The wooden dowel was inserted into the holes of each coupon to ensure that the coupons were all placed in the treated soil at the same depth

(Figure 17 and Figure 18). The corrosion test containers were placed in an indoor laboratory for a controlled environment.

The coupons were removed from the soil every 30 days for evaluation (Figure 19). After removal, they were cleaned with water and a soft-bristled brush, dried with a paper towel, placed on a towel to dry for 15 min, and then weighed. The coupons were then placed back into the corrosion testing container in the laboratory until the next evaluation. Photographs of the coupons during corrosion testing at selected times of 30, 90, 120, and 360 days after initial measurements are given in Figures A24-A91.

Figure 15. Corrosion testing container.



Figure 16. Applying dust palliative to corrosion testing container.

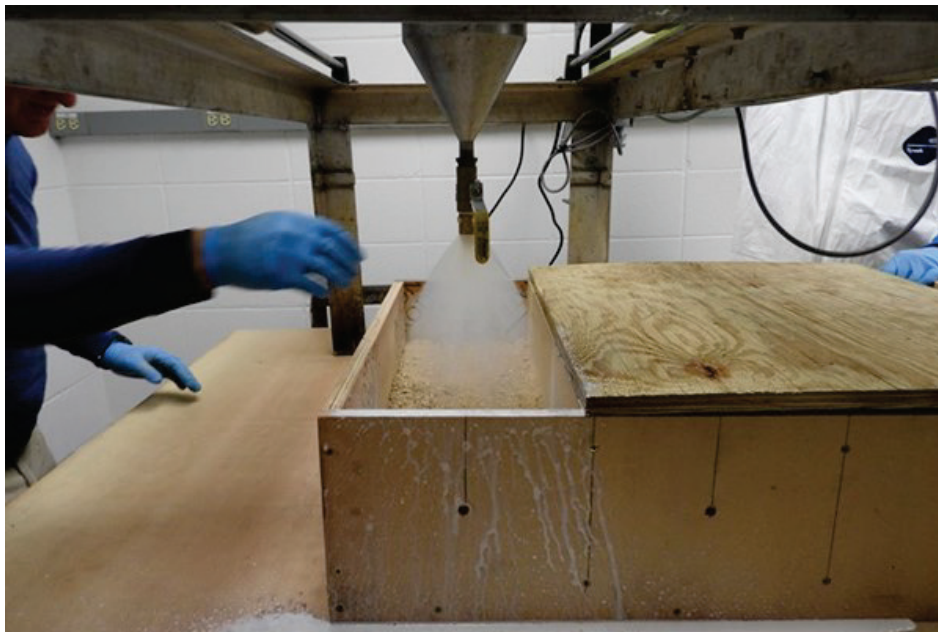


Figure 17. Metal coupon placement.



Figure 18. Metal coupons in the corrosion testing container, top view.



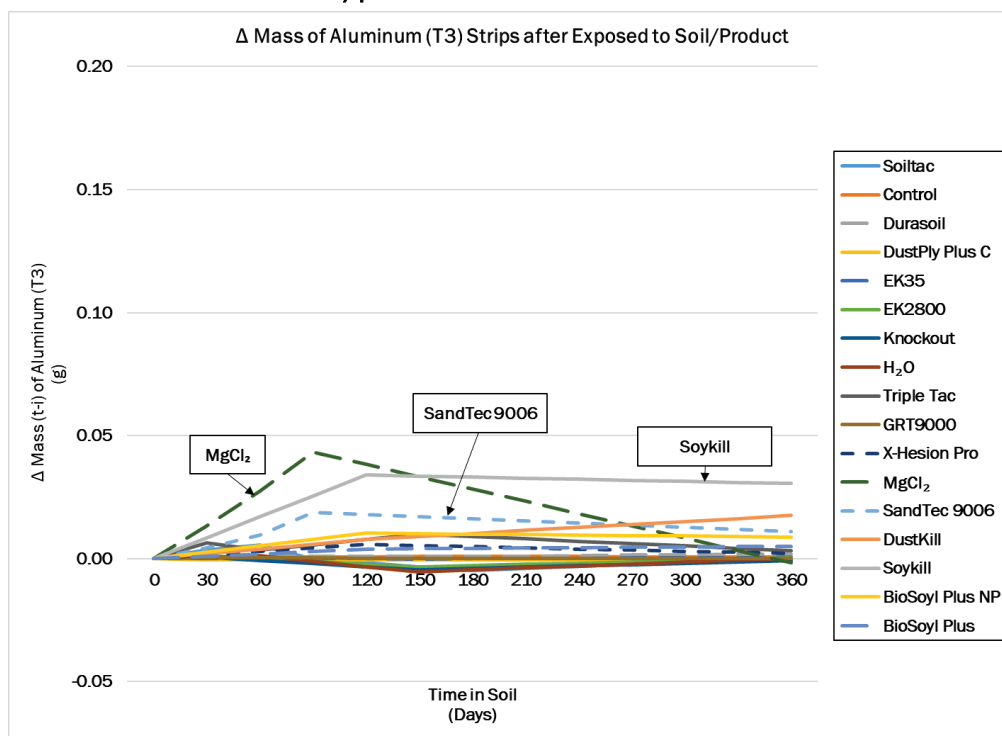
Figure 19. Examples of metal coupons after removal from the treated soil.



Measurement of the mass of each of the coupons for the four types of metal coupons was done for over 1 yr. Analysis consisted of comparing the mass to the original starting mass. Plots were made of the resultant change in mass. All the mass change ($\text{mass}_t - \text{mass}_0$) plots were scaled to the same change of the mass change regardless of type of metal to be able to compare among metal types.

The change in mass for each of the dust palliatives on aluminum (2024-T3) coupons is shown in Figure 20. The range of change in mass was from -0.005 to 0.04 g. Overall, there is little increase in mass observed in the coupons. The largest increases in mass are for the samples exposed to MgCl_2 , SandTec 9000, and Soykill. One should note that the range of change in mass was from -0.005 to 0.04 g.

Figure 20. Changes in mass of aluminum (2024-T3) coupons after exposure to soil/product as a function of time.



The change in mass for each of the dust palliatives on aluminum (7075-T6) coupons is shown in Figure 21. Similar to samples of aluminum 2024-T3, there is little increase in mass, and the samples with the largest increase were once again samples exposed to MgCl₂ and Soykill. One should note that the range of change in mass was from -0.02 to 0.04 g.

The change in mass for each of the dust palliatives on magnesium coupons is shown in Figure 22. Overall, there is little increase in mass observed in the coupons. The largest increase in mass is for the samples exposed to Soykill. One should note that the range of change in mass was from -0.03 to 0.055 g.

Figure 21. Changes in mass of aluminum (7075-T6) coupons after exposure to soil/product as a function of time.

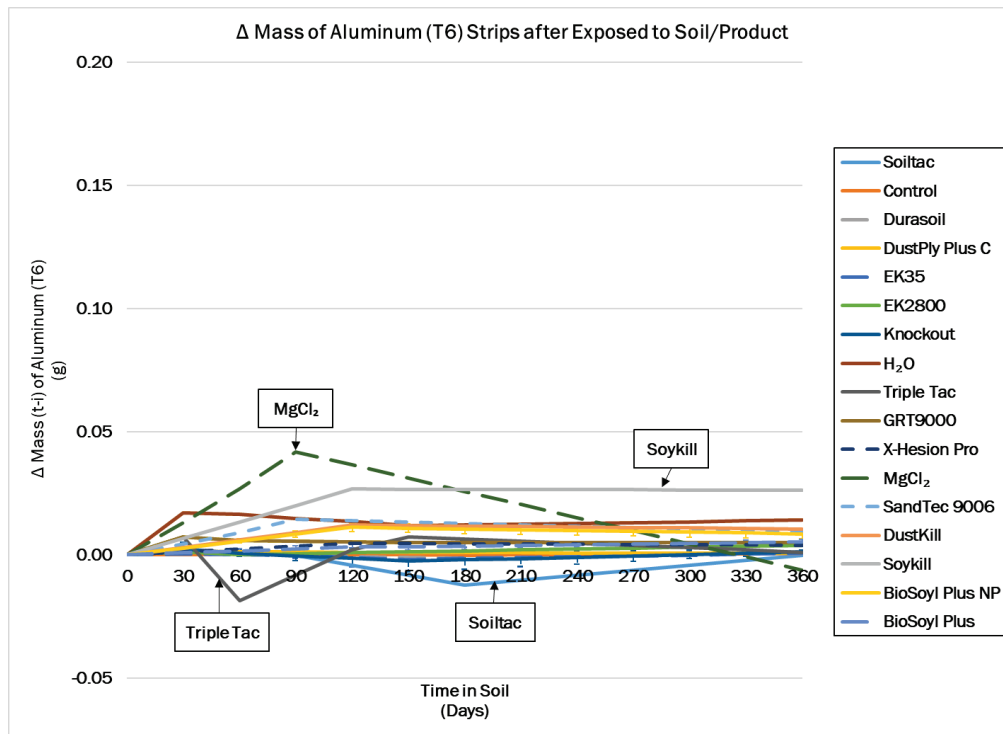
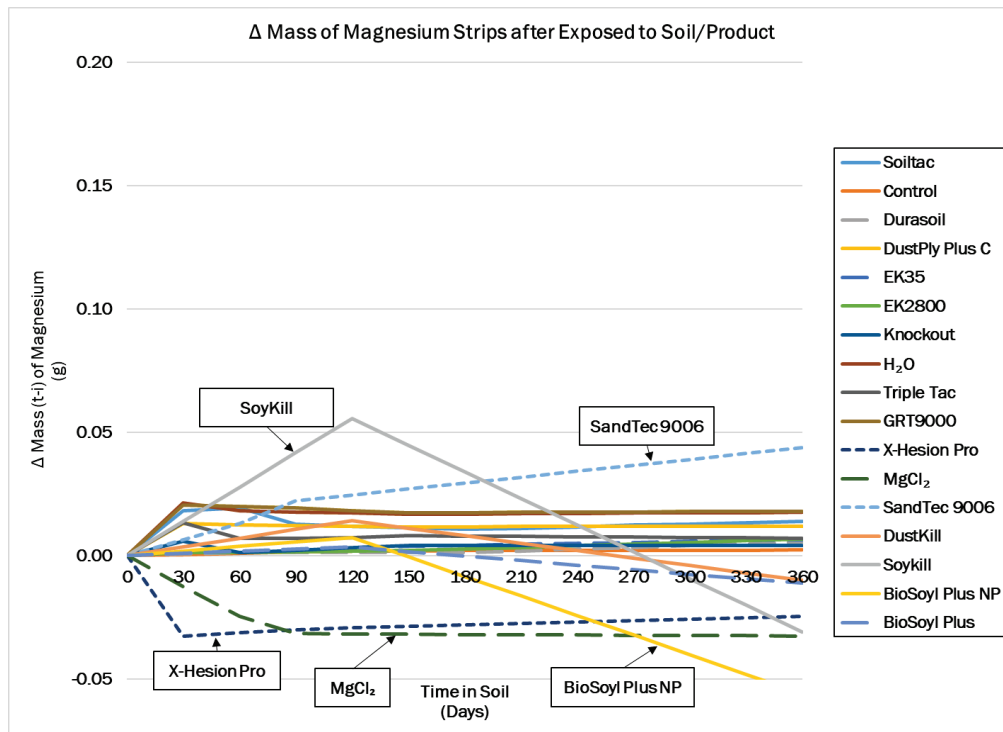
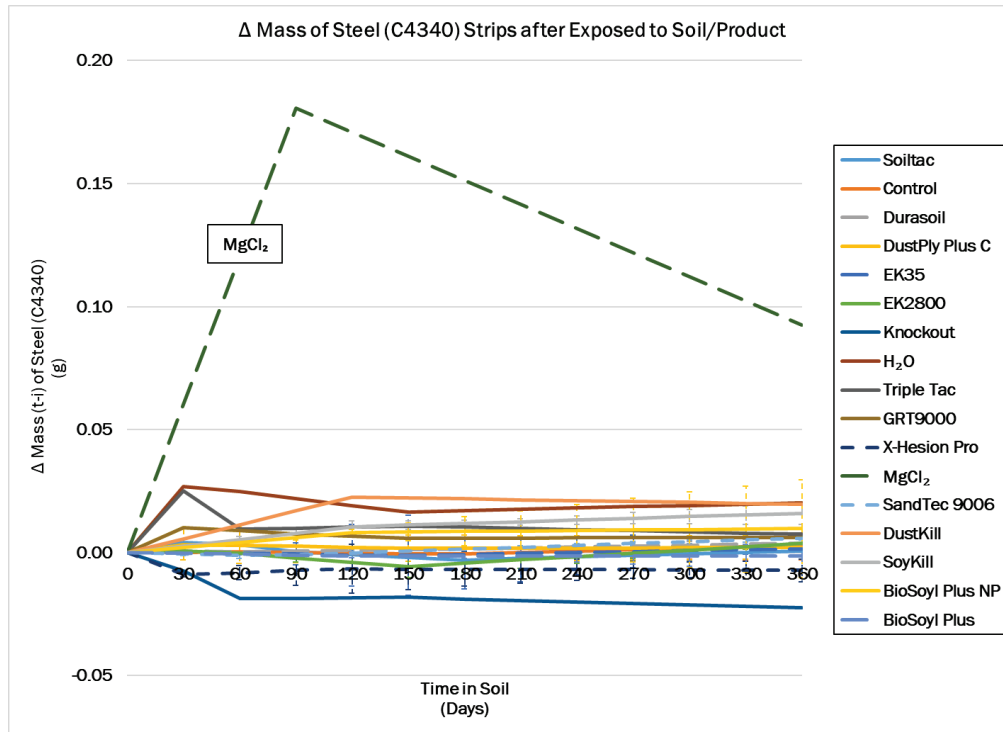


Figure 22. Changes in mass of magnesium (ZE41A) coupons after exposure to soil/product as a function of time.



The change in mass for each of the dust palliatives on steel (4340) coupons is shown in Figure 23. The range of change in mass was from -0.005 to 0.04 g. Overall, there is little increase in mass observed in the coupons. The largest increase in mass is for the samples exposed to MgCl_2 . One should note that the range of change in mass was from -0.02 to 0.18 g.

Figure 23. Changes in mass of steel (4340) coupons after exposure to soil/product as a function of time.



Overall, MgCl_2 produced the greatest change in mass for the metals that were studied. Based on that observation, it can be inferred that MgCl_2 was the most corrosive material for this suite of metals.

5 Field Testing of Dust Palliatives

5.1 Test site preparation and characterization

A selected number of the dust palliatives tested in the laboratory were also tested in the field. The field tests occurred at a remote unsurfaced road (Figure 24) at Fort Bliss in El Paso, TX, from October 2018 through January 2019. Five test items to test five different palliatives were created (Figure 25) on this unsurfaced road. Each test item was 500 ft long by 20 ft wide. The test site was broken into two areas because of a long section of caliche between Items 3 and 4. Each test item was clearly marked with a delineator (see Figure 25, right). The control for each test item was the untreated surface prior to application of any dust palliative products.

A Caterpillar 140H motor grader was used to level the test areas as well as to remove vegetation (Figure 28). The soil was soaked due to a rain event that occurred on the previous night. An extendable boom forklift, the Genie GTH-844 telehandler (Figure 29), was used for loading and unloading material and equipment. A 4,000-gal water truck (Figure 30) was used for storing and retrieving water for dilution and for rinsing equipment.

Soil test specimens were collected from two locations for classification purposes. The first soil sample was representative of the soil found in Items 1 through 3 (Figure 26). The second soil sample was representative of the soil found in Items 4 and 5 (Figure 27). The soils were both classified as a silty sand (SM) according to the USCS (ASTM 2017).

Figure 24. Test section at Fort Bliss.



Figure 27. Soil classification, representative of the soil in Items 4 and 5.

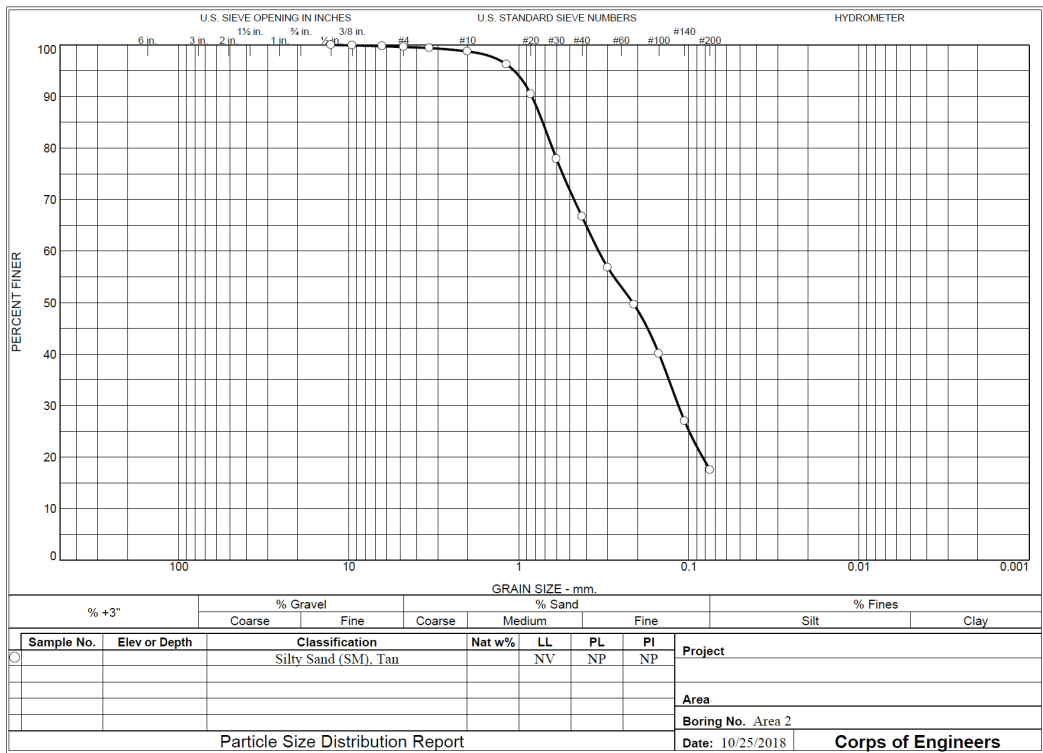


Figure 28. Motor grader used for test section construction.



Figure 29. Extendable boom forklift.



Figure 30. Water truck.



5.2 Application and trafficking

Palliatives (in totes) were staged along the test section prior to testing and were used for the palliative application, as shown in Figure 31. A Finn trailer-mounted hydroseeder (Figure 32) was used to apply palliatives. The specifications for the hydroseeder are listed in Table 3. The hydroseeder included paddles for mechanical agitation and was used for mixing the palliatives with water for dilution. The hydroseeder was equipped with hose and tower gun application equipment, but the lower spray bar was used to apply palliatives to the road test section. The spray bar had nine nozzles to produce an 8-ft-wide pattern. The nozzles were BEX F40, Model $\frac{3}{4}$ F40200, used at 15 psi to produce a spray of 12.2 gal/min. A Honda WB20XT3 self-priming pump (Figure 33) was used to extract the palliatives from the totes and transfer them to the hydroseeder.

A Ford F-250 was used to traffic the test items for evaluation of the durability of the palliatives, and each test item was tested using 10 passes at 30 mph. The test items were evaluated at 1 day, 30 days, 60 days, and 90 days after application. Trafficking was not conducted at 30 and 90 days due to rainfall.

The measurement control for each test item was the pre-application average for that test item. Each test item was trafficked and evaluated prior to the palliative application.

Figure 31. Staging of palliatives prior to testing.



Figure 32. Finn hydroseeder.



Table 3. Trailer-mounted Finn hydroseeder specifications.

Item	Specifications
Tank Capacity, gal	920
Empty Weight, lb	5,420
Working Weight, lb	14,670
Width, in.	85
Length, in.	194
Height, in.	108
Engine	33.5 HP Kubota V1505
Pump	4-in. x 2-in. Centrifugal Pump, 170 gpm @ 100 psi
Fuel Capacity, gal	14
Distribution System	Hose, Tower Gun, or Distribution Bar

Figure 33. Pump used to add palliatives to hydroseeder.

5.2.1 Testing schedule and weather data

The average monthly weather data were pulled from the National Oceanic and Atmospheric Administration's (NOAA) National Centers for Environmental Information (NCEI) website

(<https://www.ncdc.noaa.gov/cdo-web/datasets/GHCND/stations/GHCND:USW00023044/detail>). The test schedule for the evaluation is shown in Table 4, and the weather summary data for the same period are shown in Table 5. The most rainfall occurred in October (2.44 in.) during the 30-day evaluation period, and smaller amounts of rain occurred during December, which was just prior to the 90-day evaluation test. Traffic was not conducted at the 30-day or 90-day evaluation due to recent rainfall.

Table 4. Evaluation schedule.

Date	Test Event
2 October 2018	Test section preparation
3 October 2018	Pre-application testing
4 October 2018	Product application
5 October 2018	Day 1 evaluation
3 November 2018	Day 30 evaluation, no trafficking
3 December 2018	Day 60 evaluation
3 January 2019	Day 90 evaluation, no trafficking

Table 5. Average monthly weather data.

Month	Maximum Temperature (°F)	Minimum Temperature (°F)	Total Precipitation (in.)
October	74	56	2.44*
November	66	41	0.01
December	57	38	0.43*
January	59	35	0.1

*Rain event occurred prior to testing.

5.2.2 Test items

Five dust palliatives were applied and evaluated (Table 6). Each test item had a buffer prior to and after the testing area. A dust palliative, Durasoil®, which had proven in previous studies to mitigate airborne dust, was applied to the buffer areas to provide similar mitigation at the beginning and end of the test item. It was also labelled as Item 6 that occurred at the end of the fieldtest section. The different viscosities of the products necessitated varying the number of passes to produce the desired amount of palliative applied.

Table 6. Product application.

Test Item	Product	Dilution with Water	Application Rate (gsy)	Volume of Water (gal)	Volume of Product (gal)
Buffers	Durasoil®	Neat	0.4	0	747
1	BioSoyl Plus	Neat	0.8	0	712
2	X-Hesion Pro™	1 to 1	0.8	356	356
3	SandTec 9006	Neat	0.8	0	712
4	EK35	Neat	0.5	0	444
5	MgCl ₂	Pre-mixed	0.8	0	712
6	Durasoil®	Neat	0.4	0	71

5.2.3 Item 1

Item 1 was treated with BioSoyl Plus at an application rate of 0.4 gsy, placed neat (no dilution). The product was packaged in 275-gal totes. The hydroseeder was filled with approximately 356 gal of product, which was sprayed from the hydroseeder. It took 4 lane passes (2 total coats) at 3 mph to complete placement. The soil easily absorbed the solution, and no puddles were evident 2 hr after the spraying.

Figure 34 shows Item 1 during testing. Figure 34a shows the item prior to application during the pretest trafficking. Figure 34b shows the surface immediately after the surface was sprayed. Figure 34c shows the trafficking 1 day after application, while the surface is still moist. During the 30-day test, trafficking was not possible because there had been a storm at the test section the week before the test. Item 1 did not have any puddles, but the surface was still wet from the rainfall.

Figure 34d shows the trafficking after 60 days. There was still evidence of the dust palliative, as the surface looked dark and soil was packed. Only minimal dust was observed during the trafficking.

At the 90-day evaluation, there was still evidence of the palliative, and a clear delineation visible, separating the treated and untreated areas.

5.2.4 Item 2

Item 2 was treated with X-Hesion Pro™, diluted 1 to 1 with water, and applied at a rate of 0.8 gsy. The product was packaged into 275-gal totes, and approximately 356 gals of product was used along with 356 gals of water. The dilution was accomplished by emptying the product out of the tote and

pumping water into the tote and then into the hydroseeder. This served to clean the pump as well. The agitator in the hydroseeder was run the entire time to ensure adequate mixing. The product was applied in 8 lane passes (4 total coats) with the hydroseeder traveling at 3 mph. The soil easily absorbed the solution, and no puddles were evident 2 hr after the spraying.

Figure 34. Item 1 during trafficking.



Figure 35 shows Item 2 during testing. Figure 35a shows the item prior to application during the pretest trafficking. Figure 35b shows the surface immediately after the surface was sprayed. Figure 35c shows the trafficking 1 day after application while the surface is still moist. During the 30-day test, trafficking was not possible because there had been a storm at the test section the week before the test. Item 2 had a rut; therefore, a puddle at the 250-ft station was pumped out during the monitoring trip. However, the rest of the section looked dry, with little evidence of the dust palliative.

Figure 35d shows the trafficking after 60 days. Because there was a rut at the 250-ft station, one of the stationary dust collectors was moved to the beginning of the section. During trafficking, the section appeared to be very dusty.

At the 90-day evaluation, the section was too wet to traffic due to a rain event prior to testing. It was difficult to distinguish the product-treated areas from the untreated areas.

Figure 35. Item 2 during trafficking.



(a) Pretest trafficking of Item 2.



(b) Surface after spraying Item 2.



(c) Day 1 trafficking of Item 2.



(d) Day 60 surface of Item 2.

5.2.5 Item 3

Item 3 was treated with SandTec 9006 at an application rate of 0.8 gsy, placed neatly (no dilution). The product was packaged in 275-gal totes. The hydroseeder was filled with approximately 712 gal of product, which was sprayed from the hydroseeder. It took 6 lane passes (3 total coats) at 3 mph and 2 additional passes at 8 mph to empty the product onto the test bed. The soil easily absorbed the solution, and no puddles were evident 2 hr after the spraying.

Figure 36 shows Item 3 during testing. Figure 36a shows the item prior to application during the pretest trafficking. Figure 36b shows the surface immediately after the surface was sprayed. Figure 36c shows the trafficking 1 day after application while the surface is still moist. During the 30-day test, trafficking was not possible because there had been a storm at the test section the week before the test. At the 80-ft station, Item 3 had a water puddle that was pumped out during the monitoring trip. However, the rest of the section looked dry with little evidence of the dust palliative. Figure 36d shows the trafficking after 60 days. During trafficking, the section appeared to be very dusty. There appeared to be little evidence of the dust palliative except where the soil and product had curled, indicating the palliative had lost effectiveness.

Figure 36. Item 3 during trafficking.



At the 90-day evaluation, the section was too wet to traffic due to a rain event prior to testing. It was difficult to distinguish the product-treated areas from the untreated areas.

5.2.6 Item 4

Item 4 was treated with EK35 at an application rate of 0.5 gsy, placed neat (no dilution). The product was packaged in 275-gal totes, and 444 gals were sprayed onto the section. The hydroseeder applied the product at 4 mph and finished after 6 lane passes (3 total coats). The product appeared to have absorbed into the soil 2 hr after the spraying. Since EK35 has been previously tested by ERDC, a lower application rate was tested at this point to determine if less material could be used and comparable to the other products at 0.8 gsy application rates.

Figure 37 shows Item 4 during testing. Figure 37a shows the item prior to application during the pretest trafficking. Figure 37b shows the surface immediately after the surface was sprayed. Figure 37c shows the trafficking 1 day after application where the surface is still moist. During the 30-day test, trafficking was not possible because there had been a storm at the test section the week before the test. Item 3 had several water puddles towards the last 50 ft of the section. However, the rest of the section looked to be in good condition, with the palliative-treated sections easily identifiable.

Figure 37d shows the trafficking after 60 days. During trafficking, the section appeared to be holding up well, and little dust was seen near the truck tires.

The product at the initial application appeared to puddle on top of the caliche (Figure 37e) but was absorbed into the soil after a few hours. At the 90-day evaluation, the section was too wet to traffic due to a rain event prior to testing. A patch of ice was at station 125 ft (Figure 37f). The treated sections were easy to identify, with a clear line dividing the treated sections from the untreated sections.

5.2.7 Item 5

Item 5 was treated with magnesium chloride (MgCl_2) at an application rate of 0.8 gsy. The MgCl_2 was already mixed in a 30% solution and packaged in 225-gal totes. The hydroseeder was filled with approximate 712 gal of product and sprayed on the soil while traveling at 3 mph. It took 6 lane passes (3 total coats) to empty the product onto the test bed. The soil easily absorbed the solution, and no puddles were evident 2 hr after the spraying.

Figure 37. Item 4 during trafficking.

(a) Pre-test trafficking of Item 4.



(b) Surface after spraying Item 4.



(c) Day 1 trafficking of Item 4.



(d) Day 60 surface of Item 4.



(e) Pooling of product after spraying on Item 4.



(f) Ice in low spot at 90 days on Item 4.

Figure 38 shows Item 5 during testing. Figure 38a shows the item prior to application during the pretest trafficking. Figure 38b shows the surface immediately after the surface was sprayed. Figure 38c shows the trafficking 1 day after application while the surface is still moist. During the 30-day test, trafficking was not possible because there had been a storm at the test section the week before the test. However, the section looked dry with little evidence of the dust palliative.

Figure 38d shows the trafficking after 60 days. During trafficking, this section appeared to be very dusty, and very little of the product appeared to be on the section. Some areas of the test item broke apart into chunks.

At the 90-day evaluation, the section was too wet to traffic due to a rain event prior to testing; it was difficult to distinguish the treated areas from the untreated areas. Very little evidence of the product remained.

Figure 38. Item 5 during trafficking.



5.2.8 Item 6 and buffers

Durasoil® was applied approaching and following test items to ensure that the dust next to the test items did not interfere with the testing. Durasoil® was applied at a rate of 0.4 gsy, which took the hydroseeder 4 lane passes (2 total coats) at 4 mph.

The last buffer area was used as an extra test item where limited testing was performed. No trafficking was conducted on the test item, but the PI-SWRL was used to monitor the performance over time.

During the 30-day monitoring test, several areas appeared to have washed out during the rain events. Therefore, PI-SWERL data were collected only where evidence of palliative was still visible. At 60 days, the treated areas of the section were still showing evidence of palliative. At 90 days, there was only a faint line showing where the palliative had been applied.

5.3 Test methods for quantitative measurements

Test items were evaluated prior to application as a baseline measurement. The average of the test measurements prior to application was used as the control measurement.

5.3.1 Dust collectors

Two stationary dust collectors were used to provide a quantitative measure of the effectiveness of the dust palliatives. These stationary dust collectors were located approximately 12 ft from the centerline of the road and at 240- and 260-ft stations along the test section. The dust collectors were 30 in. high and were powered with a small generator in the center of the test section. Each dust collector consisted of a pre-weighed 8-in. by 10-in. Graseby GMW fiberglass filter (P/N G810) placed over a wire mesh screen through which a slight vacuum pressure was drawn by using an electric pump (Figure 39). The dust collectors were uncovered prior to trafficking (Figure 40). After 10 total passes, the filters were removed and placed in a Ziploc bag to be weighed later. The weights of the dust collected on the two filters were averaged to obtain a value for the test item.

Figure 39. Stationary dust collectors.

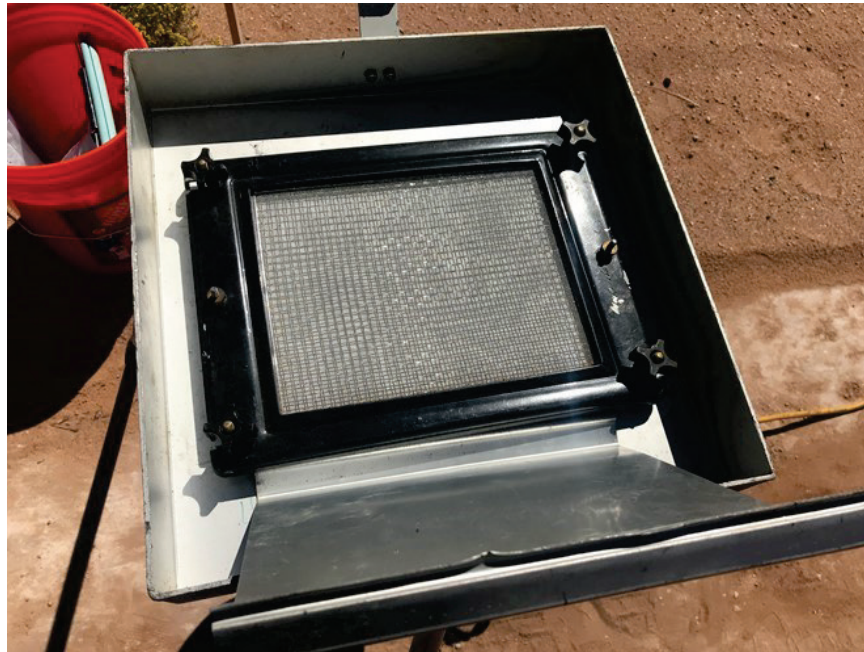


Figure 40. Layout of stationary dust collectors.



5.3.2 Stationary Haz-Dust IV

The Haz-Dust IV particulate monitor was positioned in the center of the test item at station 250 ft and mounted on a stationary dust collector stand at 19 in. above the bottom of the stand (Figure 41). This device contains a light-scattering laser photometer that provides aerosol mass readings. Airborne dust particles are reported immediately in mg/m^3 . Dust concentrations were measured for the field samples at 1 and 60 days during trafficking (Figure 42). Although the data show some variability and increase in dust produced at later ages, it should be noted that the range of dust measured was low,

from 0 to 0.3 mg/m³. The initial readings showed extremely low dust emittance. At 60 days, an increase in dust emittance was observed.

Figure 41. Close-up of stationary Haz-Dust IV position.

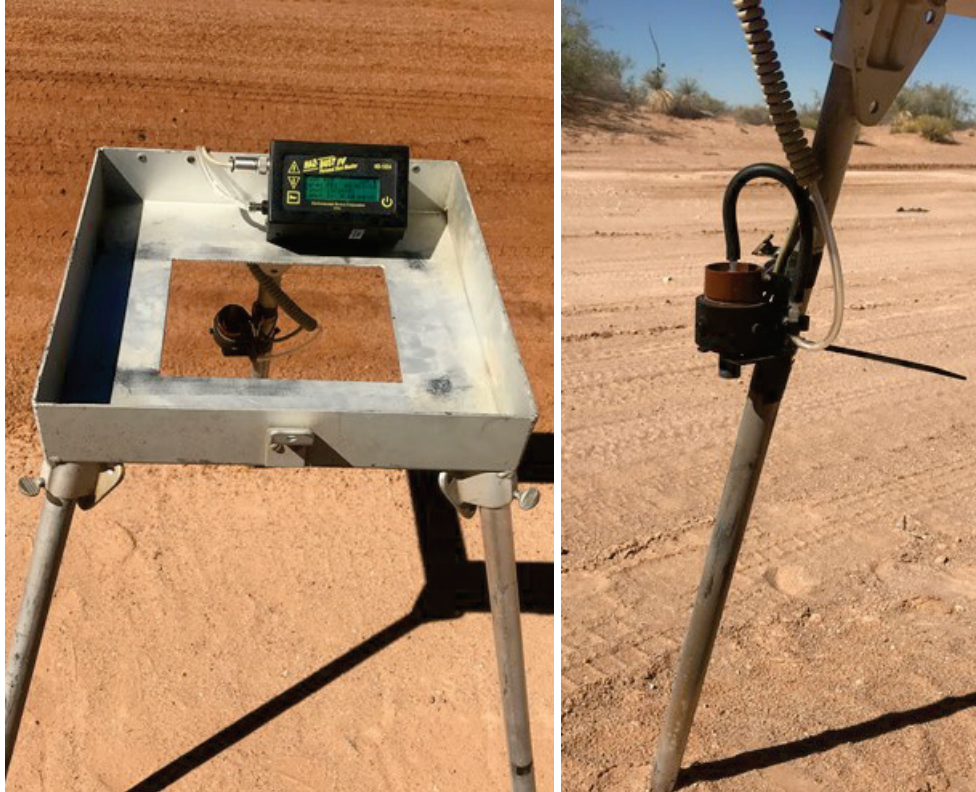
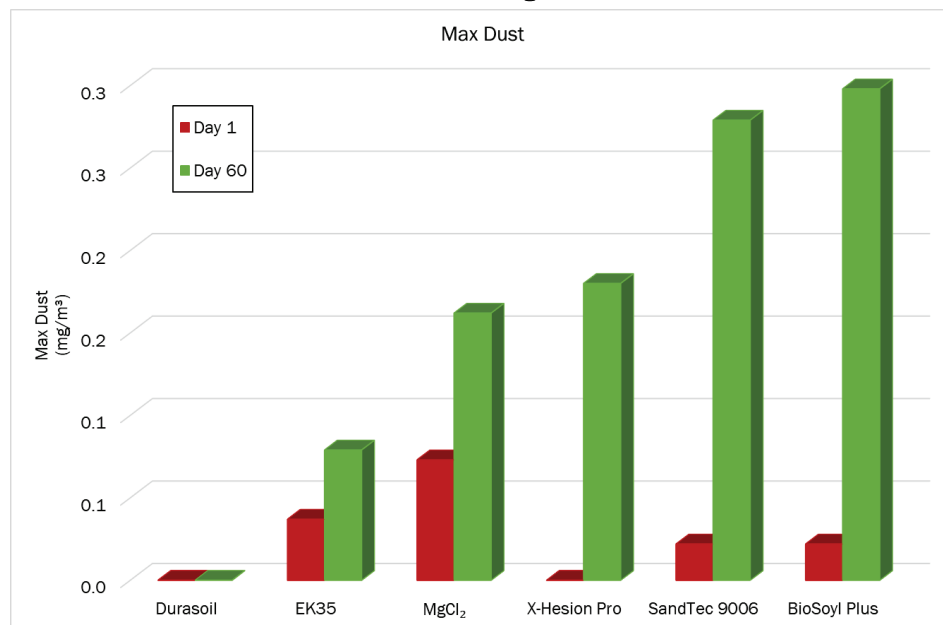


Figure 42. Maximum dust produced during field testing from the stationary Haz-Dust IV particulate monitor; no data were collected for days 30 and 90 due to rainfall prior to testing.



5.3.3 Mobile DustTrak™

A mobile Haz-Dust EPAM-5000 Environmental Particulate Air Monitor was used to monitor dust during trafficking (Figure 43). The mobile device was placed in the truck bed, and a hose was used to extend the sampling tube to 6 ft away from the back of the truck and 19 in. from the surface of the soil. Ten vehicle passes were made over each test item at a speed of 30 mph.

The mobile device collected data continuously, and the total dust concentrations measured for each vehicle pass were extracted during post-processing. These concentrations were summed and are presented in Figure 43. The mobile data collection provided useable data but was difficult to extract and interpret based on data collection times, repeated passes and turn-arounds in buffer areas, and spurious dust concentration spikes. These spikes were attributed mainly to swirling dust from behind the test vehicle being “dragged” into the test item from turn-around areas.

Figure 43. Total mobile dust concentrations measured at 1 and 60 days during trafficking.

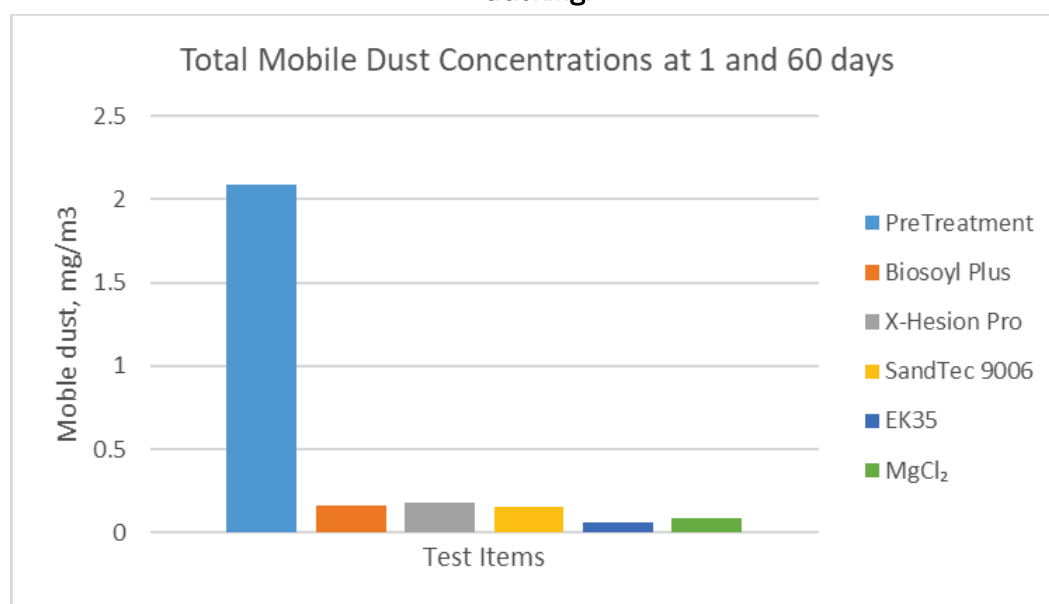


Figure 44. Attaching Mobile DustTrak™.



5.3.4 PI-SWERL

The PI-SWERL field setup (Figure 44) was similar to the laboratory setup (Chapter 3.6). Prior to testing, the Clean program (part of the PI-SWERL software) was run to ensure that the PI-SWERL was calibrated, and the H5000 setting was used for testing. Figure 45 shows the soil before and after application of the palliative prior to PI-SWERL testing. PI-SWERL tests occurred before and after application. The PI-SWERL was used in each test item at the following five stations: 100 ft, 150 ft, 250 ft, 350 ft, and 400 ft. Tests were run prior to application of palliatives and at 1 day, 30 days, 60 days, and 90 days after application (Figures 46-50).

Figure 45. PI-SWERL setup.



Figure 46. Example of pre-application (left) and post-application (right) of the palliative before the PI-SWERL test is applied.



Figure 47. PI-SWERL field data, products after one day, compared to pretest control.

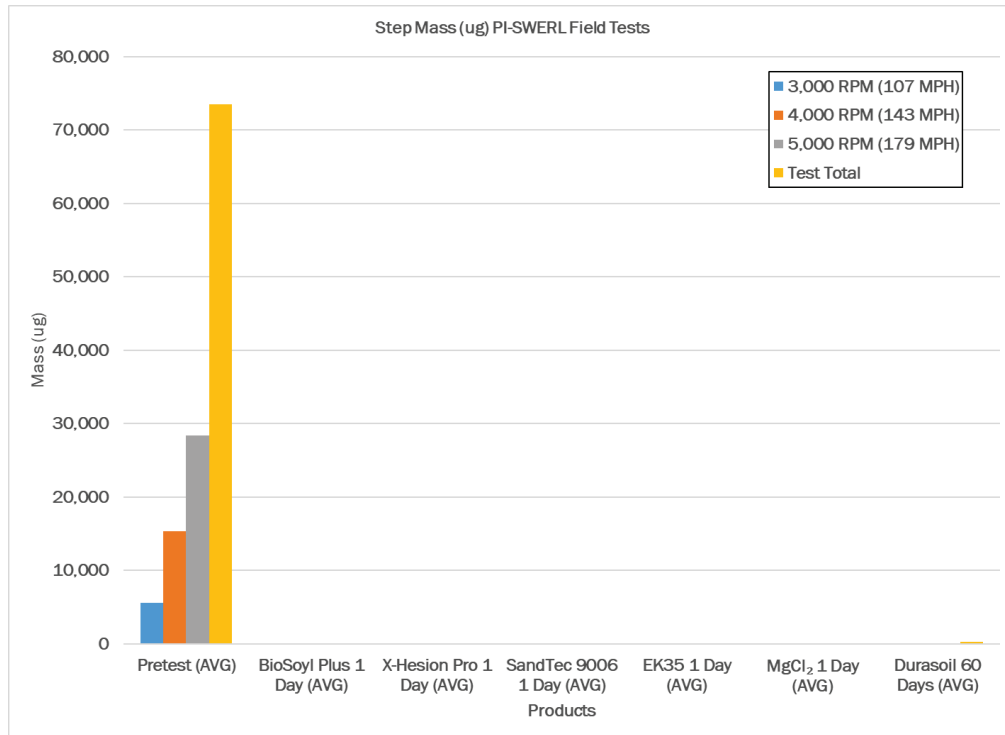


Figure 48. PI-SWERL field data, products after one day, compared to each other.

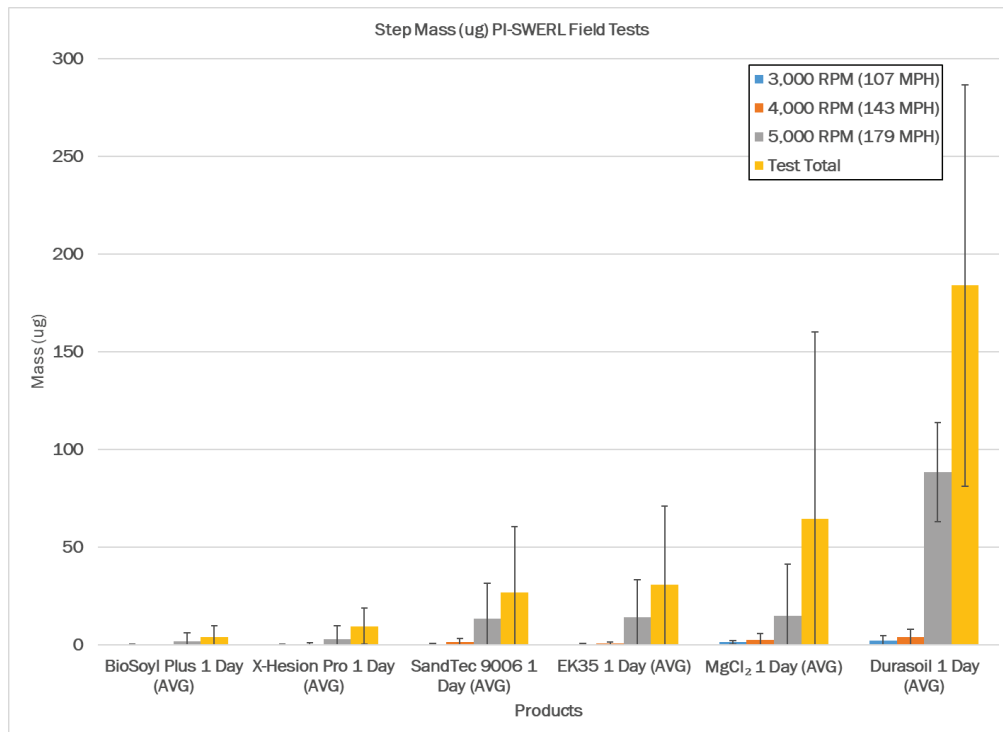


Figure 49. Thirty-day average mass of dust collected for the dust palliatives used in the field as a function of speed, as determined using the PI-SWERL.

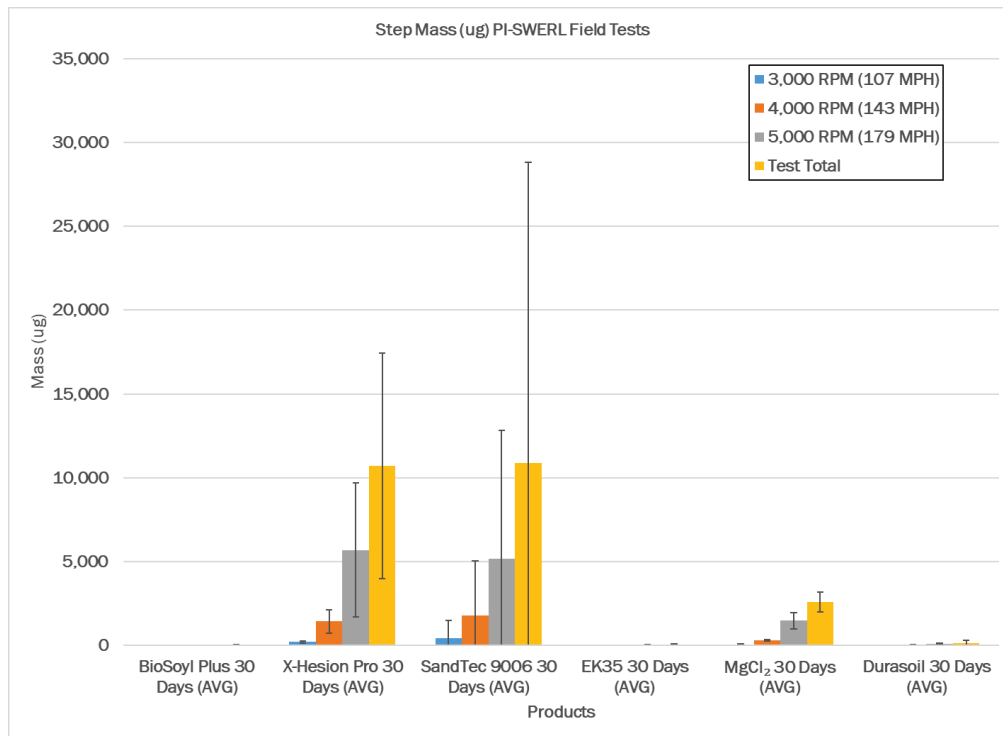


Figure 50. Sixty-day average mass of dust collected for the dust palliatives used in the field as a function of speed, as determined using the PI-SWERL.

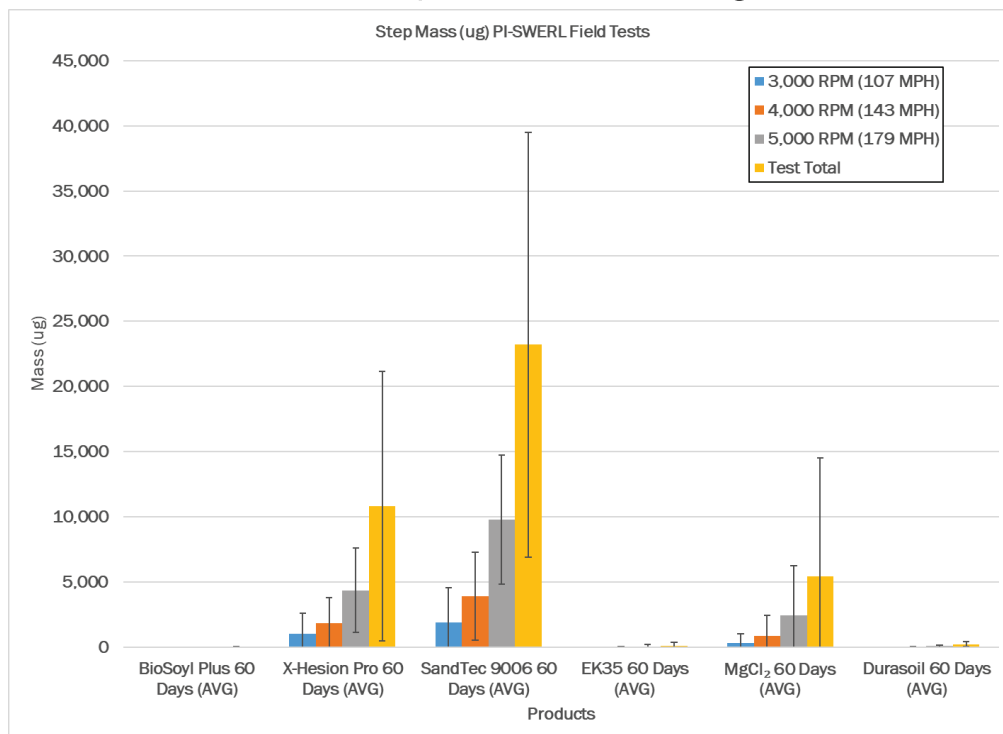
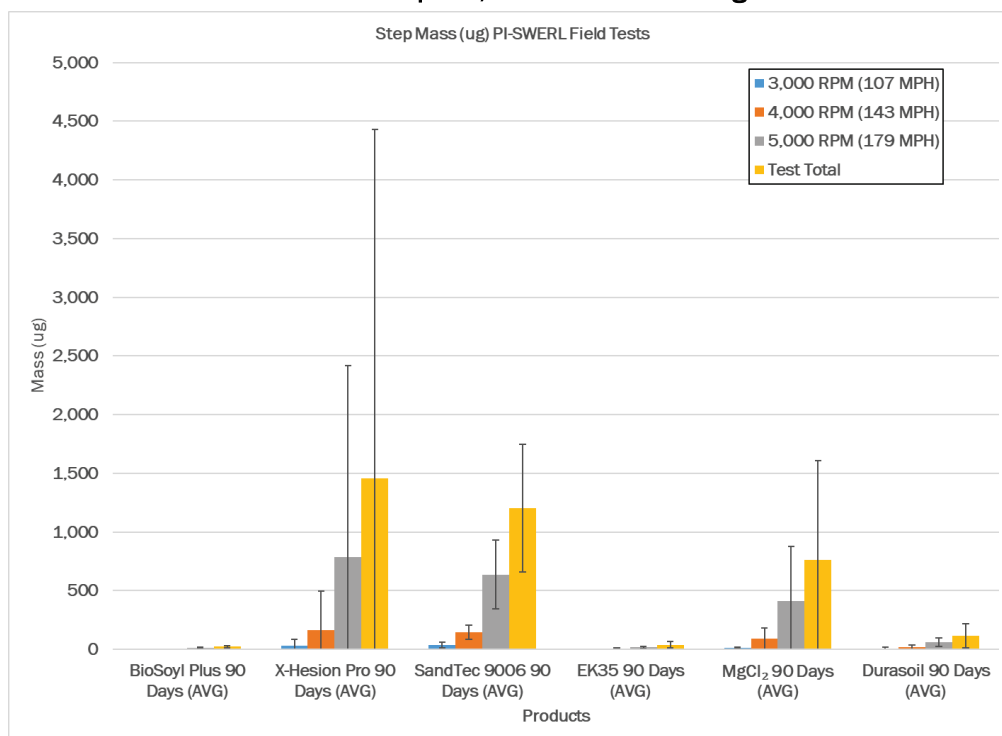


Figure 51. Ninety-day average mass of dust collected for the dust palliatives used in the field as a function of speed, as determined using the PI-SWERL.



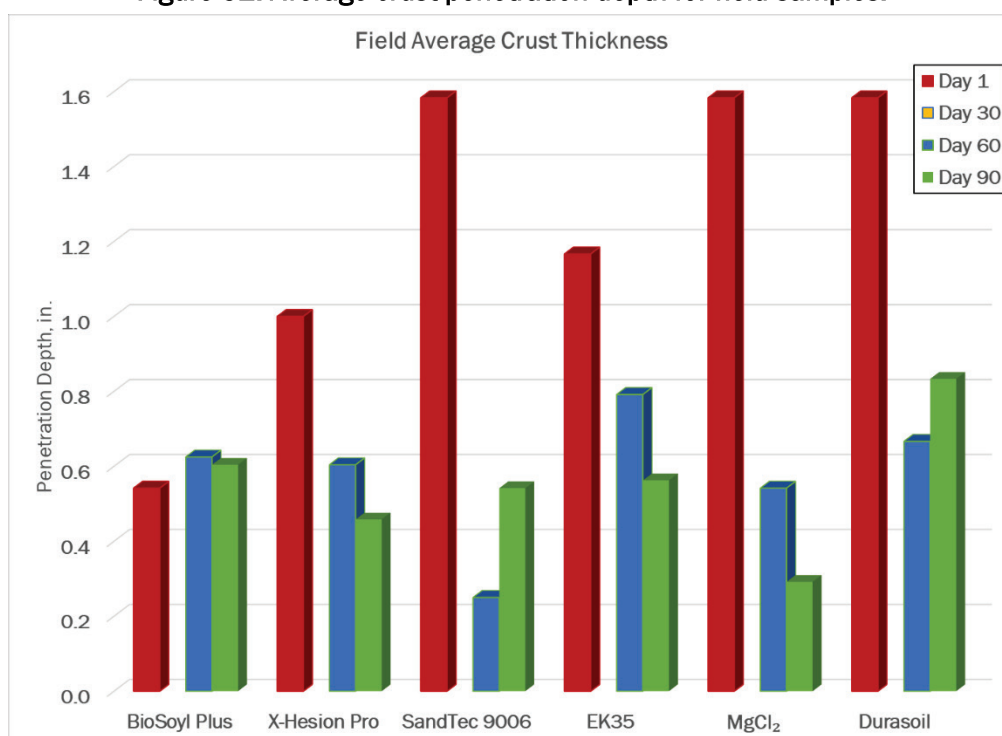
PI-SWERL data for dust measured in the field 1, 30, 60, and 90 days after application of the palliatives are shown in Figures 46-50. Figure 46 shows that the data for comparison of products after 1 day of application compared to the pretest indicate that all palliatives significantly reduced dust formation. Comparisons of the products to each other after 1, 30, 60, and 90 days of application are given in Figures 47-50, respectively. Each figure has error bars indicating the variability in the data. Although there are differences among the data, the authors note that in comparison to untreated soil, soil treated with any of the products produced significantly less fugitive dust.

5.3.5 Palliative penetration depth

Measurements were taken at five different locations on each test item to evaluate the penetration depth. A shovel was used to break through the surface crust, allowing the use of a ruler to measure the thickness of the top crust. The average depths of penetration for the field samples during 1, 60, and 90 days after application of each of the products are plotted in Figure 51. Penetration data at 30 days could not be measured due to excessive moisture in the treated soil. The range of penetration was from 0 (unmeasurable) to 1.6 in. In all cases, the depth of penetration decreased as a function of time from the initial reading due

to diffusion and rain. The 30-day measurements could not be obtained due to rainfall events. At 60 days, most samples showed decreased crust thickness from the initial measurements. At 90 days, most samples had decreased thicknesses of visually observable crust from the 60-day measurements. A few samples showed slight increase in thickness from the previous measurement. Researchers ascribe this observation to differences in amount of palliative application in a certain area or to measurement variability in different locations.

Figure 52. Average crust penetration depth for field samples.



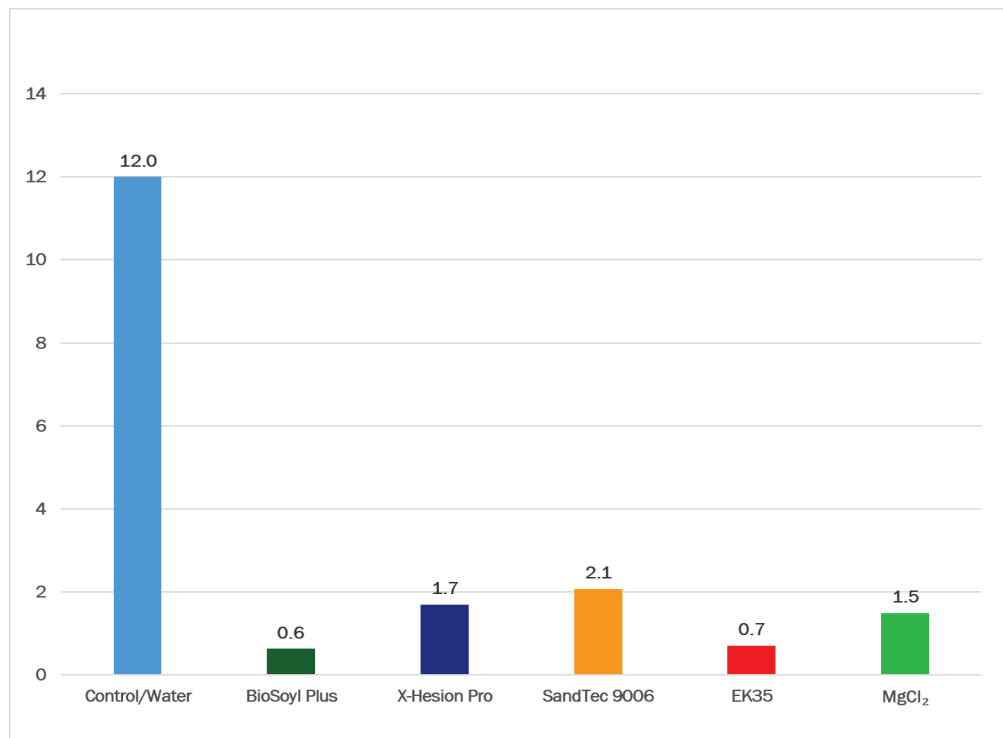
5.4 Analysis of laboratory and field testing

Figure 52 shows the normalized laboratory and field rankings. An objective ranking system was devised based on quantitative measurements with each parameter equally weighted. Each parameter was normalized by dividing the value by the water control (laboratory testing) and pretest control value (field) to yield a normalized control value of 1. The 12 parameters listed below were used to create the rankings, yielding a value for the control of 12.

- Two from air impingement testing: mass loss and maximum dust concentration.
- One from PI-SWERL lab data at 1 day after application.

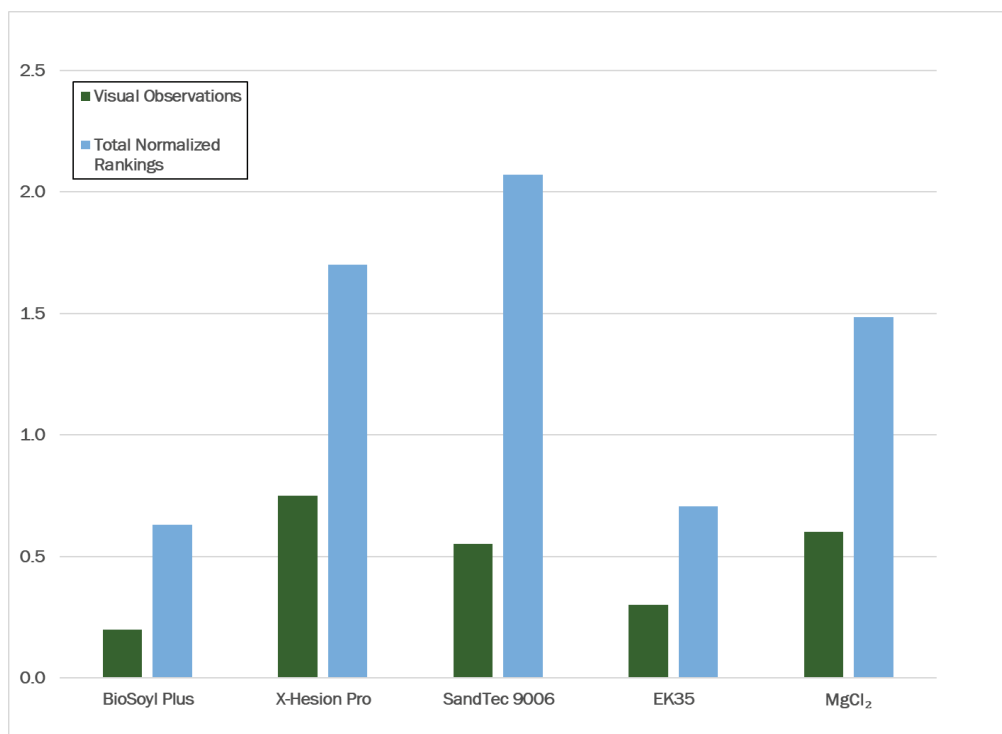
- Four from PI-SWERL field data at 1, 30, 60, and 90 days.
- Four from field traffic tests (DustTrak™ concentrations.). Stationary collections at 1 and 60 days, mobile testing at 1 and 60 days.
- Visual observations: human-observed dust severity from 0-5 (no dust to highest dust, respectively) at 60 days. On 1, 30, and 90 days, very low amounts of dust were measured because of rain.

Figure 53. Normalized laboratory and field rankings of the palliatives.



In Figure 52, the highest-performing dust palliative is BioSoyl Plus with EK35 slightly higher. X-Hesion Pro™, SandTec 9006, and magnesium chloride exhibited higher values, but this does not necessarily translate to lower performance compared to BioSoyl Plus and EK35, as these measurements are based on local conditions that vary widely. Although this ranking system is objective, it correlated well with subjective human observations in Figure 53.

Figure 54. Ranking system of the palliatives compared to the field observations of measured dust.



6 Field Conclusions and Recommendations

6.1 Conclusions

- Fourteen different dust palliatives (and water) were evaluated in the laboratory as a way to select the products to be used in the field. All five products used in these field investigations performed well as dust suppressants in the laboratory. The performance of the dust palliatives in the field in order of best performance was BioSoyl Plus followed by EK35, magnesium chloride, X-Hesion Pro™, and SandTec 9006. Of the five tested in the field only SandTec 9006, and X-Hesion Pro™ were USDA BioPreferred® products.
- BioSoyl Plus exhibited equal or better laboratory and field performance compared to synthetic products, demonstrating the capabilities of bio-based products.
- Magnesium chloride was the most corrosive (as expected) followed by Soykill on both aluminum alloys (2024-T3 and 7075-T6).
- The greatest observable change in mass for the magnesium (ZE41A) coupons was for those exposed to Soykill. Although the team cannot confirm that a change in mass indicates a higher rate of corrosion, it does indicate that a chemical reaction occurred with the metal.
- The greatest change in mass for each of the dust palliatives on steel (4340) coupons was for the samples exposed to MgCl₂.
- Inclusion of the PI-SWERL device in the testing regimen provided a significant improvement for comparison of laboratory and field measurements for air- or saltation-induced dust generation.
- Mobile testing using a towed DustTrak™ collection system was successful in providing reliable data but was problematic in interpretation because of the way the data were collected.
- The visual observations of the field team paralleled the data from all measurements, including the PI-SWERL and DustTrak™.
- Penetration measurements were obtained to delineate the effect of the palliative on the surface of both the laboratory and field samples.

6.2 Recommendations

- Suggested changes to UFC 3-260-17 (USACE 2018) include the addition of USDA BioPreferred® and certified bio-based products to the vendor list and obtaining NSNs for high-performing bio-based products identified in this report.

- Military users may benefit from a selection guide that provides the user with performance data on the variety of products available.
- Further development of the laboratory/field link between the PI-SWRL and field observations is needed to allow better discernment of performance.
- Visual observations from multiple people with a ranking system provided to quantify their observations should be included.
- Corrosion testing should be performed only on initial and 120 days. A chemical bath at the end for better testing should be included.
- For mobile testing using the DustTrak™ system, a test protocol to provide improved collection and reliability of data should be developed. Ideally, a Real Time Kinematic -Global Positioning System (RTK-GPS) that records real time location (within 2 m) and time integrated with the DustTrak™ system is needed. In the event the feature is unavailable for mobile testing, the starting, midpoint, and ending times for each pass should be recorded. In an effort to reduce measurement of dust from both the test and the buffer areas, each pass should be completed individually. A longer buffer could be used to reduce the risk of including data not from the intended test items.

References

- American Society for Testing and Materials (ASTM). 2017. *Standard practice for classification of soils for engineering purposes (Unified Soil Classification System)*. Designation D2487-17e. West Conshohocken, PA: ASTM International.
- Barnes, D. L., and B. Connor. 2017. *Palliatives on unpaved roads center for environmentally sustainable transportation in cold climates*. Final report: 06/2014 – 7/2017. Fairbanks, AK: University of Alaska Fairbanks, Center for Environmentally Sustainable Transportation in Cold Climates. <https://doi.org/10.13140/RG.2.2.32899.81448>.
- Billman, B. J., and S. P. S. Arya. 1988. Windbreak effectiveness for storage pile fugitive dust control: A wind tunnel study. *Journal of Air Pollution Control Association* 38(2):135-43. <https://doi.org/10.1080/08940630.1988.10466360>.
- Bolander, P., and A. Yamada. 1999. *Dust palliative selection and application guide*. USDA Forest Service Technology & Development Program, 9977 1207—SDTDC. San Dimas, CA: San Dimas Technology and Development Center.
- Chen, R., I. Lee, and L. Zhang. 2015. Biopolymer stabilization of mine tailings for dust control. *Journal of Geotechnical and Geoenvironmental Engineering* 141(2). [https://doi.org/10.1061/\(ASCE\)GT.1943-5606.0001240](https://doi.org/10.1061/(ASCE)GT.1943-5606.0001240).
- Dust-Quant. 2011. User's guide for the miniature Portable In-Situ Wind Erosion Lab (PI-SWRL). Vicksburg, MS: U.S. Army Engineer Research and Development Center.
- Eckhoff, T. W. 2012. Evaluating dust palliative performance and longevity using the UAF-DUSTM. MS thesis, University of Alaska Fairbanks.
- Edwards, L., J. S. Tingle, and Q. Mason. 2010. *Laboratory and field evaluation of dust abatement products for expedient helipads*. ERDC/GSL TR-10-38. Vicksburg, MS: U.S. Army Engineer Research and Development Center.
- Etyemezian, V., G. Nikolich, S. Ahonen, M. Pitchford, M. Sweeney, R. Purcell, J. A. Gillies, and H. Kuhns. 2007. The Portable *In Situ* Wind Erosion Laboratory (PI-SWRL): A new method to measure PM₁₀ windblown dust properties and potential for emissions. *Atmospheric Environment* 41:3789-3796. <https://doi.org/10.1016/j.atmosenv.2007.01.018>.
- Gebhart, D. L. 2013. *Environmental considerations for selecting cost-effective dust control technologies*. Public Works Technical Bulletin 200-1-133. Washington, DC: U. S. Army Corps of Engineers.
- Gebhart, D. L., M. L. Denight, and R. H. Grau. 1999. *Dust control guidance and technology selection key*. USACERL Report 99/21. Champaign IL: U. S. Army Construction Engineering Research Lab.
- Graber, E. R., P. Fine, and G. J. Levy. 2006. Soil stabilization in semiarid and arid land agriculture. *Journal of Materials in Civil Engineering* 18(2):190-205. [https://doi.org/10.1061/\(ASCE\)0899-1561\(2006\)18:2\(190\)](https://doi.org/10.1061/(ASCE)0899-1561(2006)18:2(190)).

- Jones, D. 2017. *Guidelines for the selection, specification and application of chemical dust control and stabilization treatments on unpaved roads*. Report No. UCPRC-GL-2017-03. Davis, CA: University of California Pavement Research Center.
- Kolias, S., V. Kasselouri-Rigopoulou, and A. Karahalios. 2005. Stabilisation of clayey soils with high calcium fly ash and cement. *Cement and Concrete Composites* 27(2):301-13. <https://doi.org/10.1016/j.cemconcomp.2004.02.019>.
- Kunz, B. K., N. S. Green, J. L. Albers, M. L. Wildhaber, and E. E. Little. 2018. Use of real-time dust monitoring and surface condition to evaluate success of unpaved road treatments. *Transportation Research Board* 2672(52):195-204. <https://doi.org/10.1177/0361198118799167>.
- Lekha, B. M., A. U. Ravi Shankar, and G. Sarang. 2013. Fatigue and engineering properties of chemically stabilized soil for pavements. *Indian Geotechnical Journal* 43(1):96-104. <https://doi.org/10.1007/s40098-012-0031-5>.
- Liu, J., B. Shi, H. Jiang, H. Huang, G. Wang, and T. Kamai. 2011. Research on the stabilization treatment of clay slope topsoil by organic polymer soil stabilizer. *Engineering Geology* 117(1-2):114-20. <https://doi.org/10.1016/j.enggeo.2010.10.011>.
- Newman, J. K., and J. F. Rushing. 2009. Full-scale testing of chemical dust palliatives in a semi-controlled environment. *Journal of Materials in Civil Engineering* 21(9):454-459.
- . 2010. Investigation of laboratory procedure for evaluating chemical dust palliative performance. *Journal of Materials in Civil Engineering* 22(11):1148-1155. [http://dx.doi.org/10.1061/\(ASCE\)MT.1943-5533.0000122](http://dx.doi.org/10.1061/(ASCE)MT.1943-5533.0000122).
- Oldham, J. C., R. C. Eaves, and D. W. White. 1977. *Materials evaluated as potential soil stabilizers*. Misc. Paper S-77-15. Vicksburg, MS: U. S. Army Engineers Waterways Experiment Station.
- Orts, W. J., A. Roa-Espinosa, R. E. Sojka, G. M. Glenn, S. H. Imam, K. Erlacher, and J. S. Pedersen. 2007. Use of synthetic polymers and biopolymers for soil stabilization in agricultural, construction, and military applications. *Journal of Materials in Civil Engineering* 19:58-66. [https://doi.org/10.1061/\(ASCE\)0899-1561\(2007\)19:1\(58\)](https://doi.org/10.1061/(ASCE)0899-1561(2007)19:1(58)).
- Qian, F., D. B. Lee, G. Nikolich, D. E. Koditschek, and D. J. Jerolmack. 2019. Rapid in situ characterization of soil erodibility with a field deployable robot. *Journal of Geophysical Research: Earth Surface* 124:1261-1280. <https://doi.org/10.1029/2018JF004887>.
- Rushing, J. F., J. A. Harrison, and J. S. Tingle. 2005. *Evaluation of application methods and products for mitigating dust for lines-of-communication and base camp operations*. ERDC/GSL TR-05-09. Vicksburg, MS: U.S. Army Engineer Research and Development Center.

- Rushing, J. F., and J. S. Tingle. 2006. *Dust control field handbook: standard practices for mitigating dust on helipads, lines of communication, airfields, and base camps - SR 06-07*. Special Report 06-7. Vicksburg, MS: U. S. Army Engineer Research and Development Center.
- Rushing, J. F., V. M. Moore, and J. S. Tingle. 2006. *Evaluation of chemical dust palliatives for helipads*. ERDC/GSL TR-06-2. Vicksburg, MS: U.S. Army Engineer Research and Development Center.
- Tingle, J. S., A. Harrison, and J. F. Rushing. 2004. *Evaluation of expedient methods for mitigating dust on helipads*. ERDC/GSL TR-04-10. Vicksburg, MS: U. S. Army Engineer Research and Development Center.
- U.S. Army Corps of Engineers. (USACE). 2018. *O&M manual: standard practice for dust control on roads, airfields, base camps, and adjacent areas*. United Facilities Criteria 3-260-17. Washington, DC: USACE, Naval Facilities Engineering Command (NAVFAC), and U. S. Air Force Civil Engineer Center (AFCEC).

Appendix: Images

Figure A1. Test specimens treated with water at application rates of (a) 0.4 gsy, (b) 0.8 gsy, and (c) 1.2 gsy.

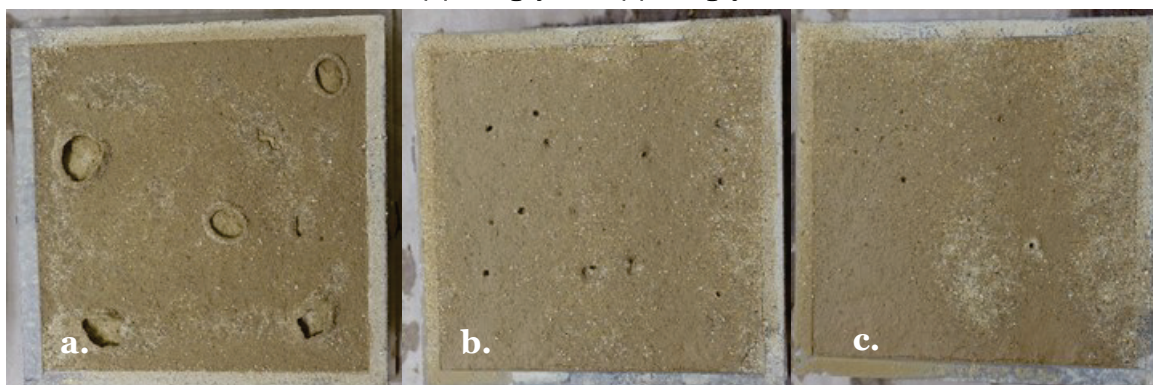


Figure A2. Test specimens treated with water, after air impingement testing, at application rates of (a) 0.4 gsy, (b) 0.8 gsy, and (c) 1.2 gsy.



Figure A3. Test specimens treated with Soiltac at application rates of (a) 0.4 gsy, (b) 0.8 gsy, and (c) 1.2 gsy.

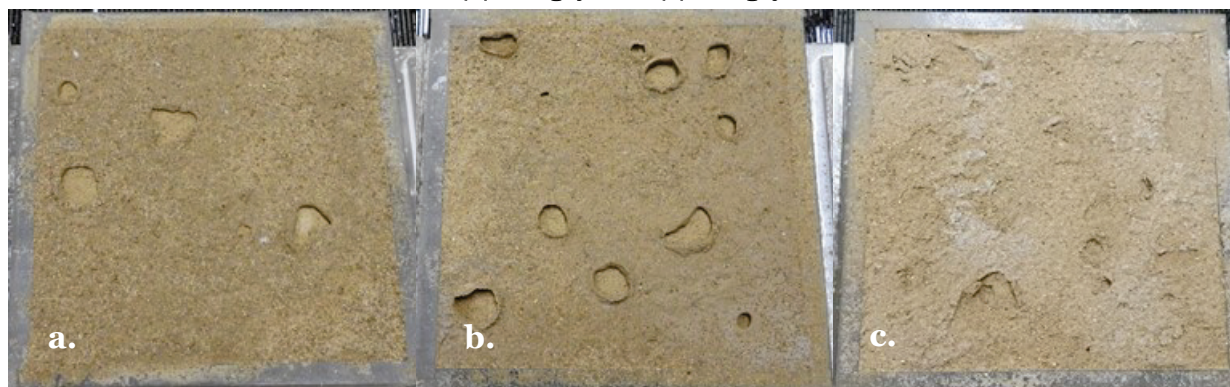


Figure A4. Test specimens treated with Soiltac, after air impingement testing, at application rates of (a) 0.4 gsy, (b) 0.8 gsy, and (c) 1.2 gsy.



Figure A5. Test specimens treated with Durasoil at application rates of (a) 0.4 gsy, (b) 0.8 gsy, and (c) 1.2 gsy.

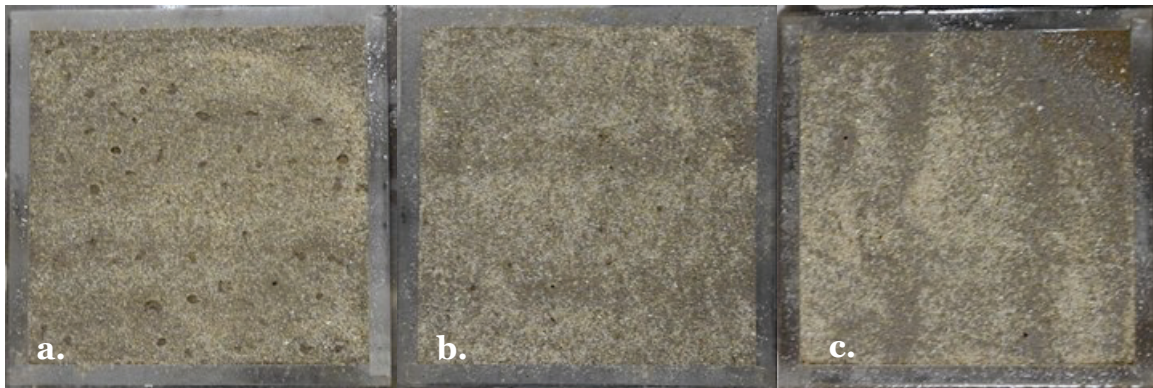


Figure A6. Test specimens treated with Durasoil, after air impingement testing, at application rates of (a) 0.4 gsy, (b) 0.8 gsy, and (c) 1.2 gsy.

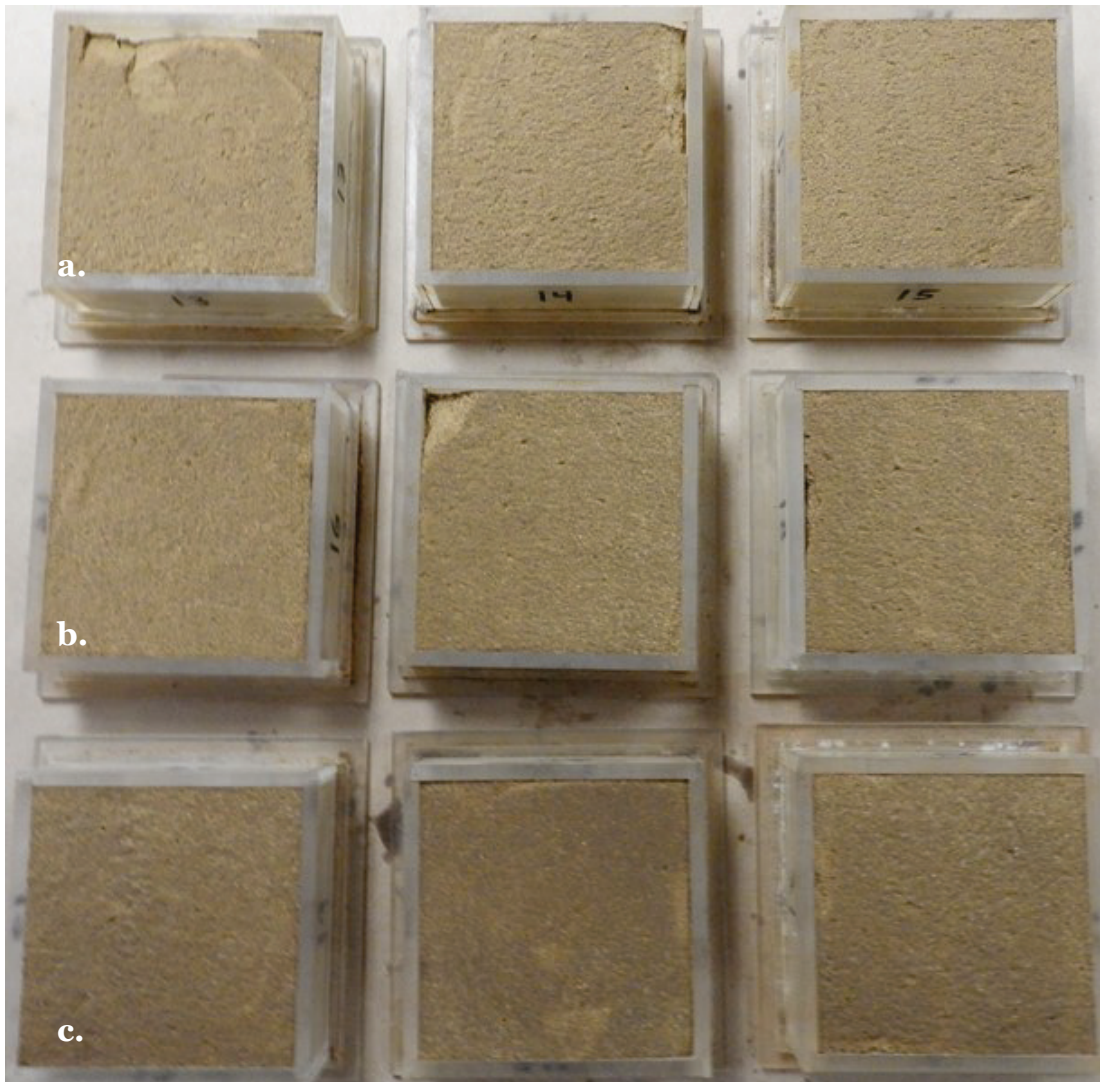


Figure A7. Test specimens treated with EK35 at application rates of (a) 0.4 gsy, (b) 0.8 gsy, and (c) 1.2 gsy.

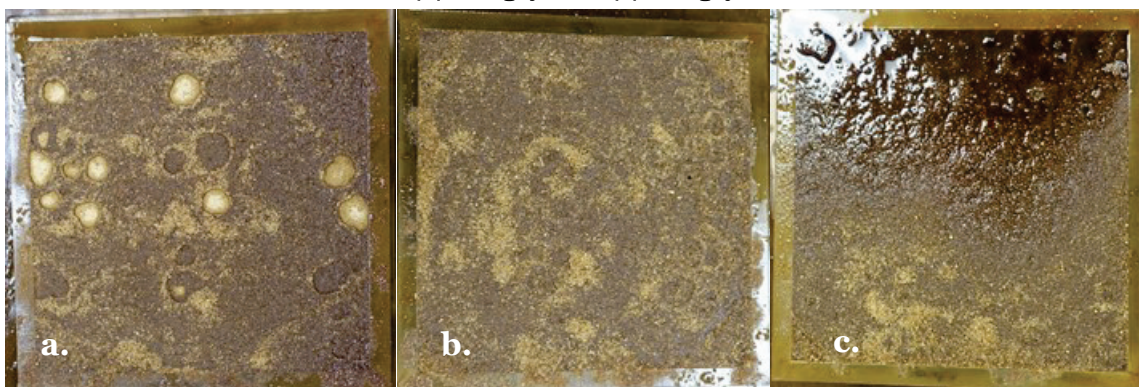


Figure A8. Test specimens treated with EK35, after air impingement testing, at application rates of (a) 0.4 gsy, (b) 0.8 gsy, and (c) 1.2 gsy.

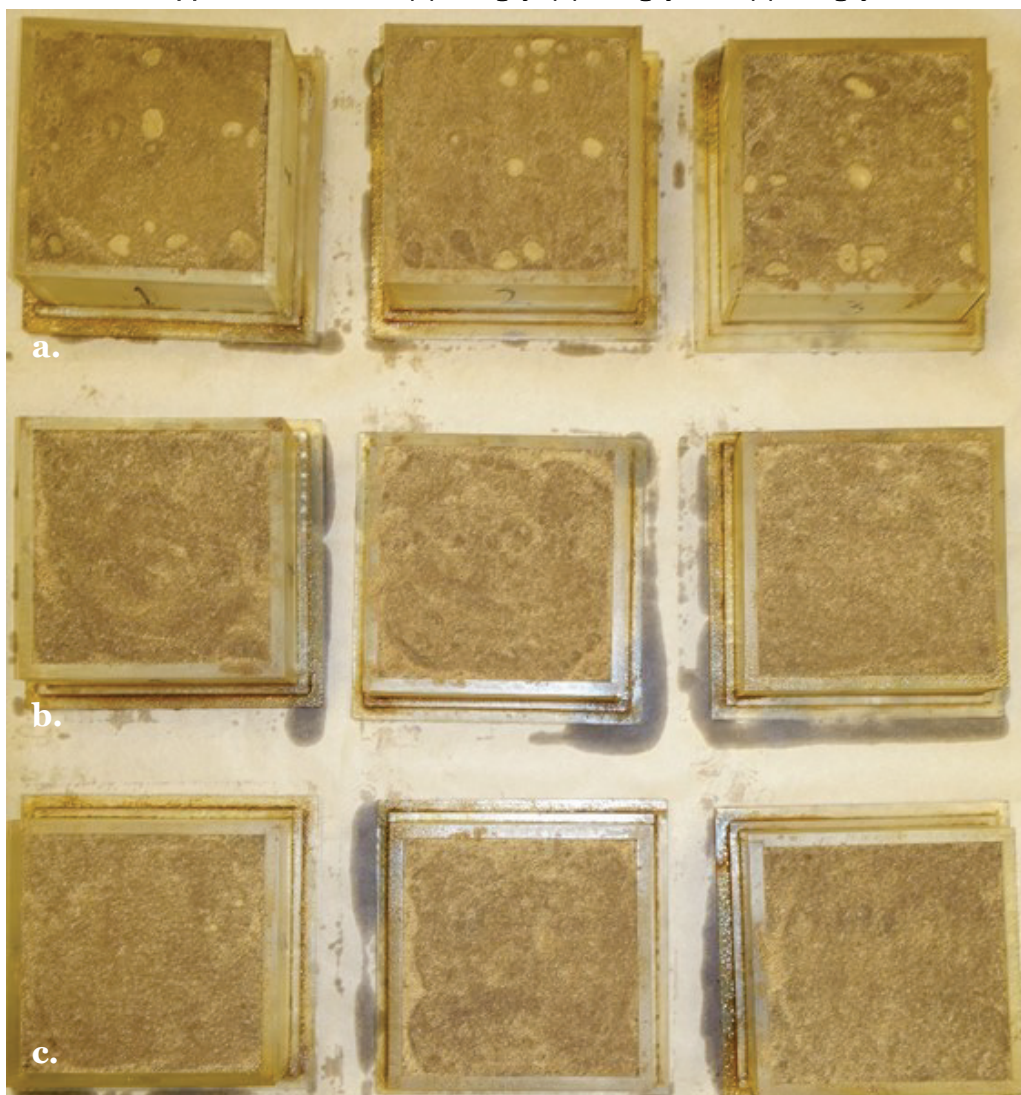


Figure A9. Test specimens treated with EK2800 at application rates of (a) 0.4 gsy, (b) 0.8 gsy, and (c) 1.2 gsy.

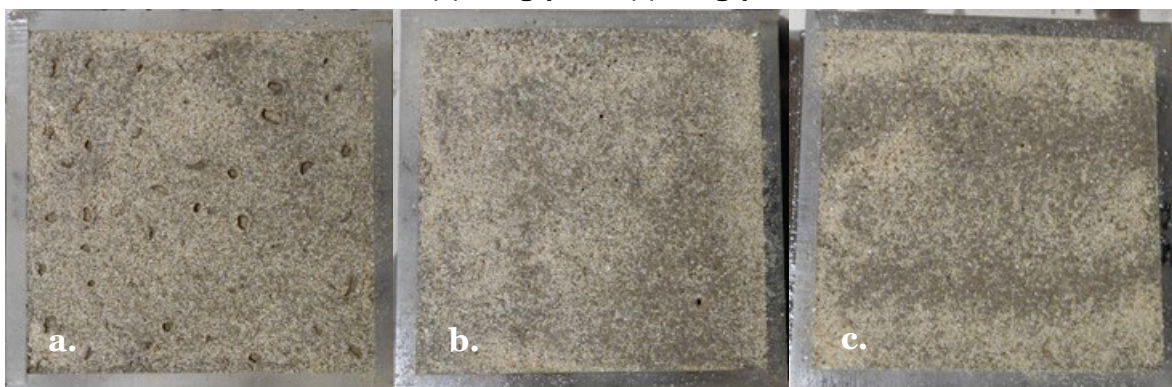


Figure A10. Test specimens treated with EK2800, after air impingement testing, at application rates of (a) 0.4 gsy, (b) 0.8 gsy, and (c) 1.2 gsy.

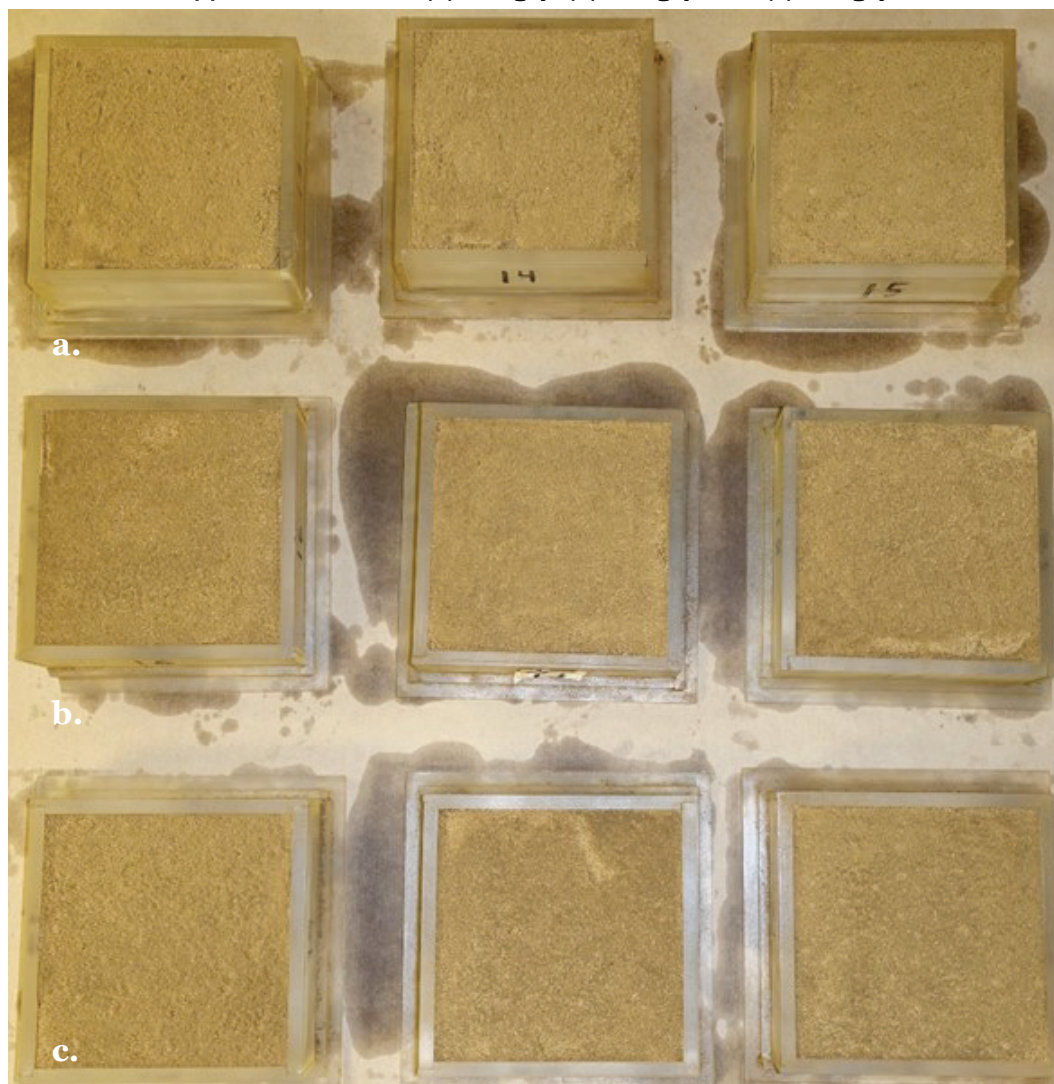


Figure A11. Test specimens treated with DustPly Plus C at application rates of (a) 0.4 gsy, (b) 0.8 gsy, and (c) 1.2 gsy.

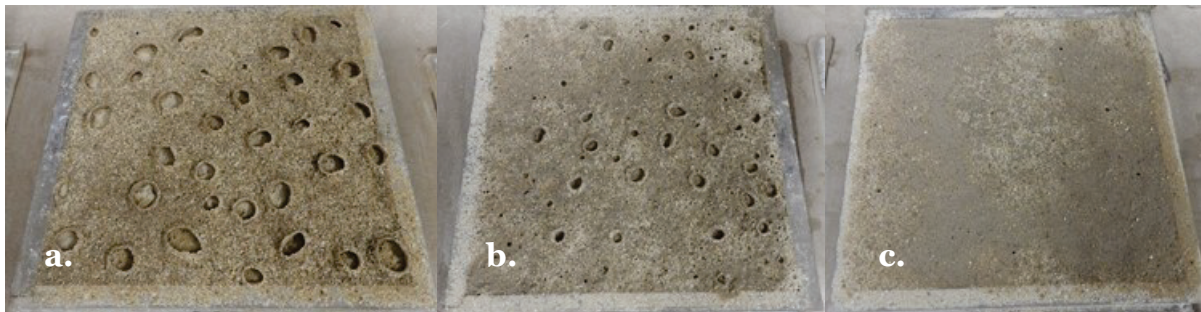


Figure A12. Test specimens treated with DustPly Plus C, after air impingement testing, at application rates of (a) 0.4 gsy, (b) 0.8 gsy, and (c) 1.2 gsy.



Figure A13. Test specimens treated with Knockout at application rates of (a) 0.4 gsy, (b) 0.8 gsy, and (c) 1.2 gsy.

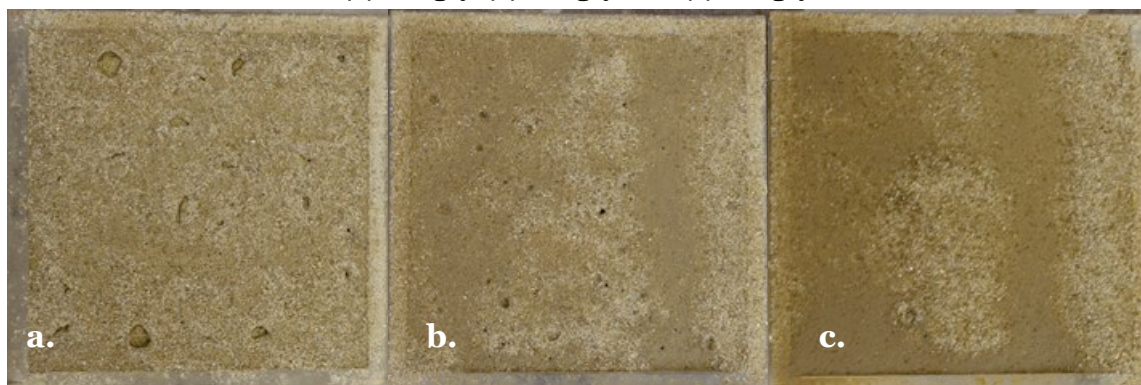


Figure A14. Test specimens treated with Knockout, after air impingement testing, at application rates of (a) 0.4 gsy, (b) 0.8 gsy, and (c) 1.2 gsy.

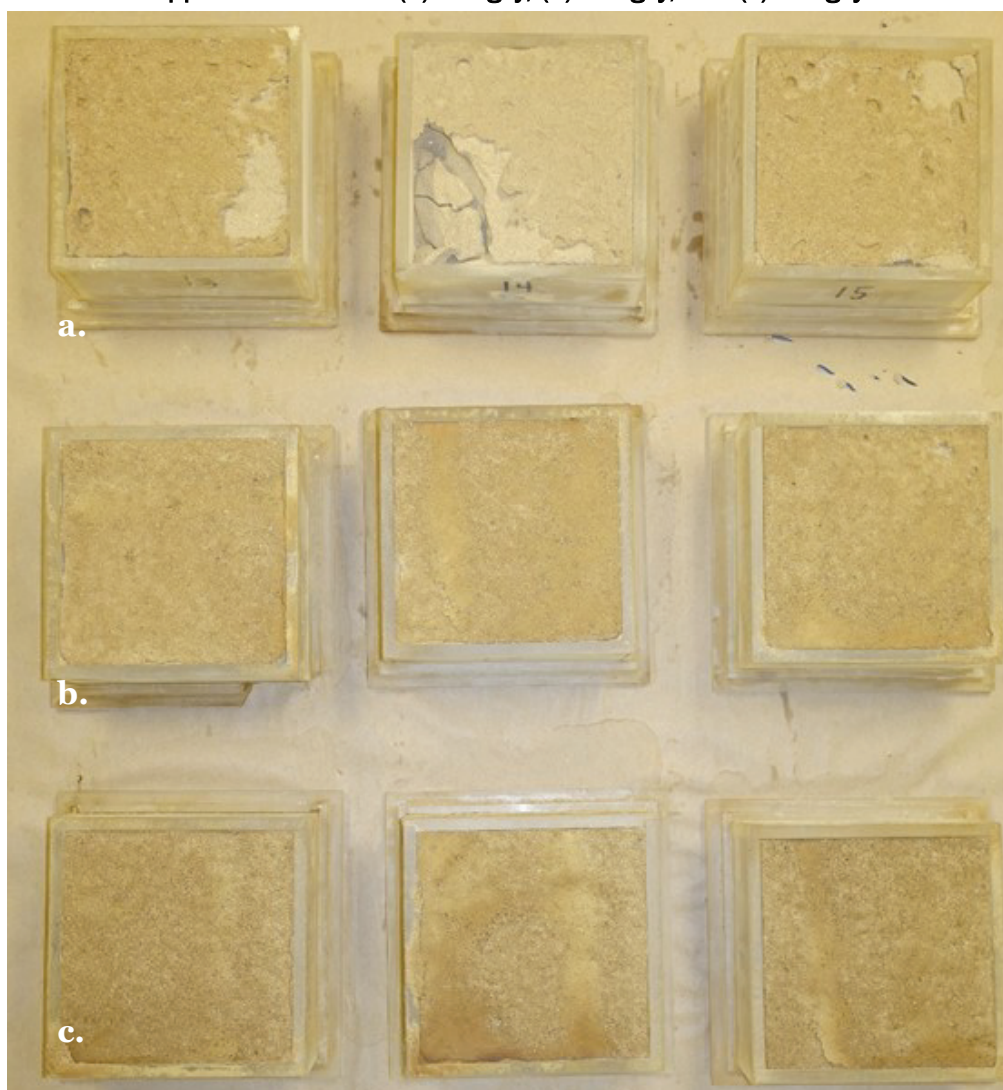


Figure A15. Test specimens treated with Triple Tac at application rates of (a) 0.4 gsy, (b) 0.8 gsy, and (c) 1.2 gsy.

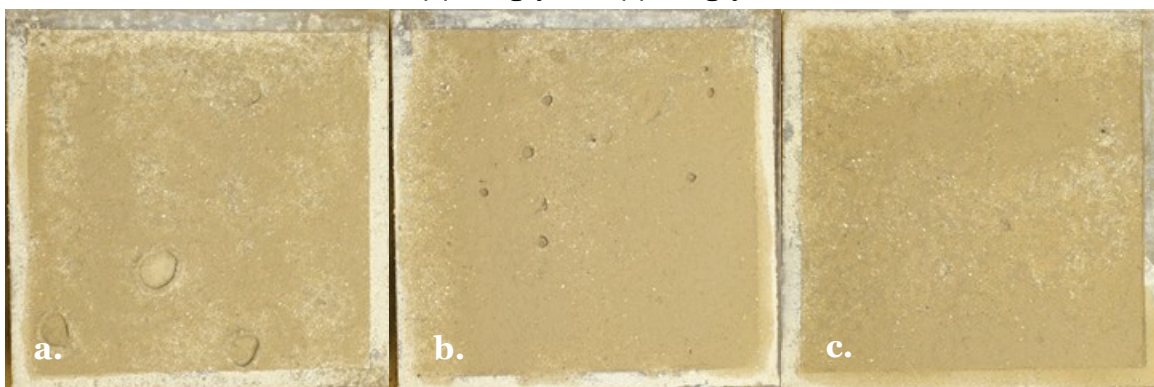


Figure A16. Test specimens treated with Triple Tac, after air impingement testing, at application rates of (a) 0.4 gsy, (b) 0.8 gsy, and (c) 1.2 gsy.



Figure A17. Test specimens treated with GRT 9000 at application rates of (a) 0.4 gsy, (b) 0.8 gsy, and (c) 1.2 gsy.

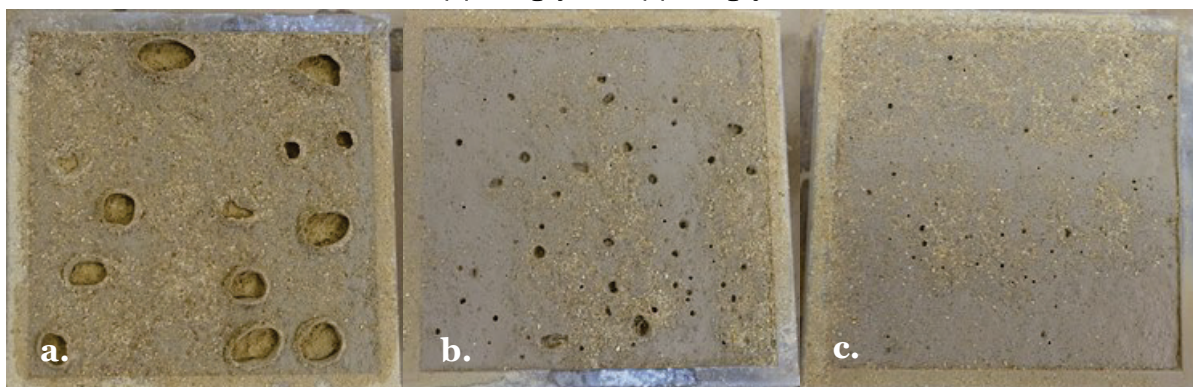


Figure A18. Test specimens treated with GRT 9000, after air impingement testing, at application rates of (a) 0.4 gsy, (b) 0.8 gsy, and (c) 1.2 gsy.



Figure A19. Test specimens treated with MgCl_2 at application rates of (a) 0.4 gsy, (b) 0.8 gsy, and (c) 1.2 gsy.

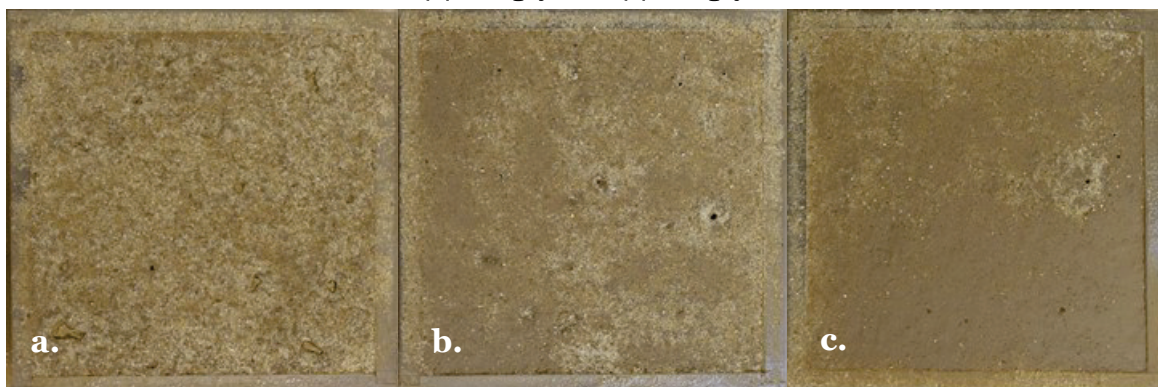


Figure A20. Test specimens treated with MgCl_2 , after air impingement testing, at application rates of (a) 0.4 gsy, (b) 0.8 gsy, and (c) 1.2 gsy.

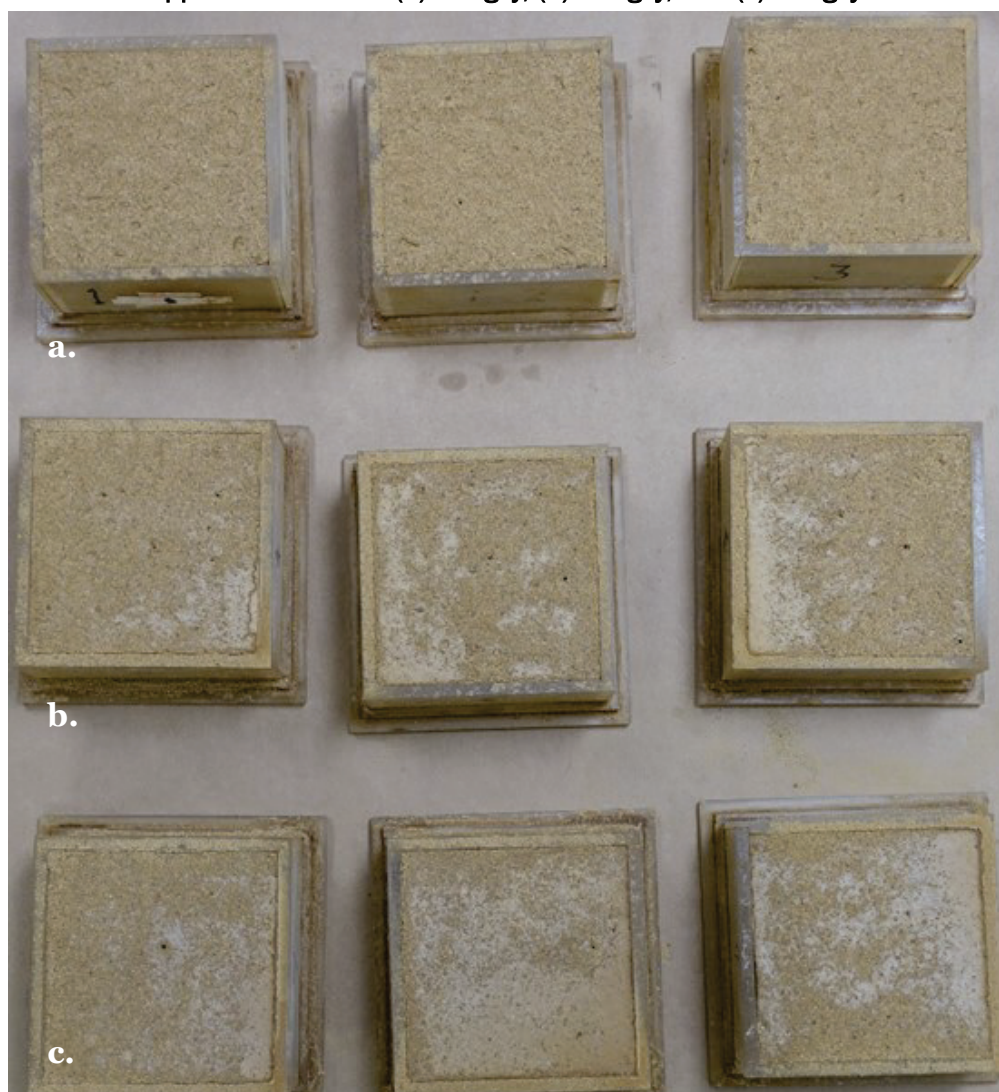


Figure A21. Test specimens treated with X-Hesion Pro at application rates of (a) 0.4 gsy, (b) 0.8 gsy, and (c) 1.2 gsy.

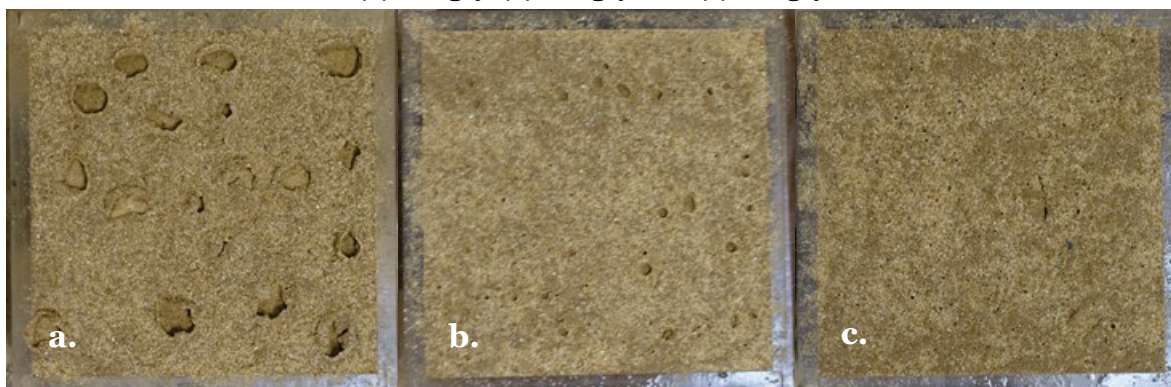


Figure A22. Test specimens treated with X-Hesion Pro, after air impingement testing, at application rates of (a) 0.4 gsy, (b) 0.8 gsy, and (c) 1.2 gsy.



Figure A23. Test specimens treated with SandTec 9006 at application rates of (a) 0.4 gsy, (b) 0.8 gsy, and (c) 1.2 gsy.

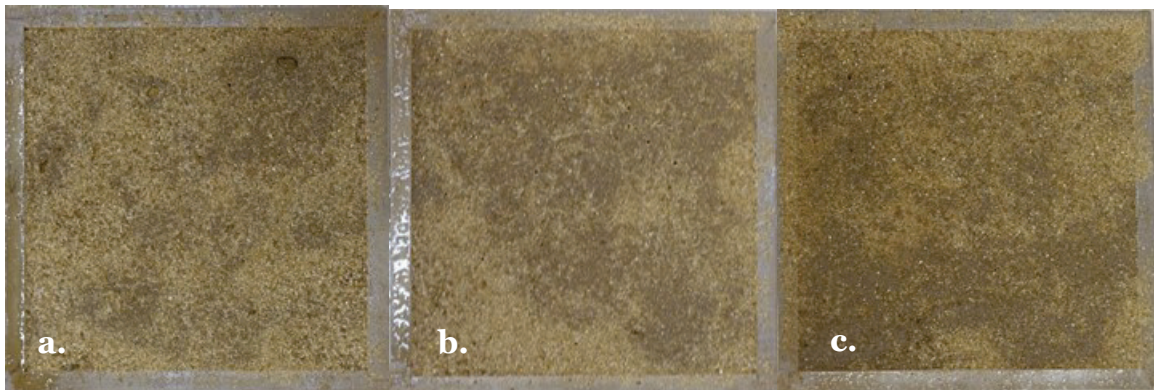


Figure A24. Test specimens treated with SandTec 9006, after air impingement testing, at application rates of (a) 0.4 gsy, (b) 0.8 gsy, and (c) 1.2 gsy.

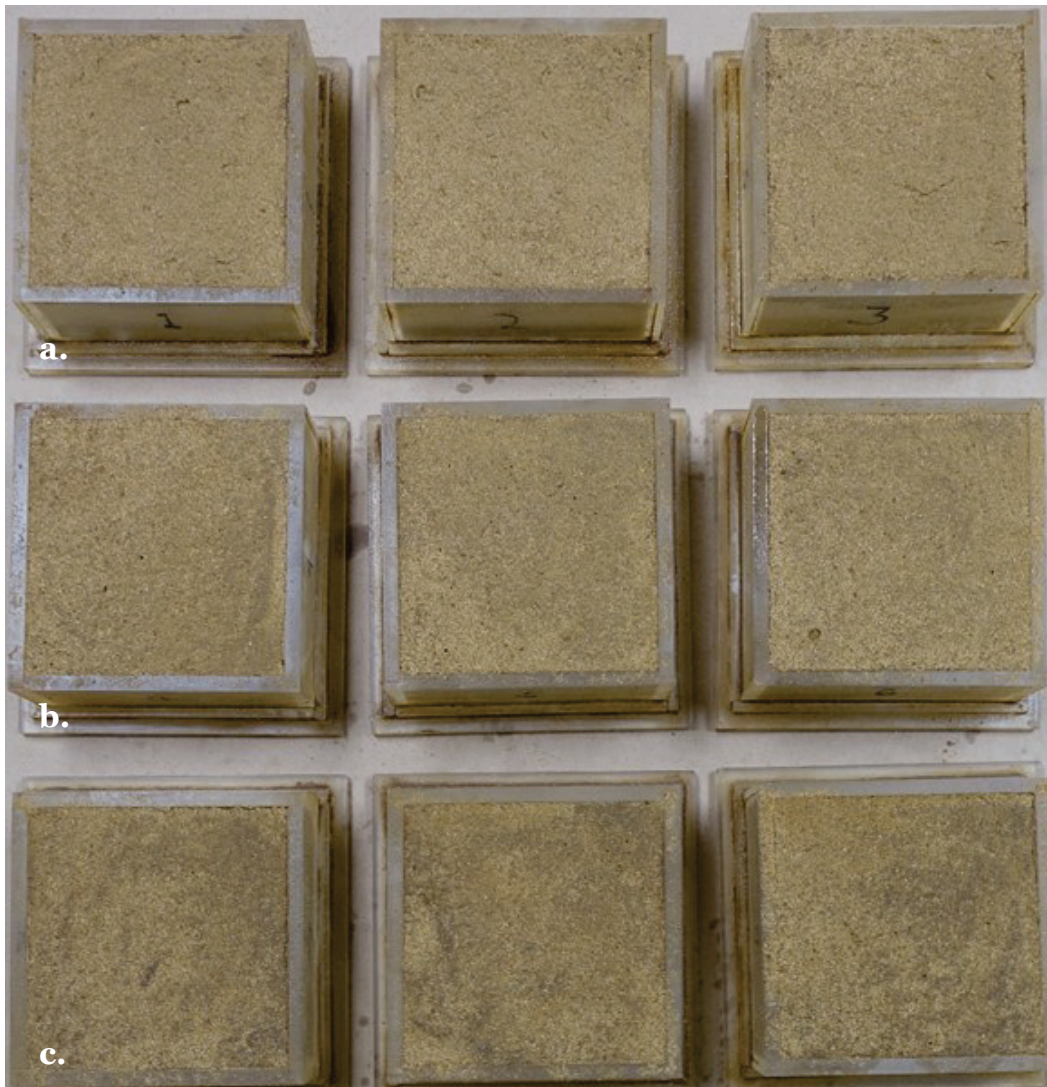


Figure A25. Metal coupons after 30 days in untreated soil: (left) fronts and (right) backs. Metals are (a) magnesium, (b) aluminum T3, (c) aluminum T6, and (d) steel.

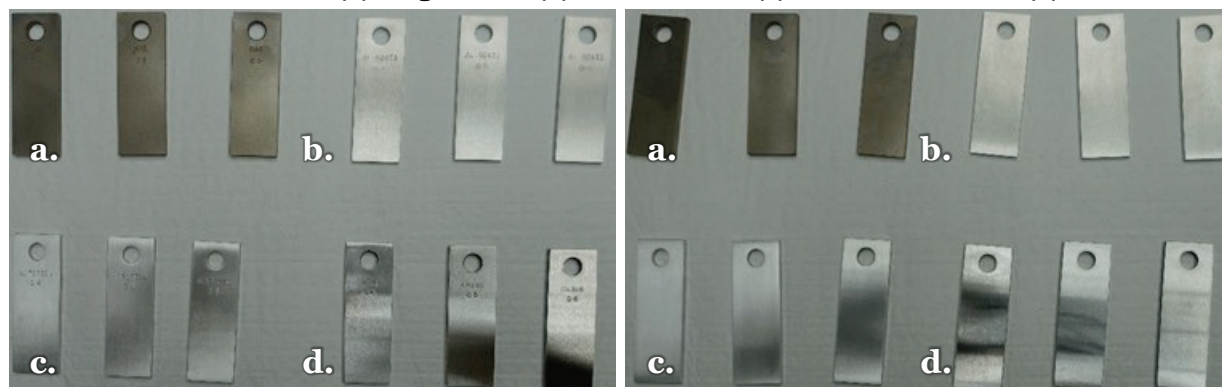


Figure A26. Metal coupons after 90 days in untreated soil: (left) fronts and (right) backs. Metals are (a) magnesium, (b) aluminum T3, (c) aluminum T6, and (d) steel.

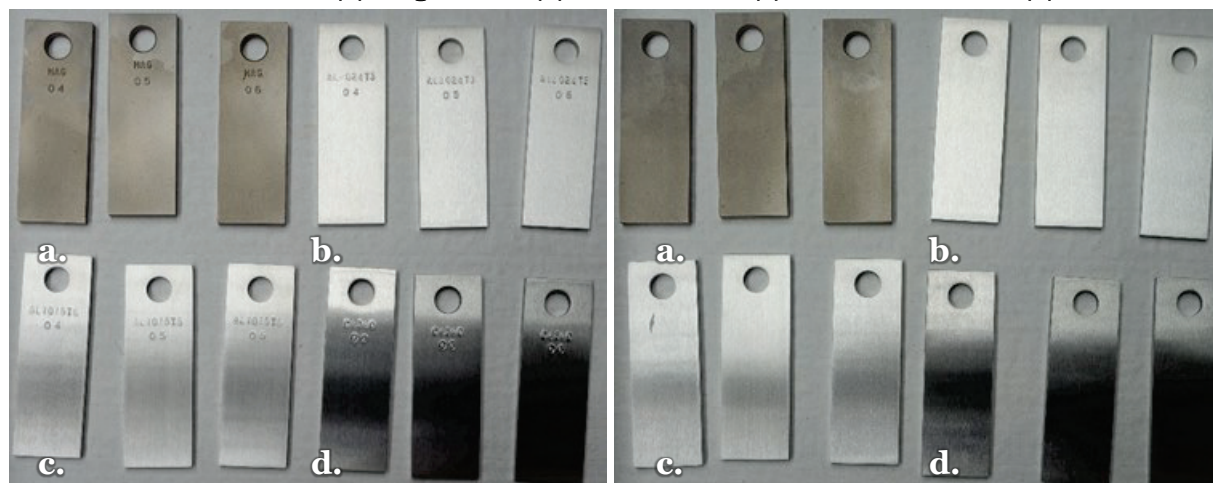


Figure A27. Metal coupons after 120 days in untreated soil: (left) fronts and (right) backs. Metals are (a) magnesium, (b) aluminum T3, (c) aluminum T6, and (d) steel.

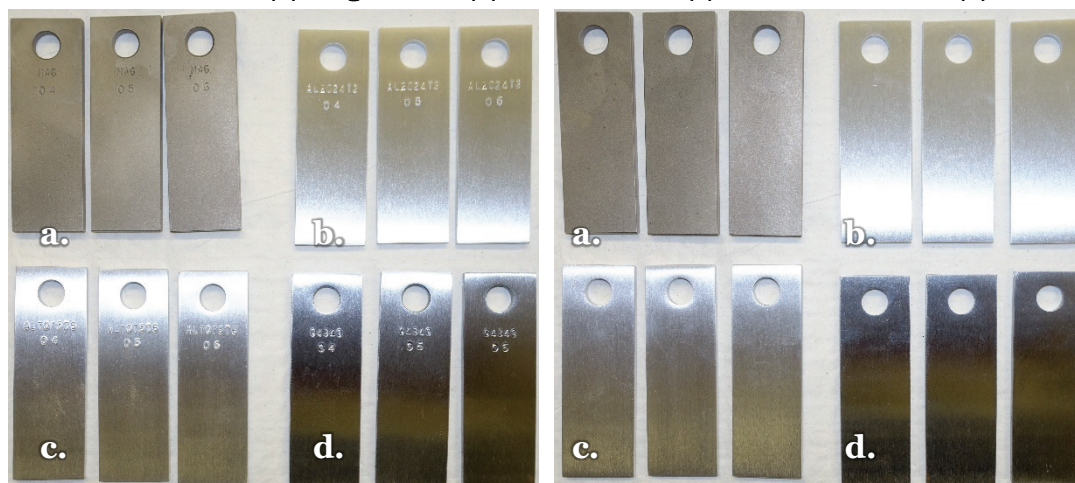


Figure A28. Metal coupons after 360 days in untreated soil: (left) fronts and (right) backs. Metals are (a) magnesium, (b) aluminum T3, (c) aluminum T6, and (d) steel.

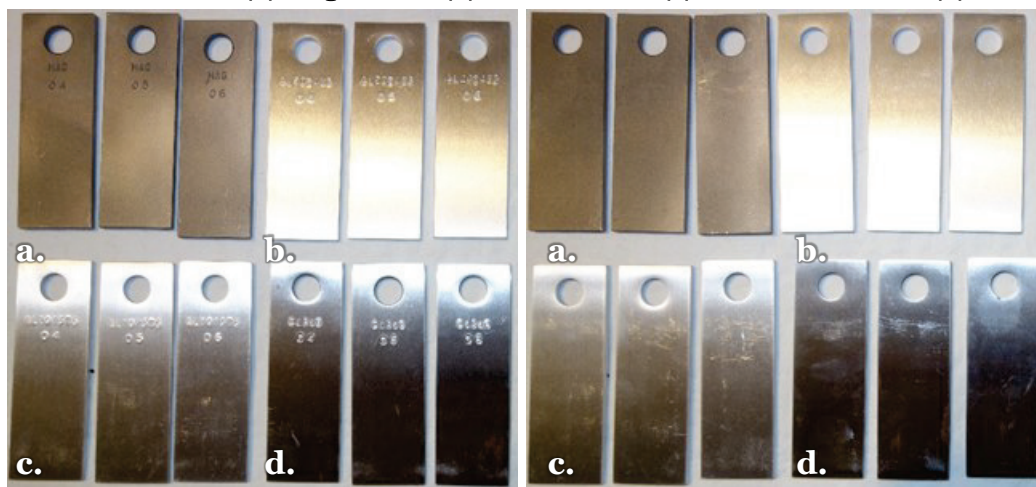


Figure A29. Metal coupons after 30 days in soil treated with water: (left) fronts and (right) backs. Metals are (a) magnesium, (b) aluminum T3, (c) aluminum T6, and (d) steel.



Figure A30. Metal coupons after 90 days in soil treated with water: (left) fronts and (right) backs. Metals are (a) magnesium, (b) aluminum T3, (c) aluminum T6, and (d) steel.

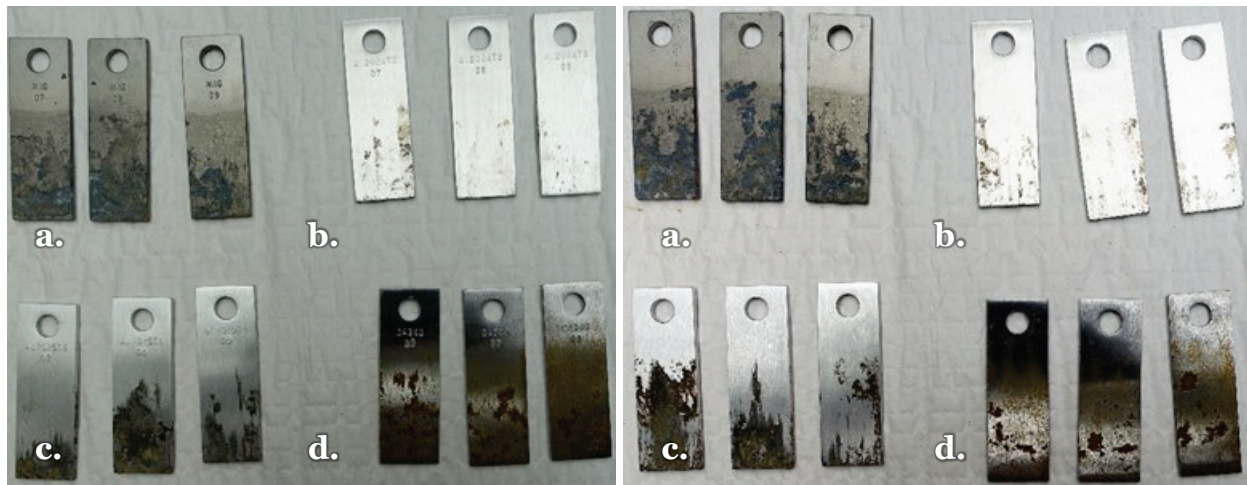


Figure A31. Metal coupons after 120 days in soil treated with water: (left) fronts and (right) backs. Metals are (a) magnesium, (b) aluminum T3, (c) aluminum T6, and (d) steel.

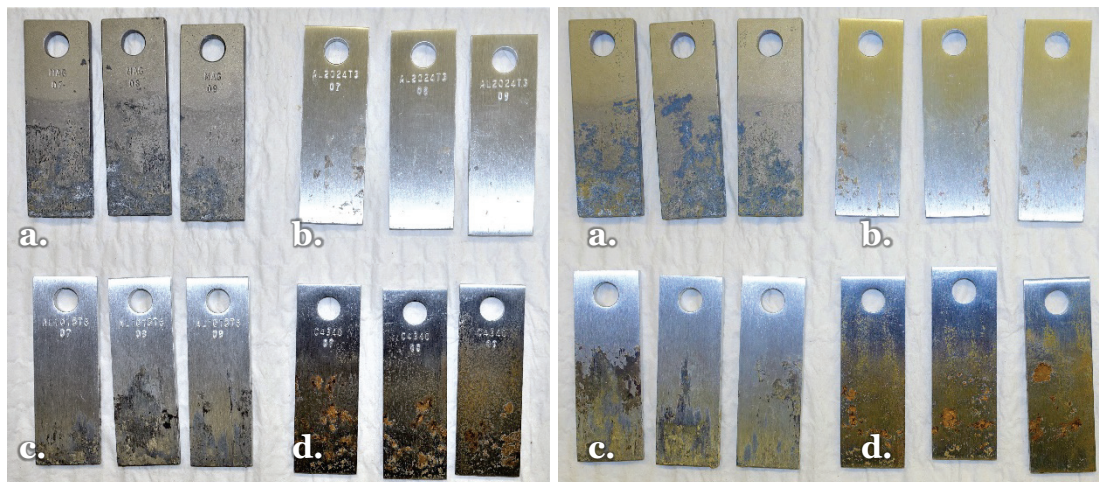


Figure A32. Metal coupons after 360 days in soil treated with water: (left) fronts and (right) backs. Metals are (a) magnesium, (b) aluminum T3, (c) aluminum T6, and (d) steel.

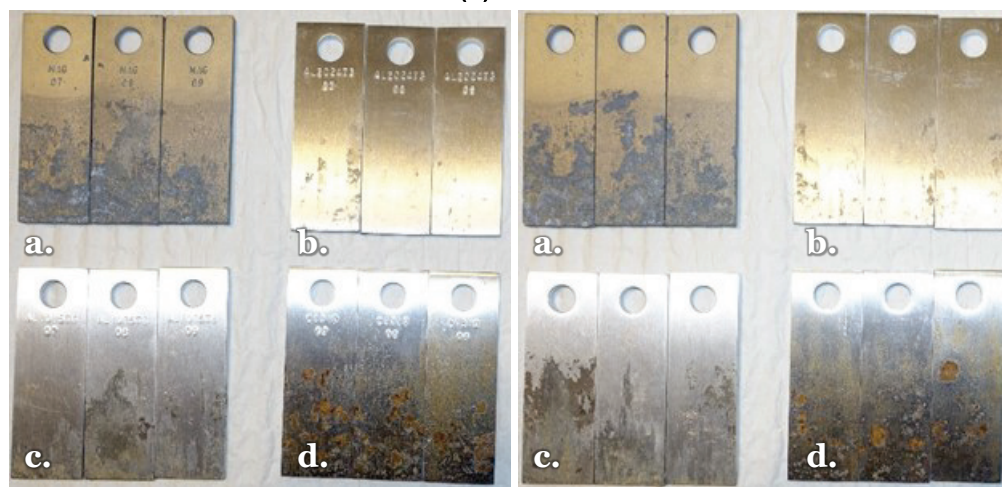


Figure A33. Metal coupons after 30 days in soil treated with Soiltac: (left) fronts and (right) backs. Metals are (a) magnesium, (b) aluminum T3, (c) aluminum T6, and (d) steel.

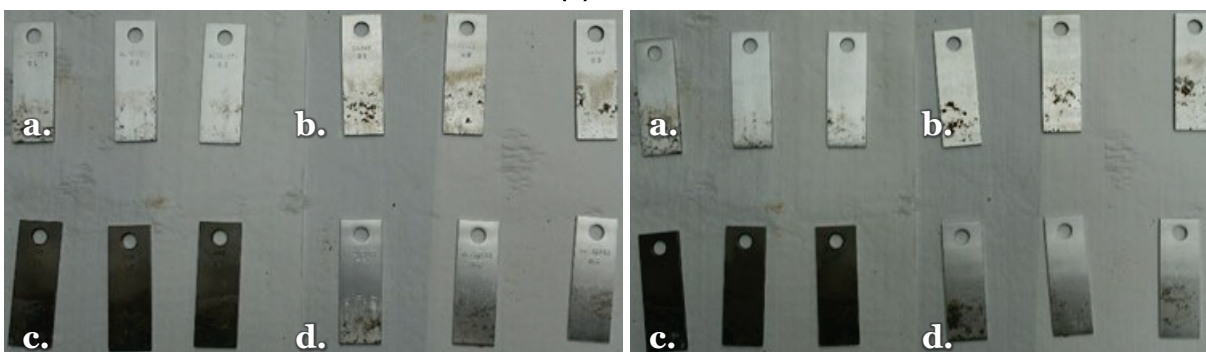


Figure A34. Metal coupons after 90 days in soil treated with Soiltac: (left) fronts and (right) backs. Metals are (a) magnesium, (b) aluminum T3, (c) aluminum T6, and (d) steel.

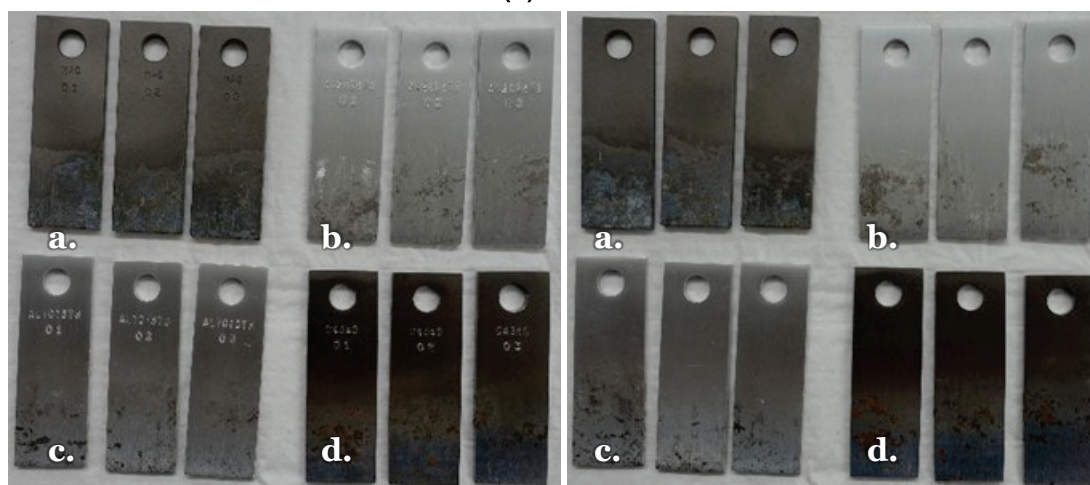


Figure A35. Metal coupons after 120 days in soil treated with Soiltec: (left) fronts and (right) backs. Metals are (a) magnesium, (b) aluminum T3, (c) aluminum T6, and (d) steel.

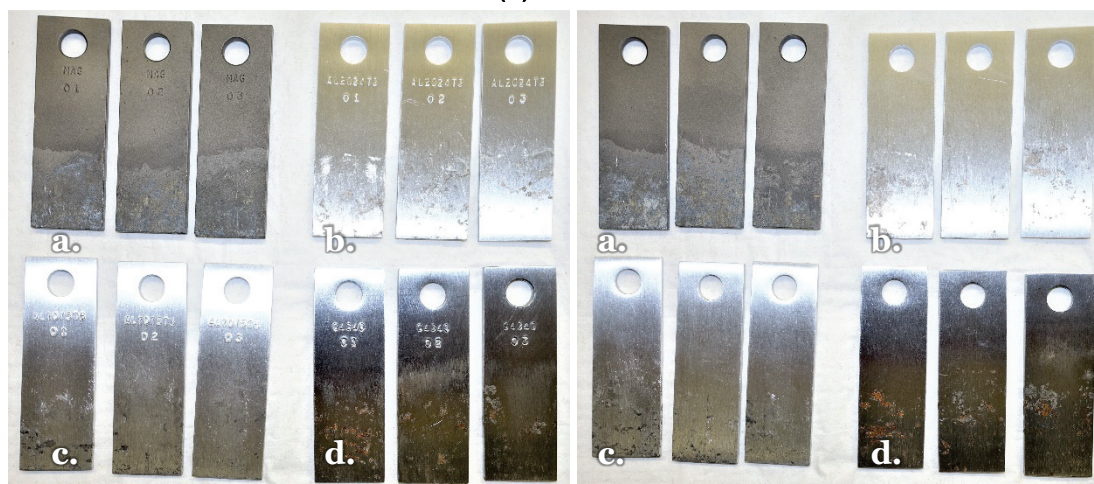


Figure A36. Metal coupons after 360 days in soil treated with Soiltec: (left) fronts and (right) backs. Metals are (a) magnesium, (b) aluminum T3, (c) aluminum T6, and (d) steel.

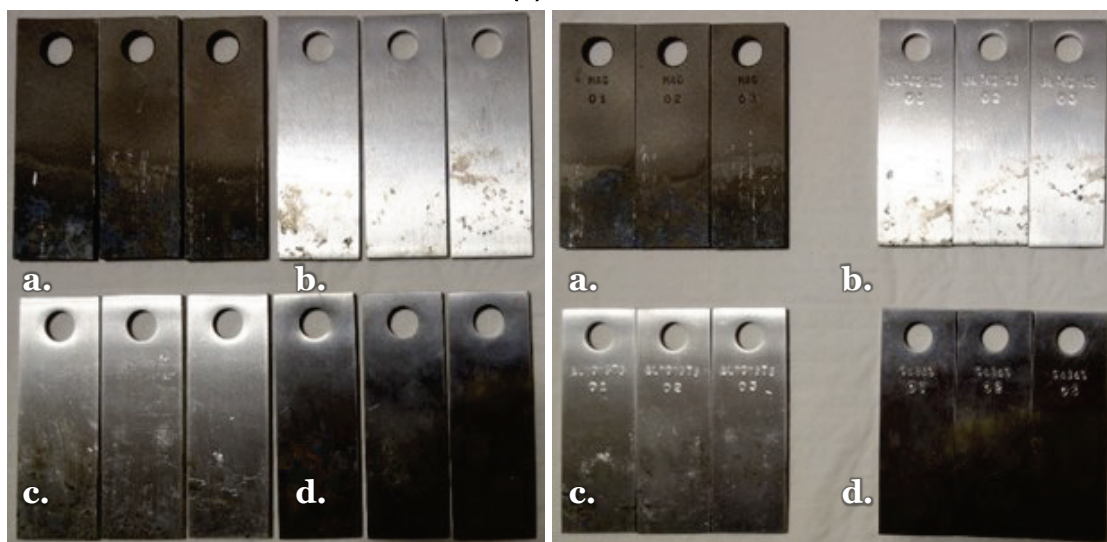


Figure A37. Metal coupons after 30 days in soil treated with Durasoil: (left) fronts and (right) backs. Metals are (a) magnesium, (b) aluminum T3, (c) aluminum T6, and (d) steel.

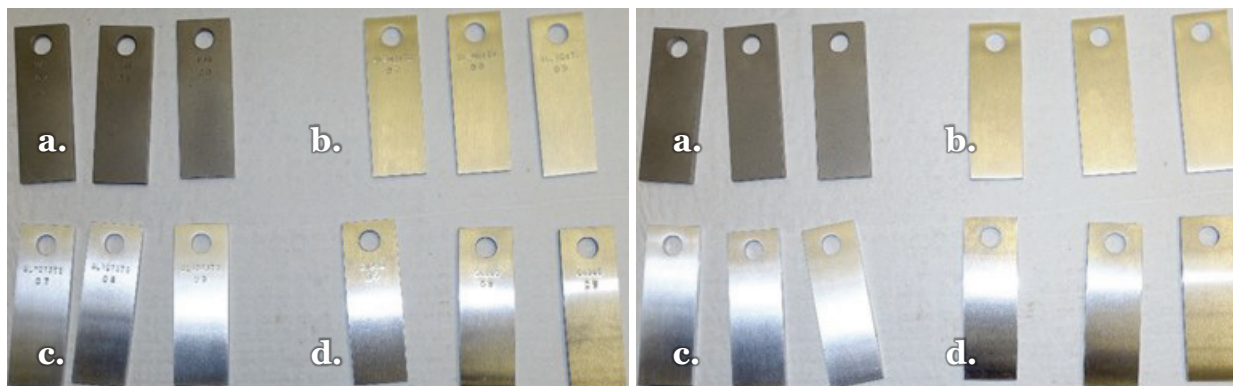


Figure A38. Metal coupons after 120 days in soil treated with Durasoil: (left) fronts and (right) backs. Metals are (a) magnesium, (b) aluminum T3, (c) aluminum T6, and (d) steel.

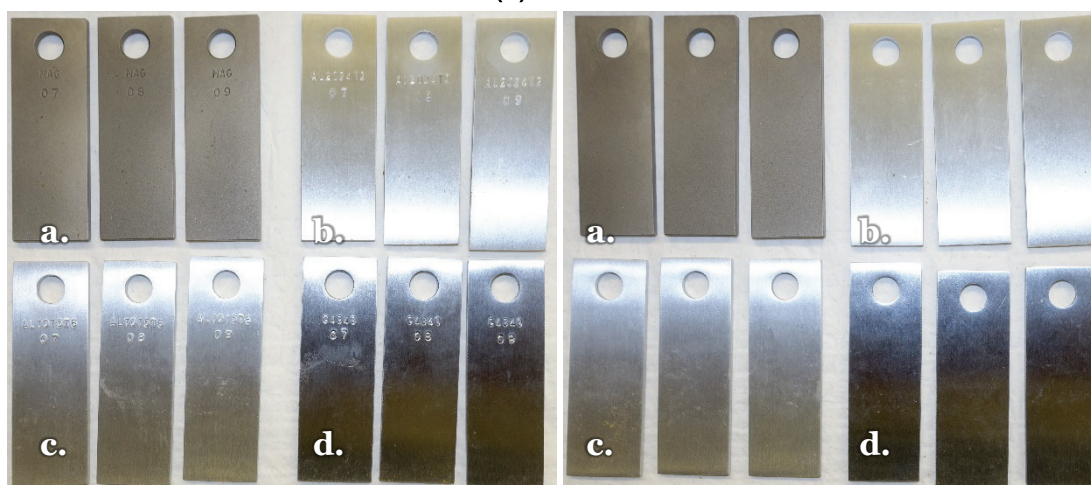


Figure A39. Metal coupons after 360 days in soil treated with Durasoil: (left) fronts and (right) backs Metals are (a) magnesium, (b) aluminum T3, (c) aluminum T6, and (d) steel.

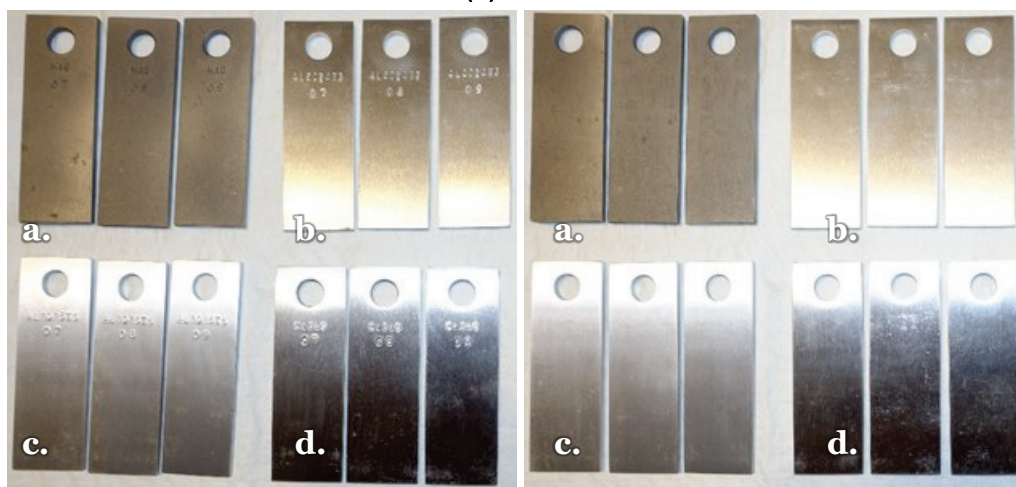


Figure A40. Metal coupons after 30 days in soil treated with DustPly Plus C: (left) fronts and (right) backs Metals are (a) magnesium, (b) aluminum T3, (c) aluminum T6, and (d) steel.

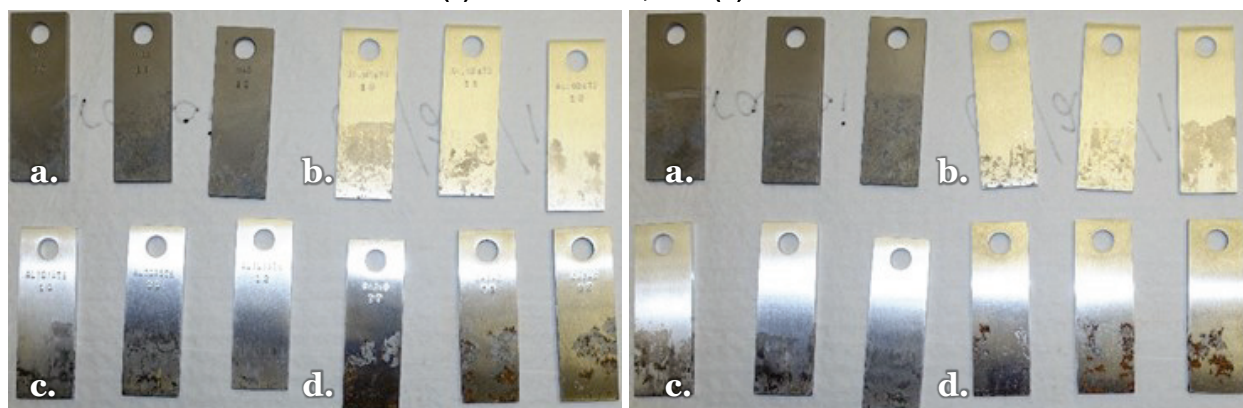


Figure A41. Metal coupons after 90 days in soil treated with DustPly Plus C: (left) fronts and (right) backs. Metals are (a) magnesium, (b) aluminum T3, (c) aluminum T6, and (d) steel.

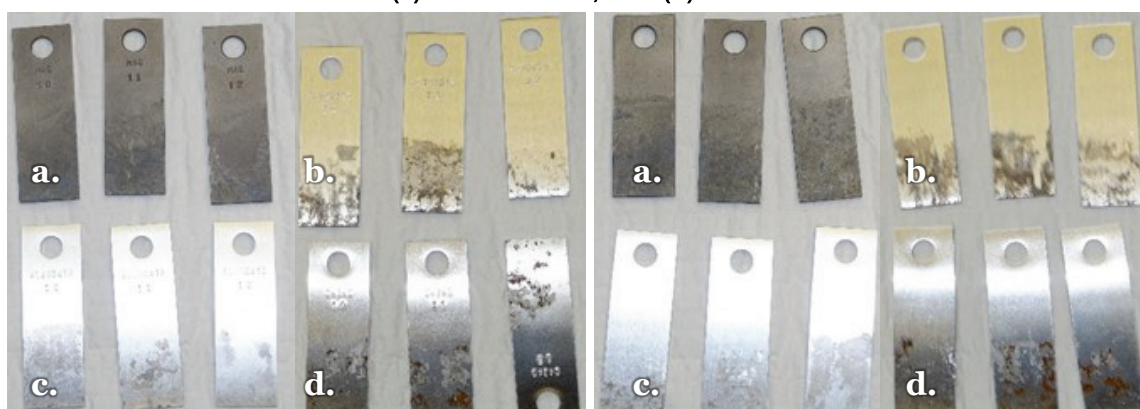


Figure A42. Metal coupons after 120 days in soil treated with DustPly Plus C: (left) fronts and (right) backs. Metals are (a) magnesium, (b) aluminum T3, (c) aluminum T6, and (d) steel.



Figure A43. Metal coupons after 360 days in soil treated with DustPly Plus C: (left) fronts and (right) backs. Metals are (a) magnesium, (b) aluminum T3, (c) aluminum T6, and (d) steel.

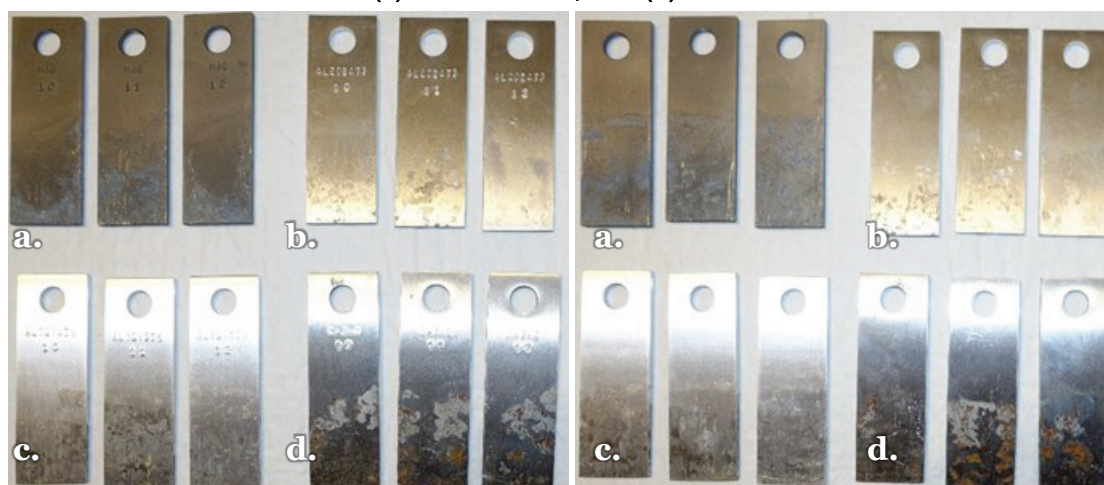


Figure A44. Metal coupons after 30 days in soil treated with EK35: (left) fronts and (right) backs. Metals are (a) magnesium, (b) aluminum T3, (c) aluminum T6, and (d) steel.

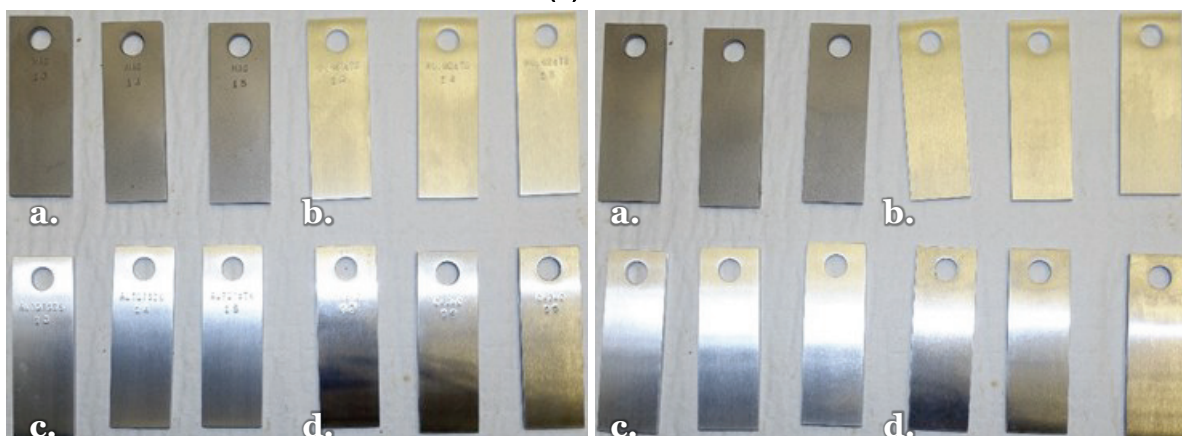


Figure A45. Metal coupons after 90 days in soil treated with EK35: (left) fronts and (right) backs. Metals are (a) magnesium, (b) aluminum T3, (c) aluminum T6, and (d) steel.

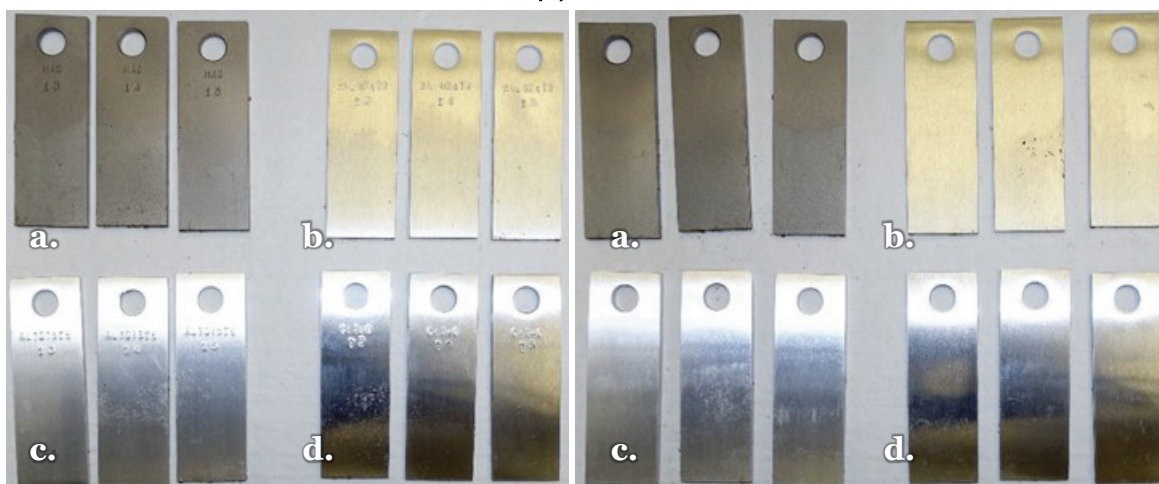


Figure A46. Metal coupons after 120 days in soil treated with EK35: (left) fronts and (right) backs. Metals are (a) magnesium, (b) aluminum T3, (c) aluminum T6, and (d) steel.

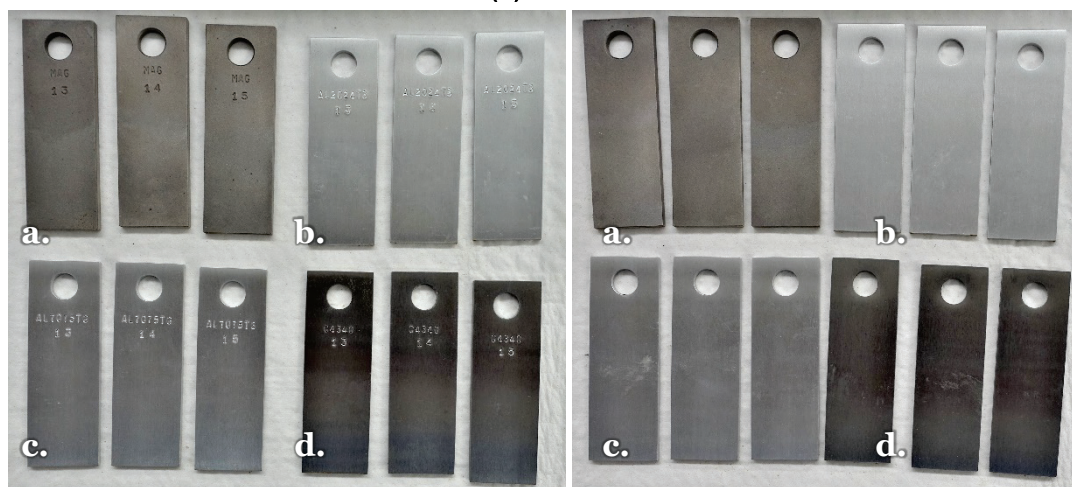


Figure A47. Metal coupons after 360 days in soil treated with EK35: (left) fronts and (right) backs. Metals are (a) magnesium, (b) aluminum T3, (c) aluminum T6, and (d) steel.



Figure A48. Metal coupons after 30 days in soil treated with EK2800: (left) fronts and (right) backs. Metals are (a) magnesium, (b) aluminum T3, (c) aluminum T6, and (d) steel.

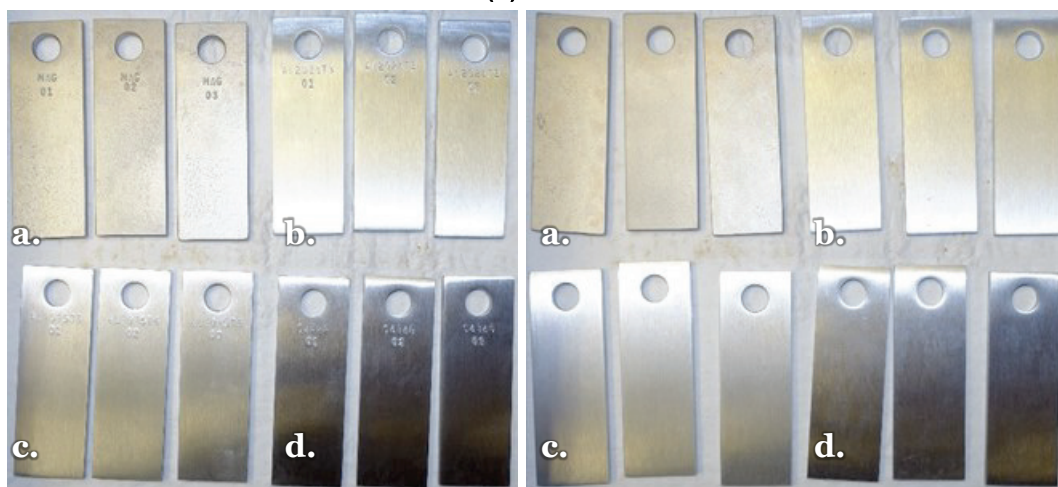


Figure A49. Metal coupons after 90 days in soil treated with EK2800: (left) fronts and (right) backs. Metals are (a) magnesium, (b) aluminum T3, (c) aluminum T6, and (d) steel.

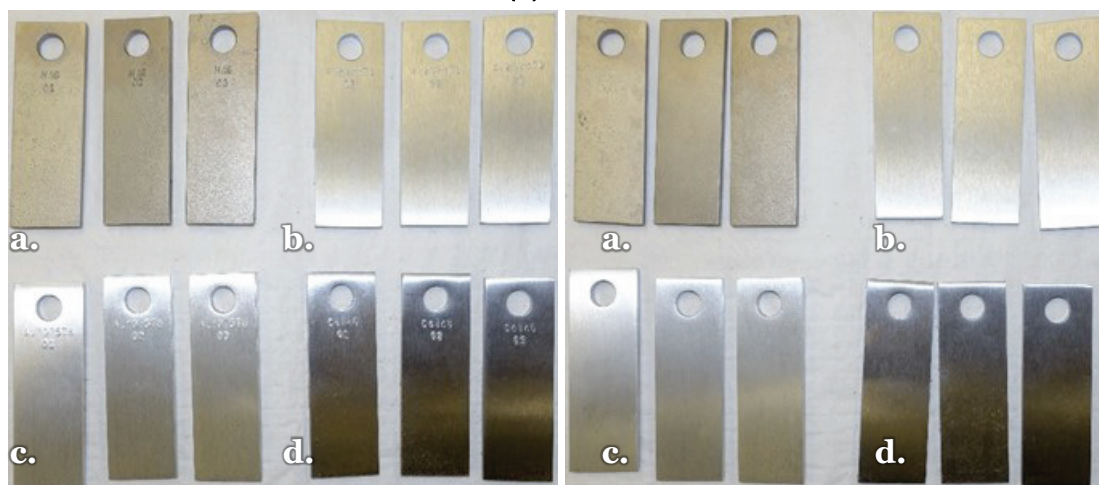


Figure A50. Metal coupons after 120 days in soil treated with EK2800: (left) fronts and (right) backs. Metals are (a) magnesium, (b) aluminum T3, (c) aluminum T6, and (d) steel.

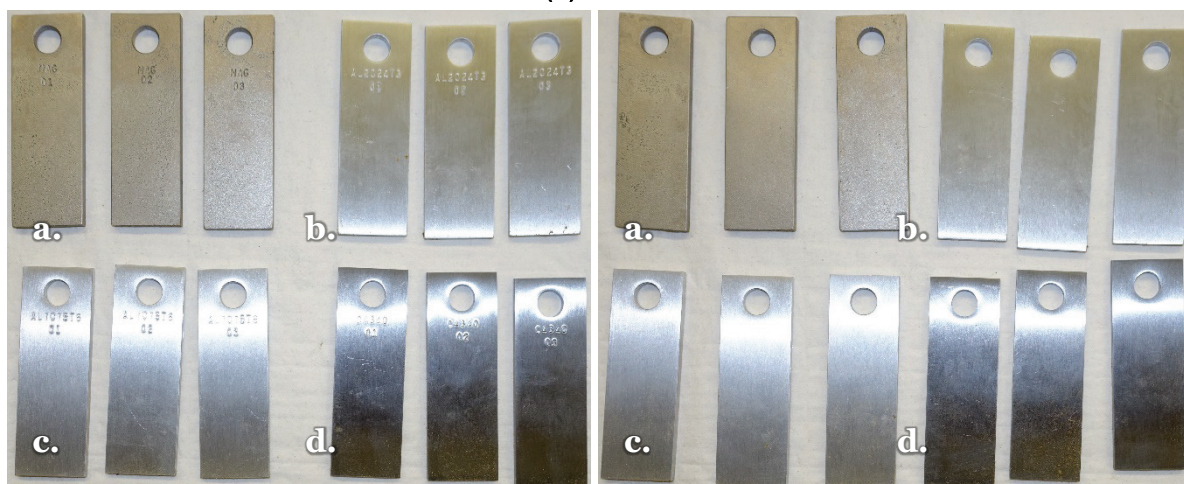


Figure A51. Metal coupons after 360 days in soil treated with EK2800: (left) fronts and (right) backs. Metals are (a) magnesium, (b) aluminum T3, (c) aluminum T6, and (d) steel.

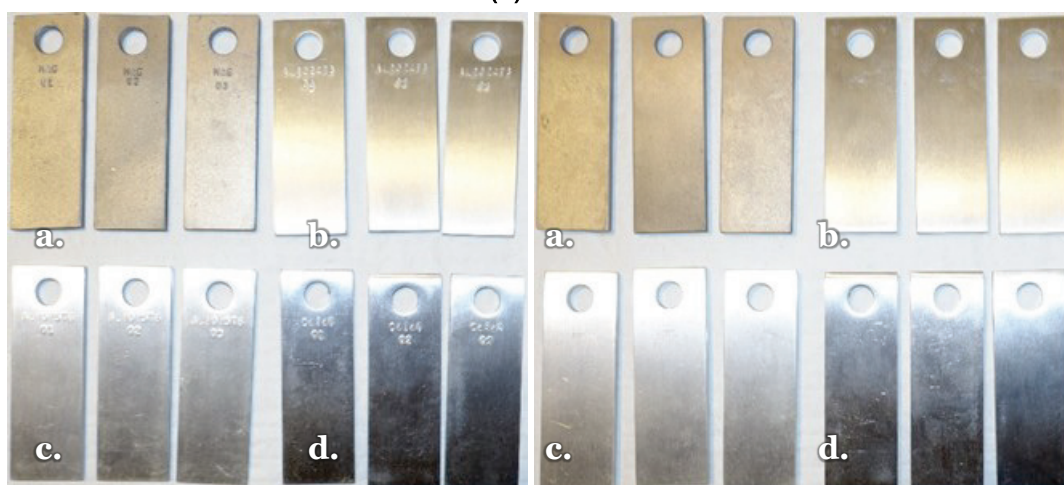


Figure A52. Metal coupons after 30 days in soil treated with Knockout: (left) fronts and (right) backs. Metals are (a) magnesium, (b) aluminum T3, (c) aluminum T6, and (d) steel.

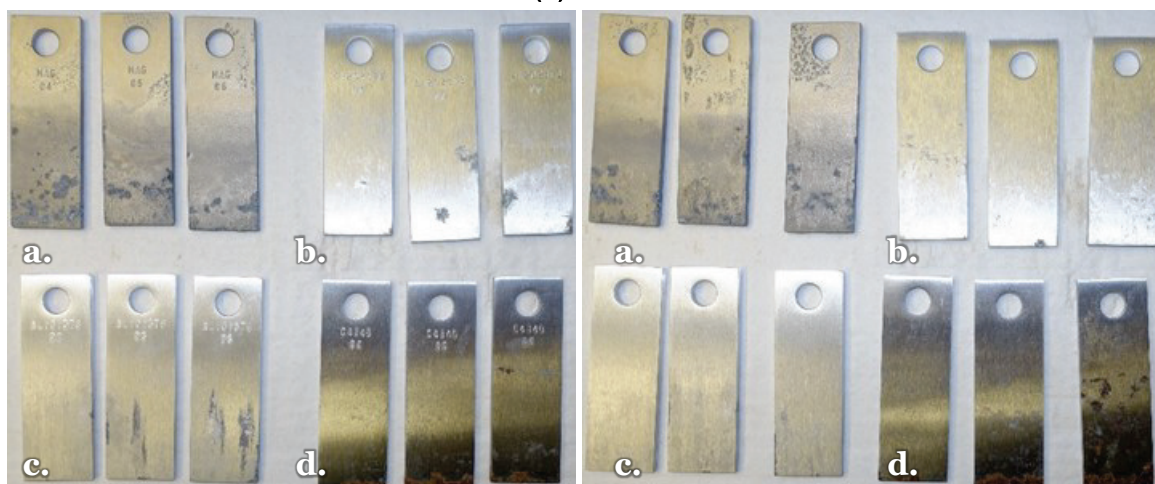


Figure A53. Metal coupons after 90 days in soil treated with Knockout: (left) fronts and (right) backs. Metals are (a) magnesium, (b) aluminum T3, (c) aluminum T6, and (d) steel.

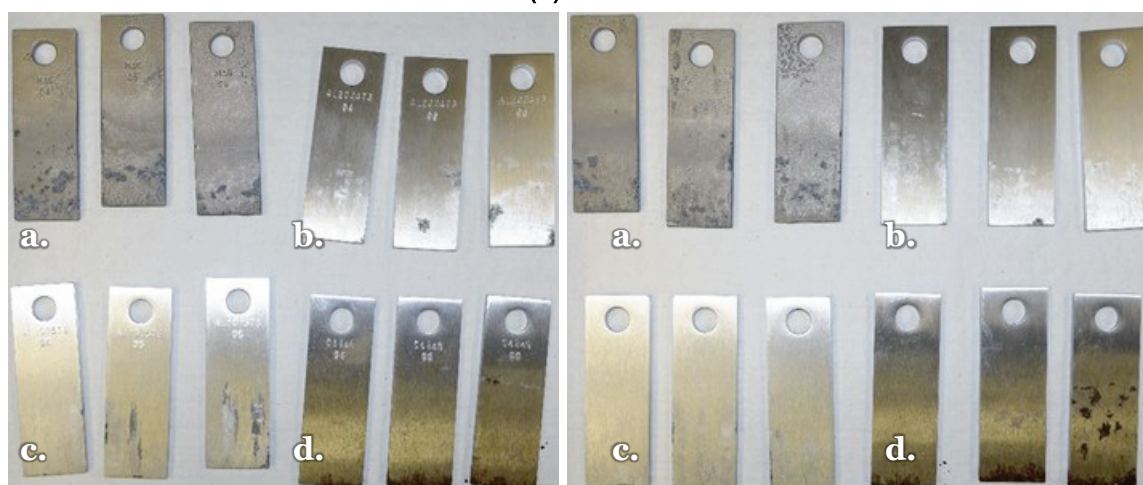


Figure A54. Metal coupons after 120 days in soil treated with Knockout: (left) fronts and (right) backs. Metals are (a) magnesium, (b) aluminum T3, (c) aluminum T6, and (d) steel.

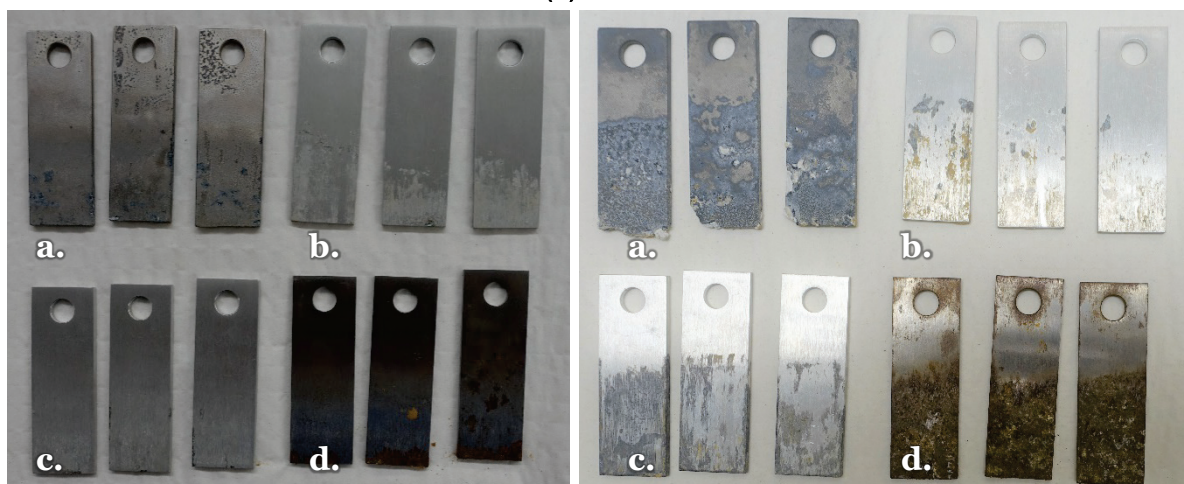


Figure A55. Metal coupons after 360 days in soil treated with Knockout: (left) fronts and (right) backs. Metals are (a) magnesium, (b) aluminum T3, (c) aluminum T6, and (d) steel.

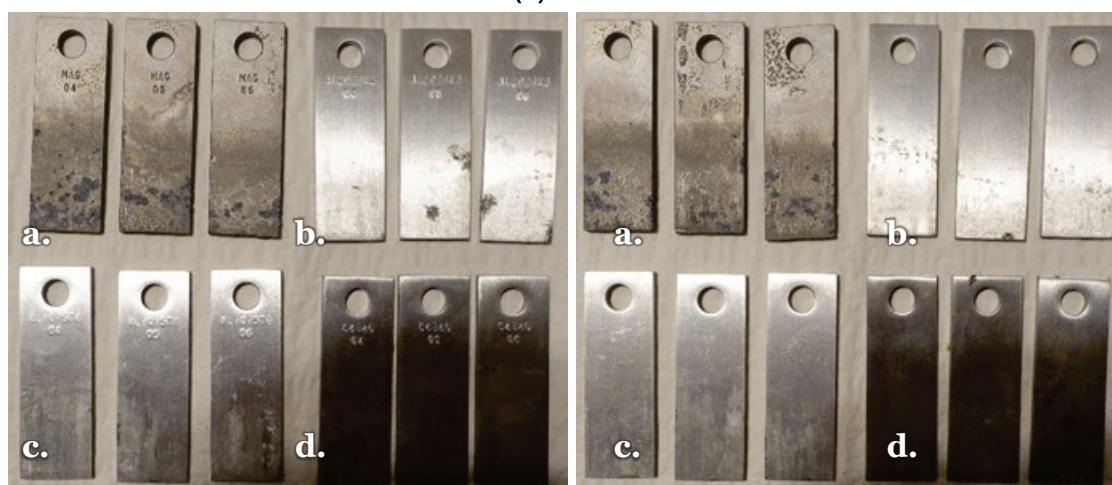


Figure A56. Metal coupons after 30 days in soil treated with Triple Tac: (left) fronts and (right) backs. Metals are (a) magnesium, (b) aluminum T3, (c) aluminum T6, and (d) steel.



Figure A57. Metal coupons after 60 days in soil treated with Triple Tac: (left) fronts and (right) backs. Metals are (a) magnesium, (b) aluminum T3, (c) aluminum T6, and (d) steel.

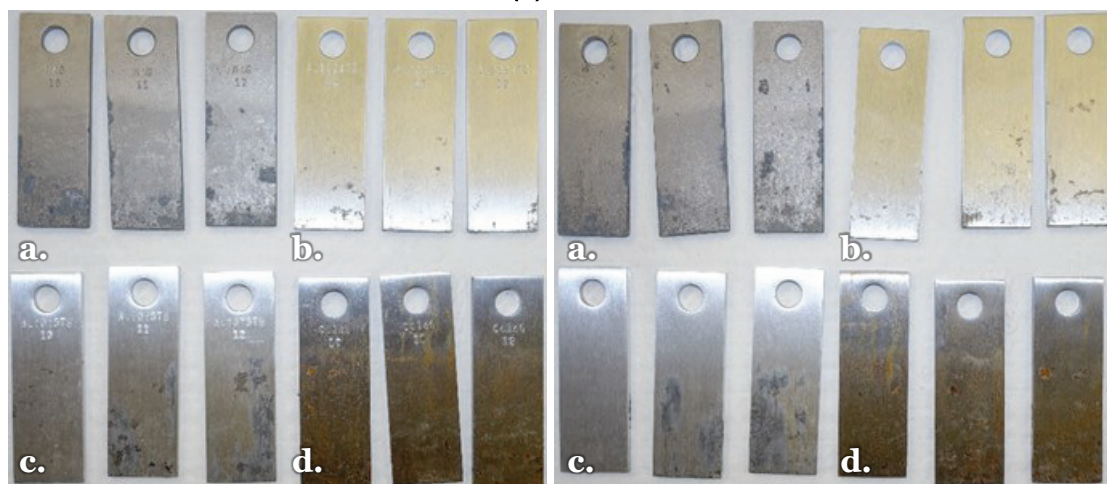


Figure A58. Metal coupons after 120 days in soil treated with Triple Tac: (left) fronts and (right) backs. Metals are (a) magnesium, (b) aluminum T3, (c) aluminum T6, and (d) steel.

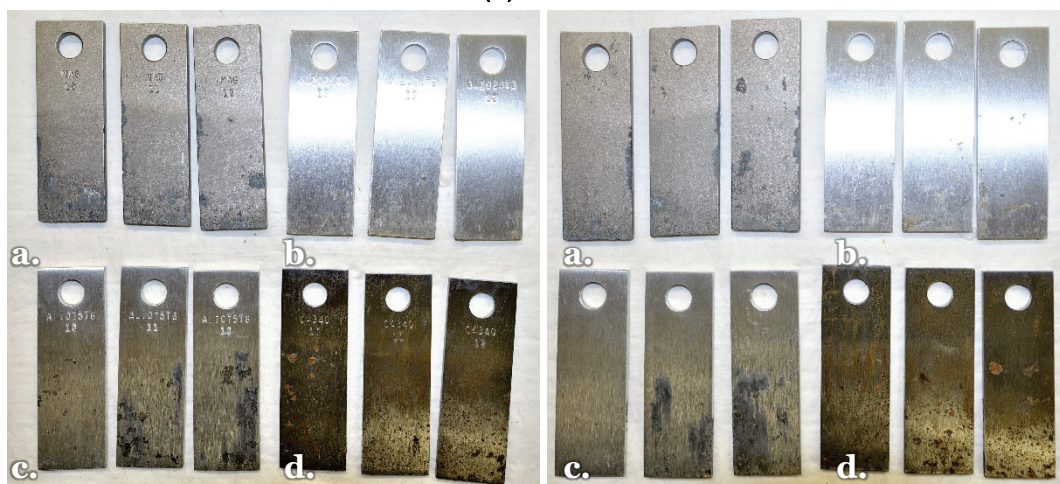


Figure A59. Metal coupons after 360 days in soil treated with Triple Tac: (left) fronts and (right) backs. Metals are (a) magnesium, (b) aluminum T3, (c) aluminum T6, and (d) steel.

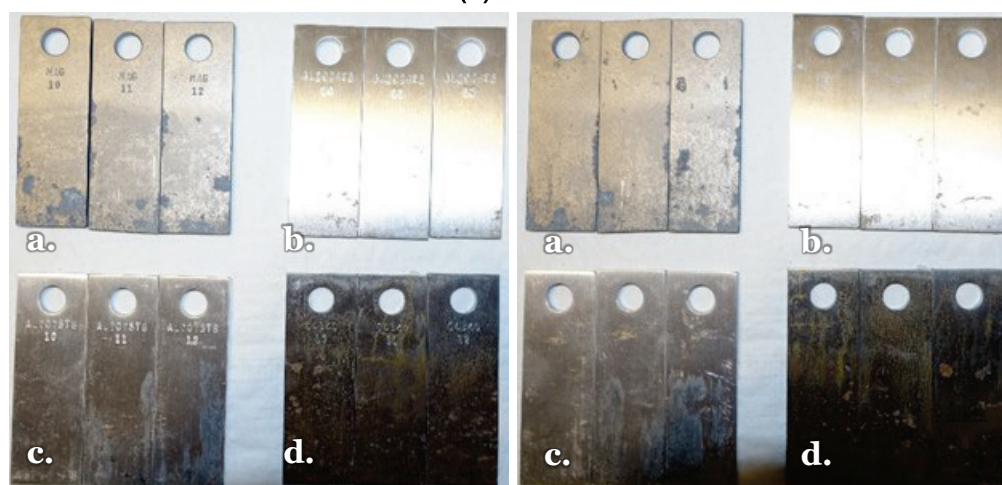


Figure A60. Metal coupons after 30 days in soil treated with GRT 9000: (left) fronts and (right) backs. Metals are (a) magnesium, (b) aluminum T3, (c) aluminum T6, and (d) steel.

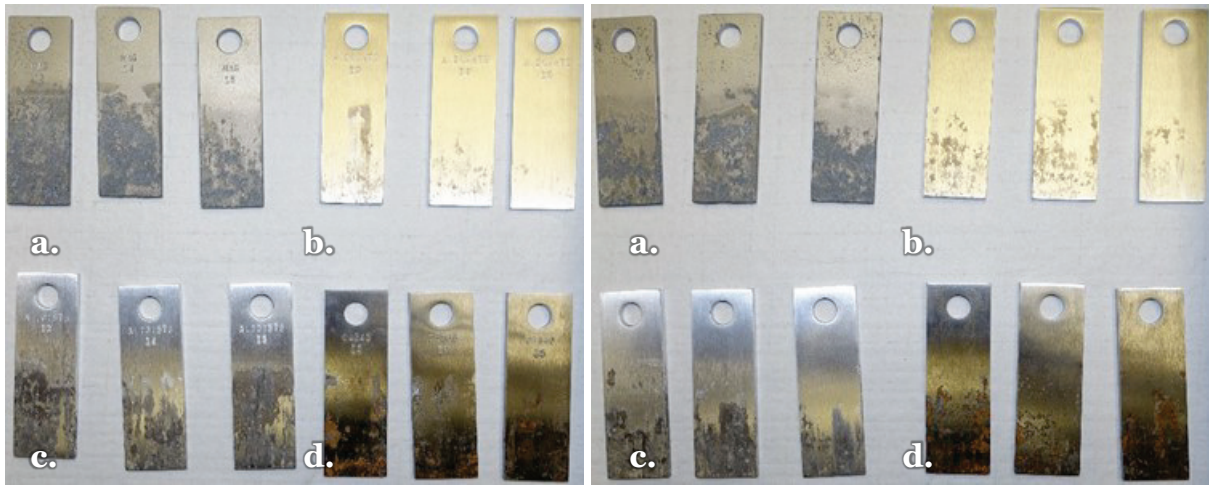


Figure A61. Metal coupons after 90 days in soil treated with GRT 9000: (left) fronts and (right) backs. Metals are (a) magnesium, (b) aluminum T3, (c) aluminum T6, and (d) steel.



Figure A62. Metal coupons after 120 days in soil treated with GRT 9000: (left) fronts and (right) backs. Metals are (a) magnesium, (b) aluminum T3, (c) aluminum T6, and (d) steel.

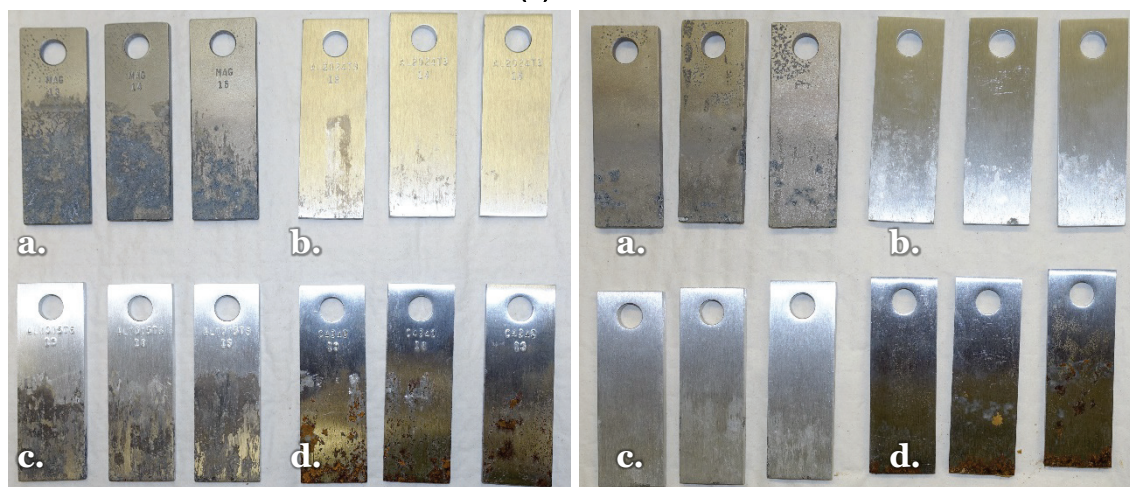


Figure A63. Metal coupons after 360 days in soil treated with GRT 9000: (left) fronts and (right) backs. Metals are (a) magnesium, (b) aluminum T3, (c) aluminum T6, and (d) steel.

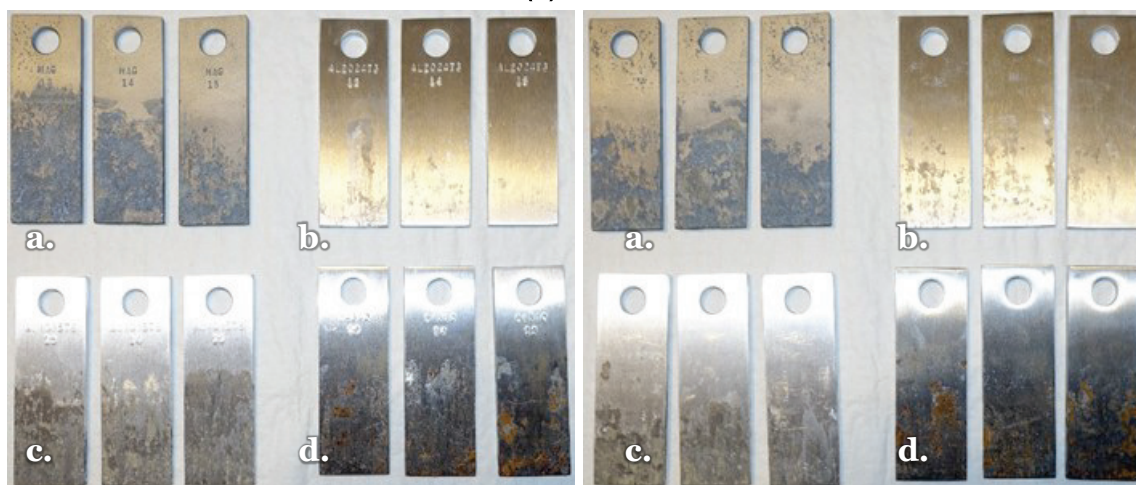


Figure A64. Metal coupons after 30 days in soil treated with X-Hesion Pro: (left) fronts and (right) backs. Metals are (a) magnesium, (b) aluminum T3, (c) aluminum T6, and (d) steel.

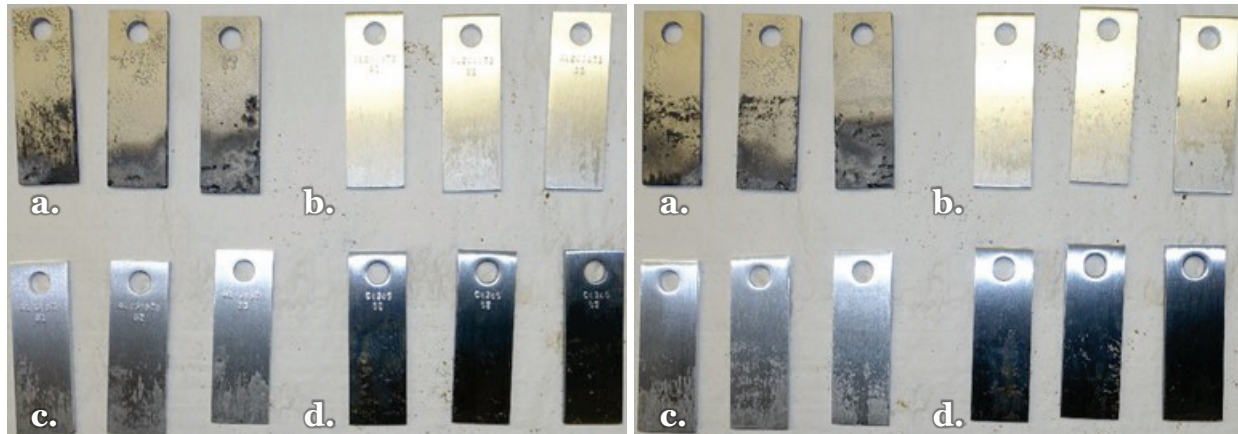


Figure A65. Metal coupons after 90 days in soil treated with X-Hesion Pro: (left) fronts and (right) backs. Metals are (a) magnesium, (b) aluminum T3, (c) aluminum T6, and (d) steel.

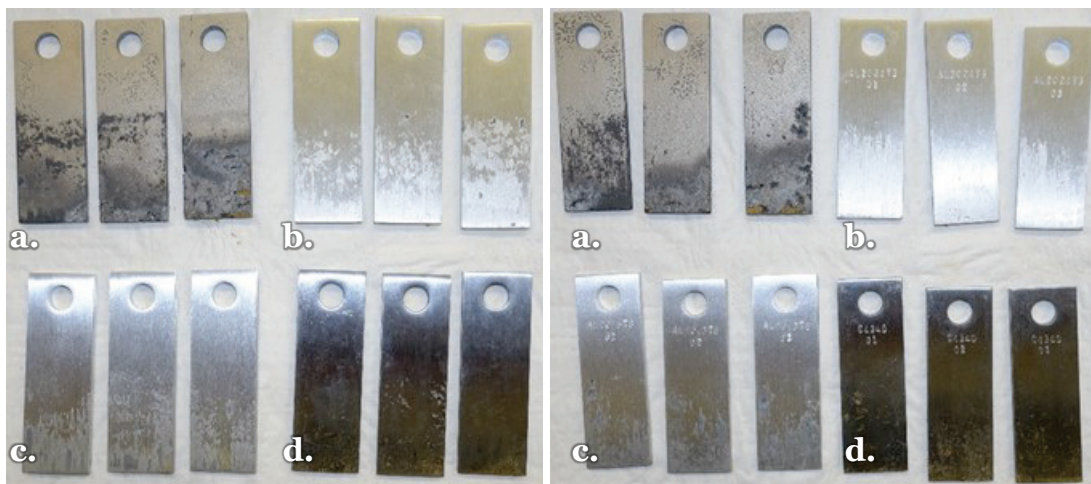


Figure A66. Metal coupons after 120 days in soil treated with X-Hesion Pro: (left) fronts and (right) backs. Metals are (a) magnesium, (b) aluminum T3, (c) aluminum T6, and (d) steel.

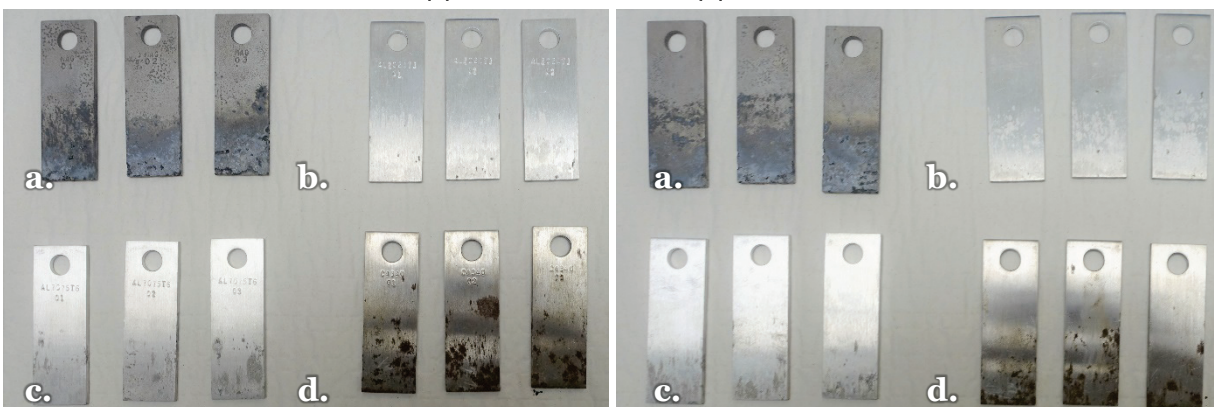


Figure A67. Metal coupons after 360 days in soil treated with X-Hesion Pro: (left) fronts and (right) backs. Metals are (a) magnesium, (b) aluminum T3, (c) aluminum T6, and (d) steel.

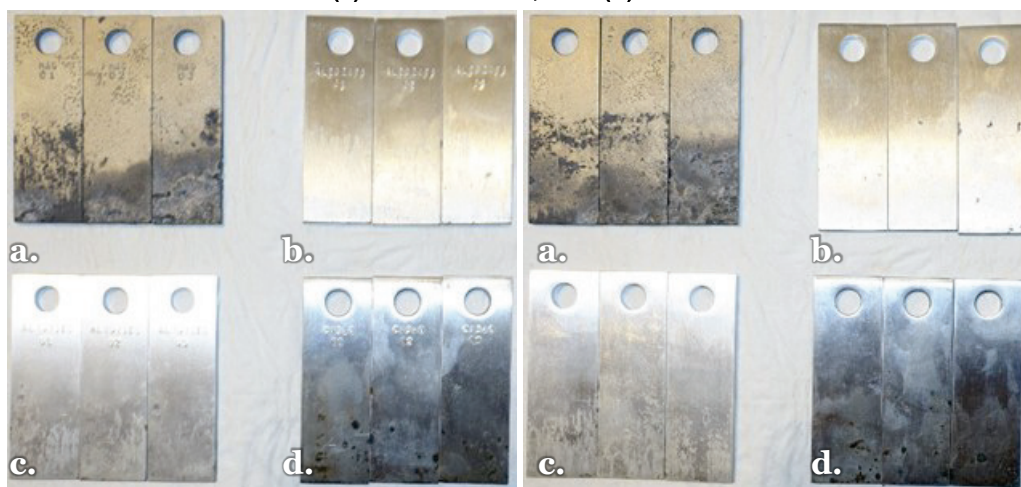


Figure A68. Metal coupons after 30 days in soil treated with $MgCl_2$: (left) fronts and (right) backs. Metals are (a) magnesium, (b) aluminum T3, (c) aluminum T6, and (d) steel.

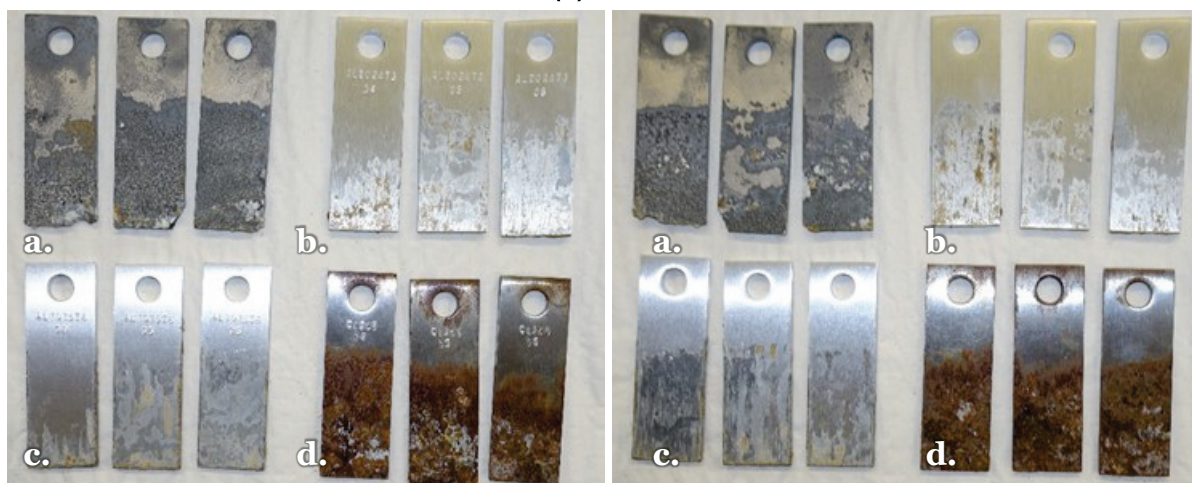


Figure A69. Metal coupons after 90 days in soil treated with MgCl_2 : (left) fronts and (right) backs. Metals are (a) magnesium, (b) aluminum T3, (c) aluminum T6, and (d) steel.

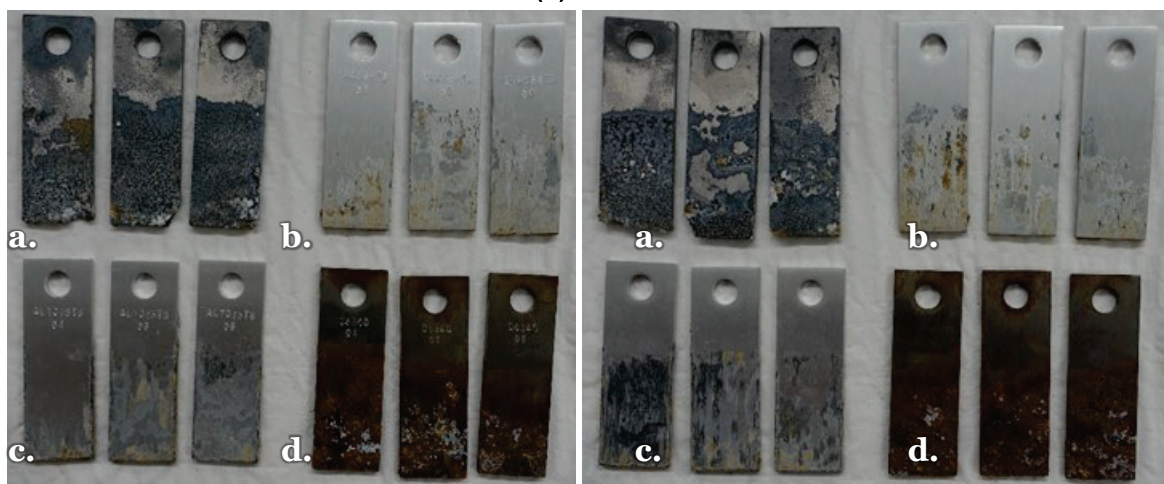


Figure A70. Metal coupons after 120 days in soil treated with MgCl_2 : (left) fronts and (right) backs. Metals are (a) magnesium, (b) aluminum T3, (c) aluminum T6, and (d) steel.

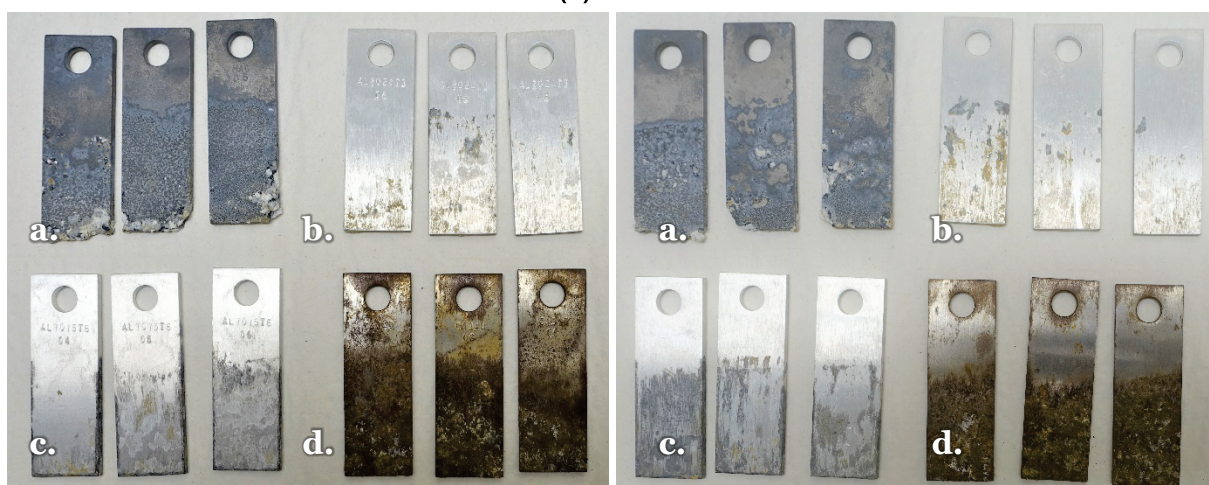


Figure A71. Metal coupons after 360 days in soil treated with $MgCl_2$: (left) fronts and (right) backs. Metals are (a) magnesium, (b) aluminum T3, (c) aluminum T6, and (d) steel.

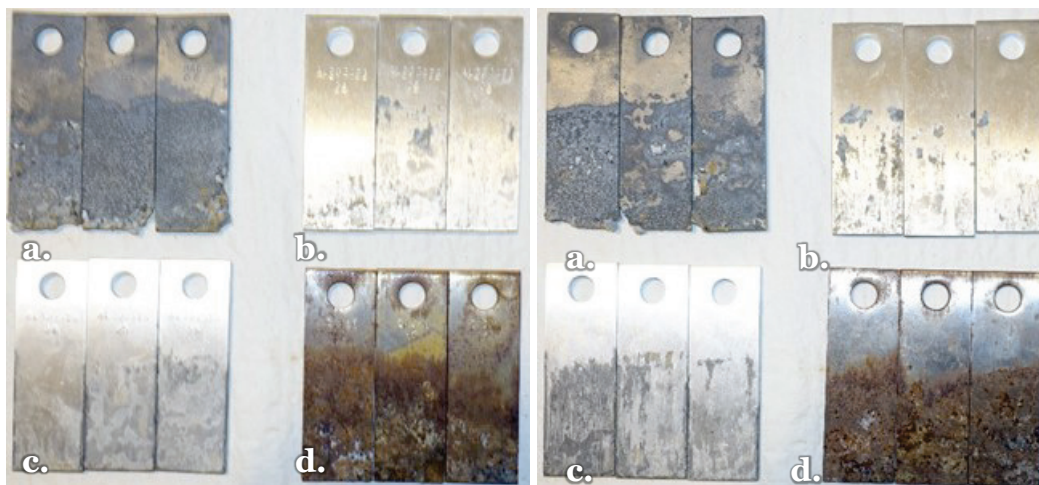


Figure A72. Metal coupons after 30 days in soil treated with SandTec 9006: (left) fronts and (right) backs. Metals are (a) magnesium, (b) aluminum T3, (c) aluminum T6, and (d) steel.

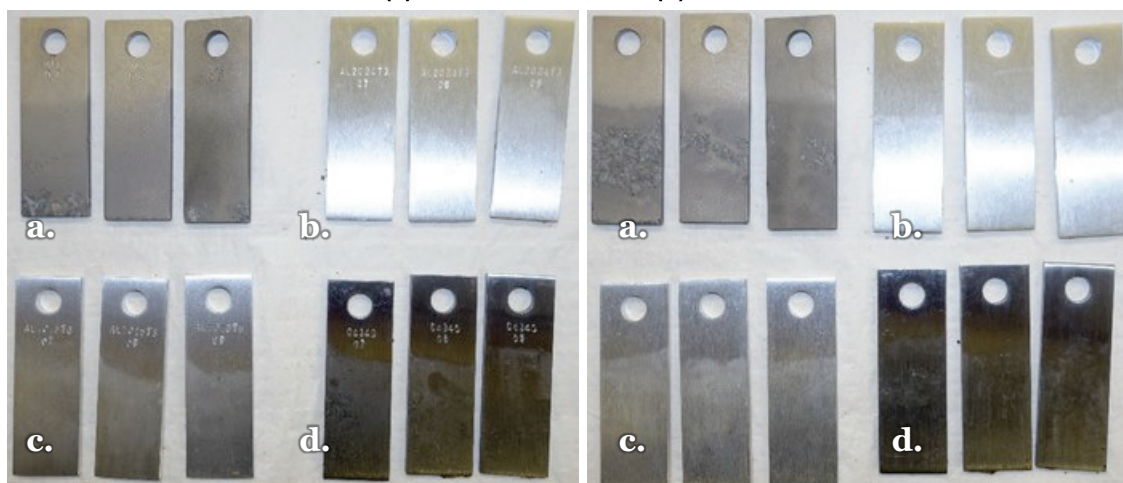


Figure A73. Metal coupons after 90 days in soil treated with SandTec 9006: (left) fronts and (right) backs. Metals are (a) magnesium, (b) aluminum T3, (c) aluminum T6, and (d) steel.

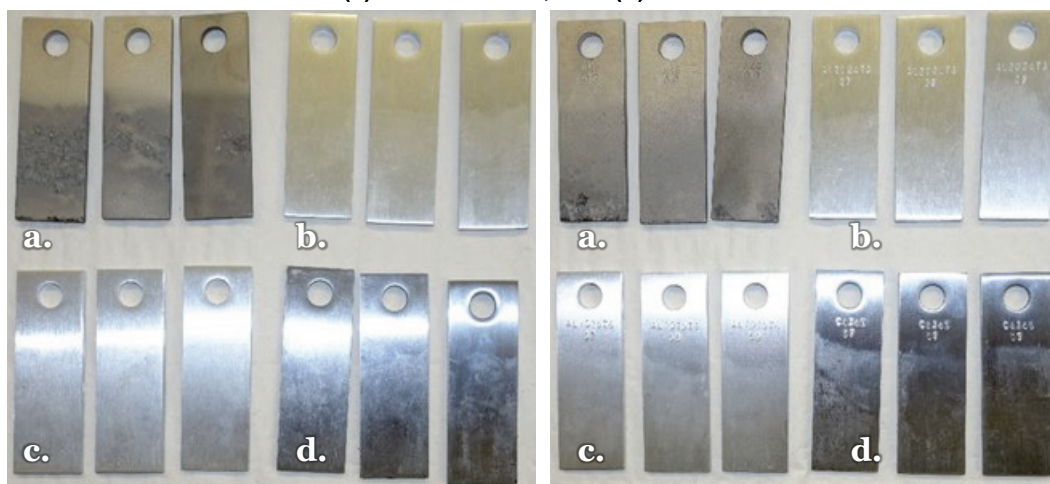


Figure A74. Metal coupons after 120 days in soil treated with SandTec 9006: (left) fronts and (right) backs. Metals are (a) magnesium, (b) aluminum T3, (c) aluminum T6, and (d) steel.



Figure A75. Metal coupons after 360 days in soil treated with SandTec 9006: (left) fronts and (right) backs. Metals are (a) magnesium, (b) aluminum T3, (c) aluminum T6, and (d) steel.

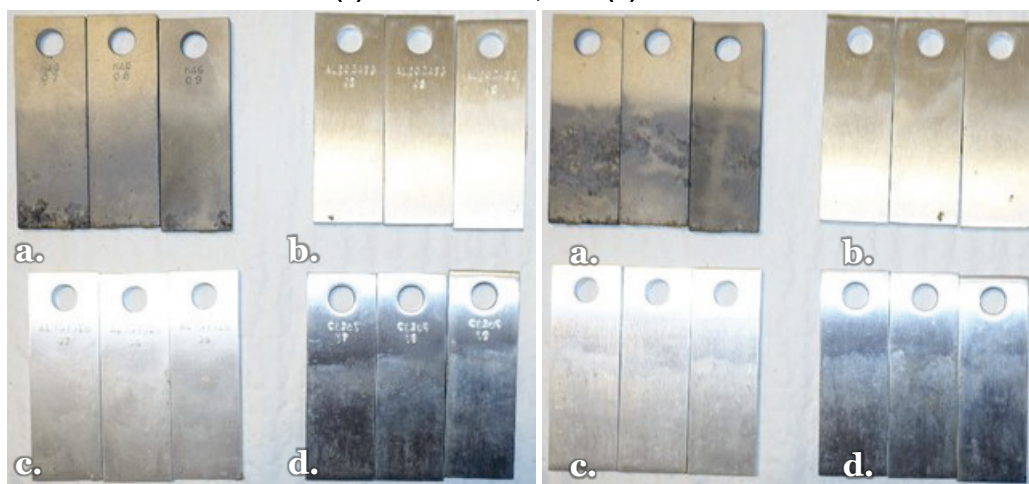


Figure A76. Metal coupons after 30 days in soil treated with DustKill: (left) fronts and (right) backs. Metals are (a) magnesium, (b) aluminum T3, (c) aluminum T6, and (d) steel.

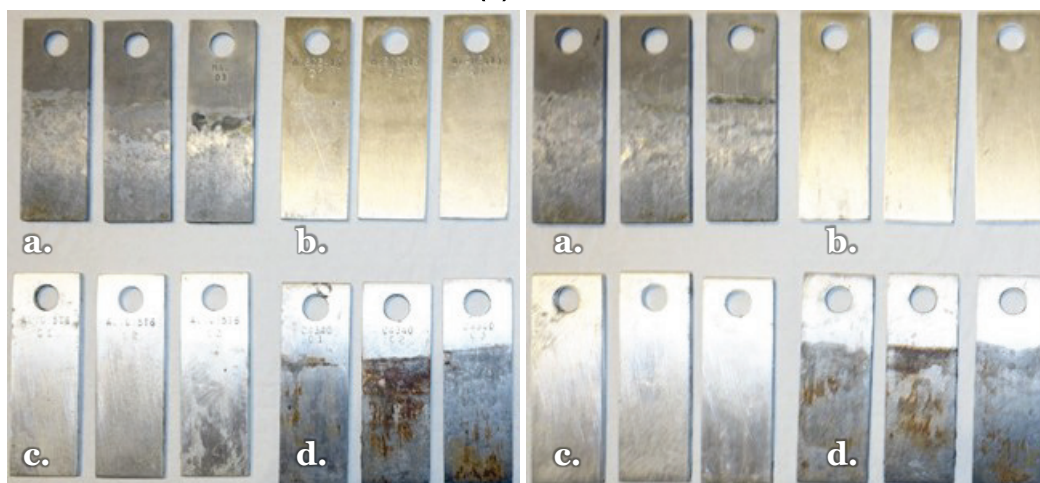


Figure A77. Metal coupons after 90 days in soil treated with DustKill: (left) fronts and (right) backs. Metals are (a) magnesium, (b) aluminum T3, (c) aluminum T6, and (d) steel.

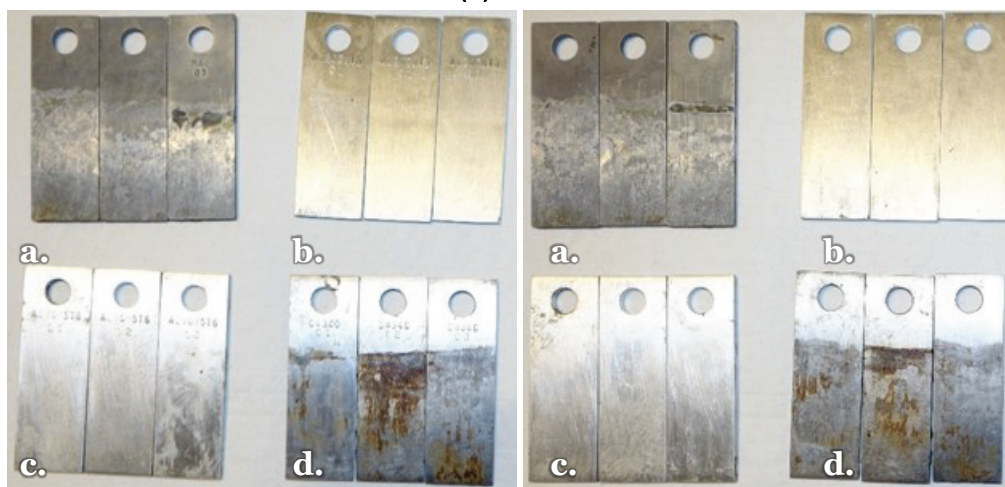


Figure A78. Metal coupons after 120 days in soil treated with DustKill: (left) fronts and (right) backs. Metals are (a) magnesium, (b) aluminum T3, (c) aluminum T6, and (d) steel.

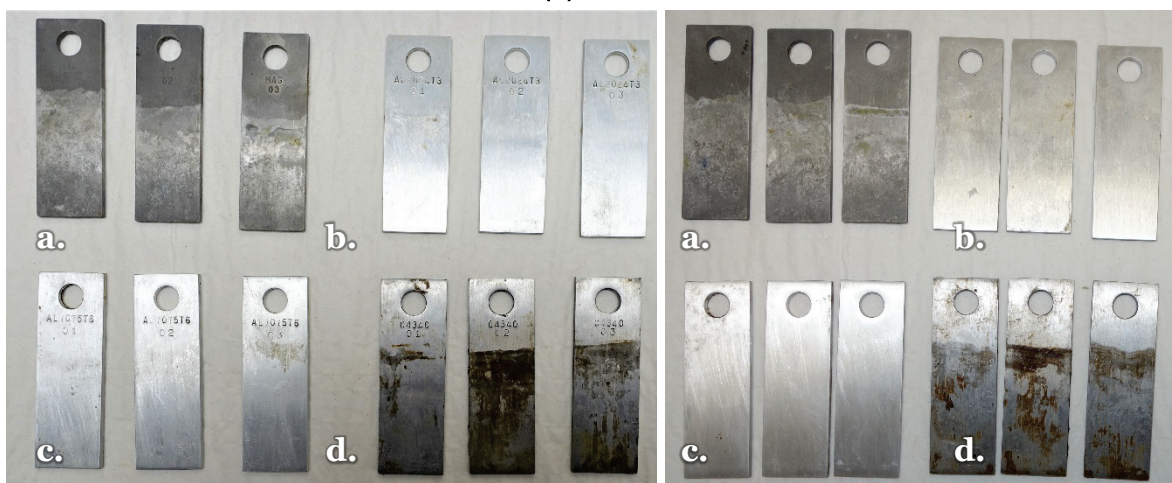


Figure A79. Metal coupons after 360 days in soil treated with DustKill: (left) fronts and (right) backs. Metals are (a) magnesium, (b) aluminum T3, (c) aluminum T6, and (d) steel.

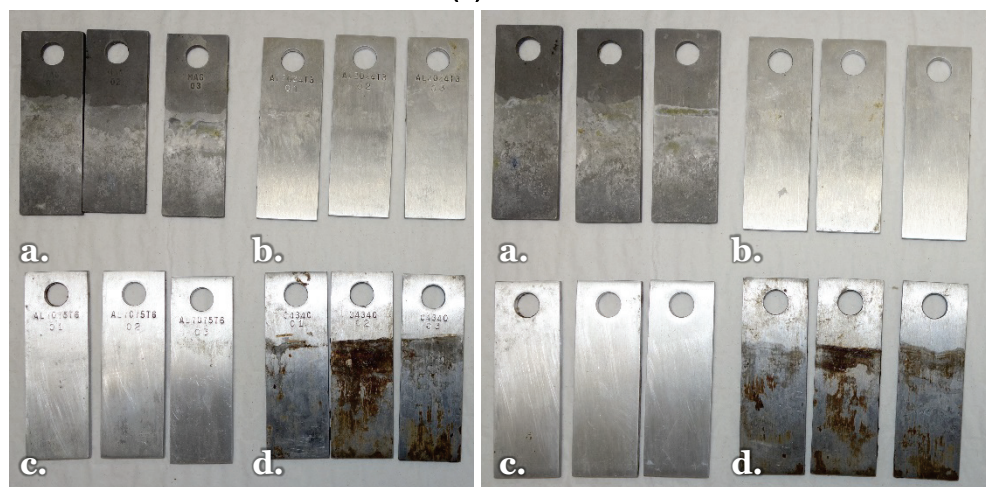


Figure A80. Metal coupons after 30 days in soil treated with Soykill: (left) fronts and (right) backs. Metals are (a) magnesium, (b) aluminum T3, (c) aluminum T6, and (d) steel.

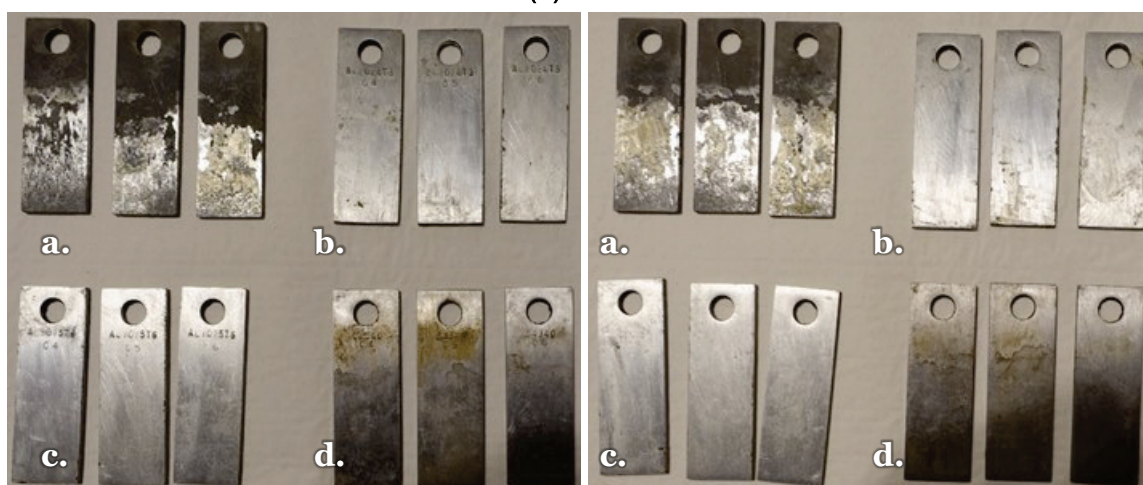


Figure A81. Metal coupons after 90 days in soil treated with Soykill: (left) fronts and (right) backs. Metals are (a) magnesium, (b) aluminum T3, (c) aluminum T6, and (d) steel.

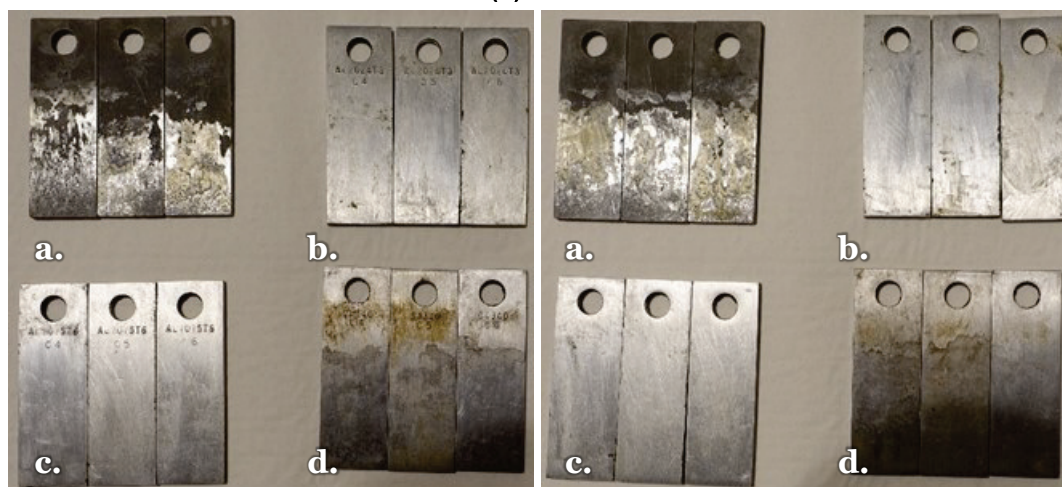


Figure A82. Metal coupons after 120 days in soil treated with Soykill: (left) fronts and (right) backs. Metals are (a) magnesium, (b) aluminum T3, (c) aluminum T6, and (d) steel.

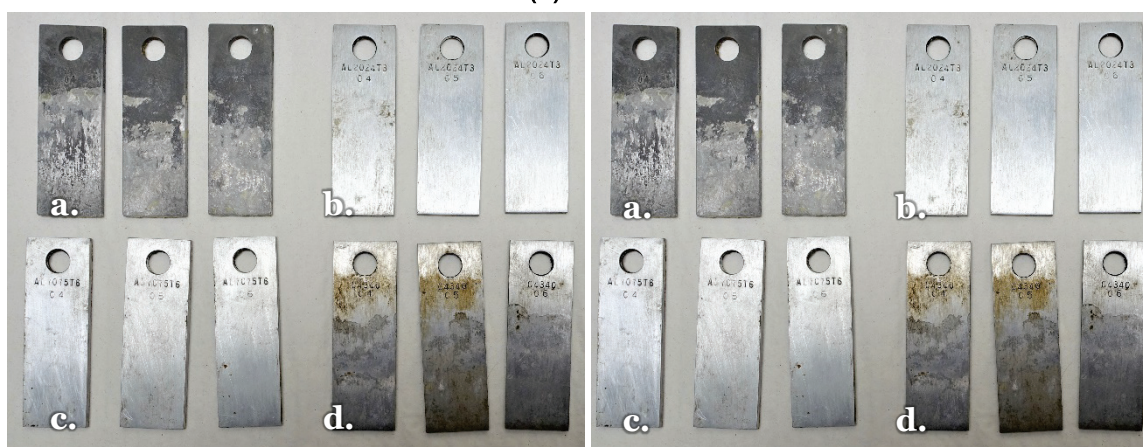


Figure A83. Metal coupons after 360 days in soil treated with Soykill: (left) fronts and (right) backs. Metals are (a) magnesium, (b) aluminum T3, (c) aluminum T6, and (d) steel.

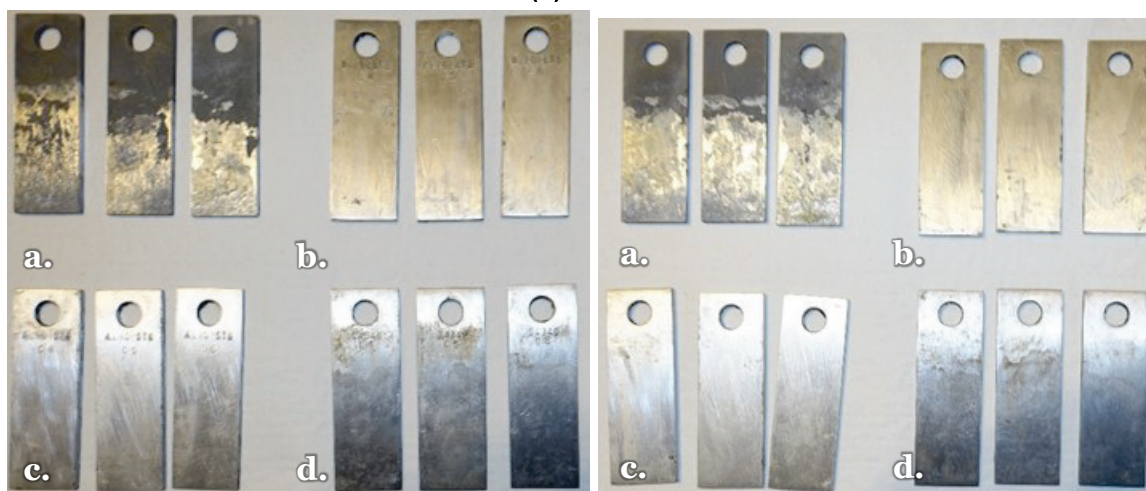


Figure A84. Metal coupons after 30 days in soil treated with BioSoyl Plus NP: (left) fronts and (right) backs. Metals are (a) magnesium, (b) aluminum T3, (c) aluminum T6, and (d) steel.

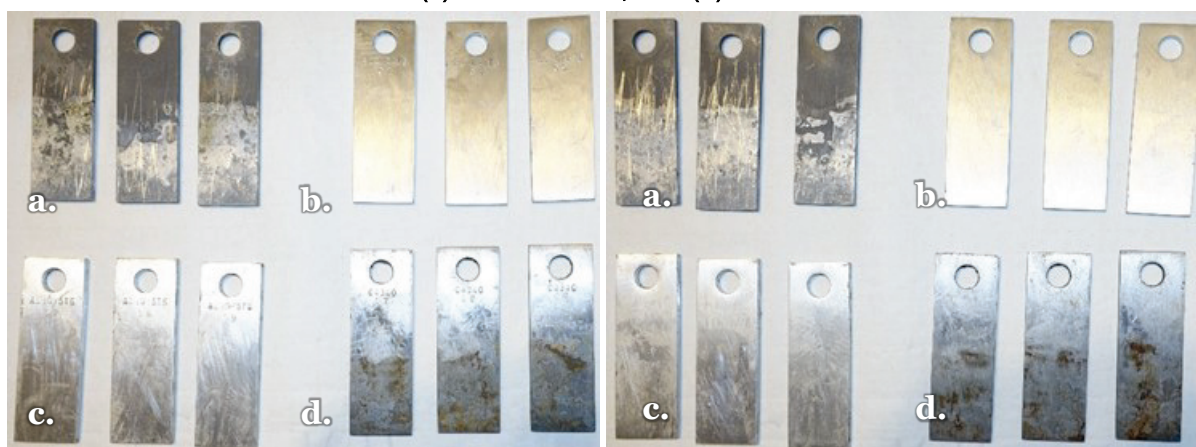


Figure A85. Metal coupons after 90 days in soil treated with BioSoyl Plus NP: (left) fronts and (right) backs. Metals are (a) magnesium, (b) aluminum T3, (c) aluminum T6, and (d) steel.

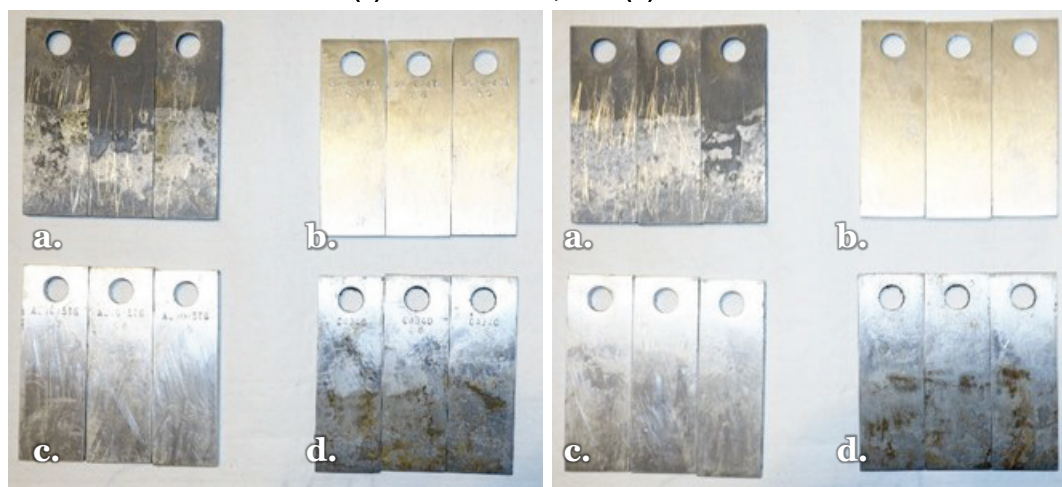


Figure A86. Metal coupons after 120 days in soil treated with BioSoyl Plus NP: (left) fronts and (right) backs. Metals are (a) magnesium, (b) aluminum T3, (c) aluminum T6, and (d) steel.

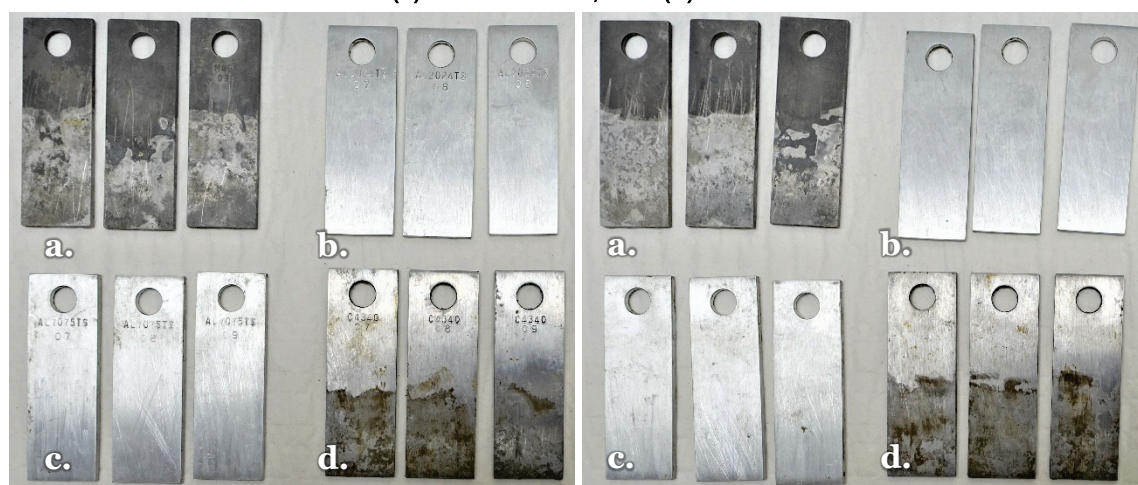


Figure A87. Metal coupons after 360 days in soil treated with BioSoyl Plus NP: (left) fronts and (right) backs. Metals are (a) magnesium, (b) aluminum T3, (c) aluminum T6, and (d) steel.

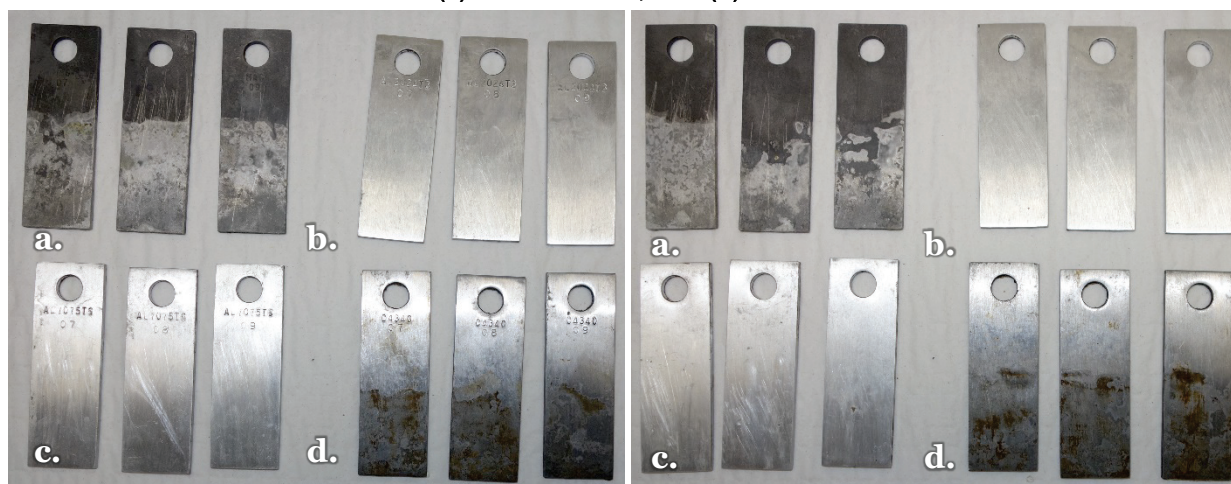


Figure A88. Metal coupons after 30 days in soil treated with BioSoyl Plus (left) fronts and (right) backs. Metals are (a) magnesium, (b) aluminum T3, (c) aluminum T6, and (d) steel.

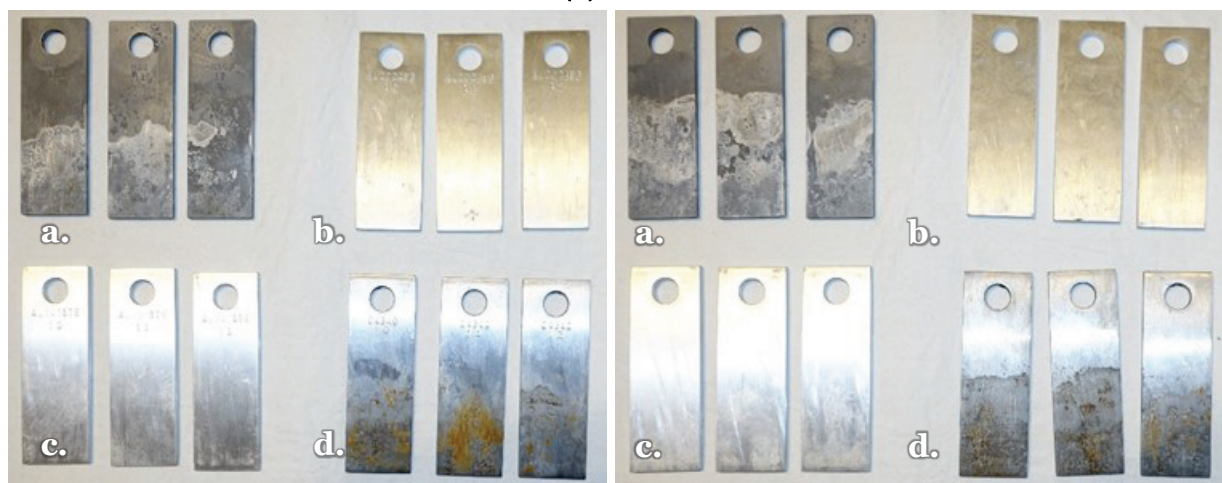


Figure A89. Metal coupons after 90 days in soil treated with BioSoyl Plus: (left) fronts and (right) backs. Metals are (a) magnesium, (b) aluminum T3, (c) aluminum T6, and (d) steel.

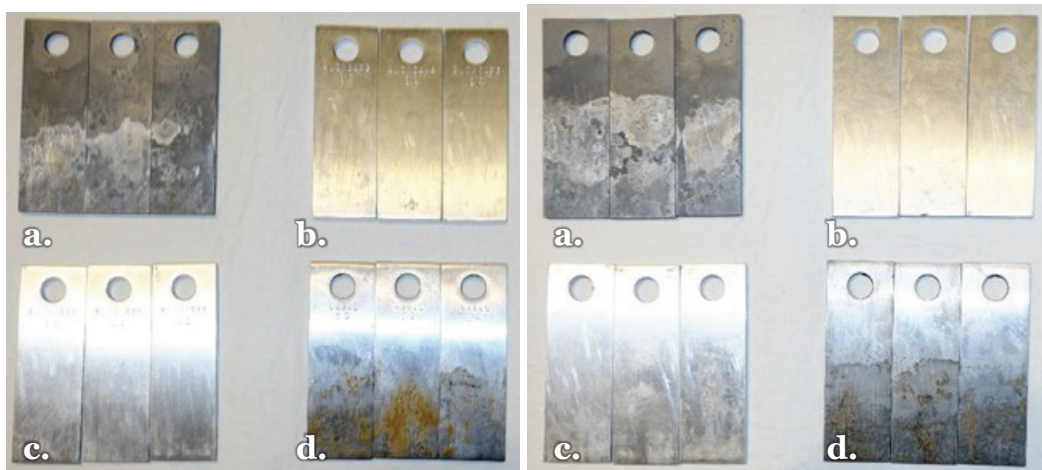
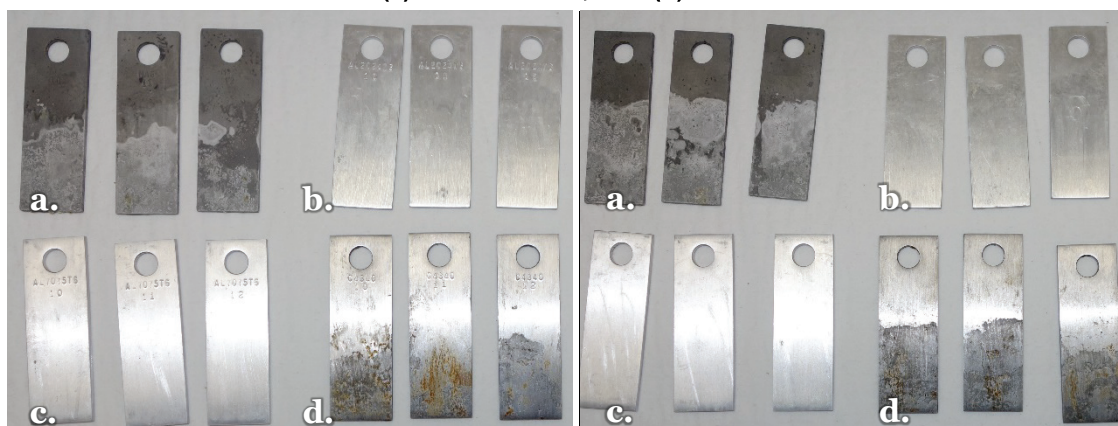


Figure A90. Metal coupons after 120 days in soil treated with BioSoyl Plus: (left) fronts and (right) backs. Metals are (a) magnesium, (b) aluminum T3, (c) aluminum T6, and (d) steel.



Figure A91. Metal coupons after 360 days in soil treated with BioSoyl Plus: (left) fronts and (right) backs. Metals are (a) magnesium, (b) aluminum T3, (c) aluminum T6, and (d) steel.



Unit Conversion Factors

Multiply	By	To Obtain
cubic feet	0.02831685	cubic meters
cubic inches	1.6387064 E-05	cubic meters
degrees (angle)	0.01745329	radians
degrees Fahrenheit	(F-32)/1.8	degrees Celsius
feet	0.3048	meters
gallons (U.S. liquid)	3.785412 E-03	cubic meters
horsepower (550 foot-pounds force per second)	745.6999	watts
Inches	0.0254	meters
inch-pounds (force)	0.1129848	newton meters
miles (U.S. statute)	1,609.347	meters
miles per hour	0.44704	meters per second
pounds (force)	4.448222	newtons
square feet	0.09290304	square meters
square inches	6.4516 E-04	square meters

REPORT DOCUMENTATION PAGE

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OMB No. 0704-0188

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