Technical Report

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solid earth

Implementation of Solid Earth Inc. for Soil Stabilization, Dust, Erosion Mitigation and Eco Paving

The New Economy Initiative (NEI) Science and Technology Centers (STCs)

Arizona State University

By

Jolina J. Karam, Ph.D.

Carlos J. Obando, Ph.D.

Jose R. Medina, Ph.D, P.E.

Kamil E. Kaloush, Ph.D, P.E.

School of Sustainable Engineering and the Built Environment

Ira A. Fulton Schools of Engineering

Arizona State University

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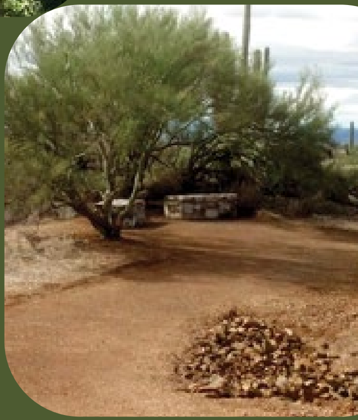


Introduction

Soil stabilization is a crucial engineering practice that significantly benefits both environmental sustainability and project efficiency. By enhancing soil properties, stabilization reduces dust, air pollution, erosion, and sediment runoff, while also allowing for the use of marginal soils and preserving prime agricultural land. It improves soil strength, durability, and load-bearing capacity, making it adaptable for various applications from construction to landscaping. This technique is not only environmentally friendly but also cost-effective, utilizing locally sourced materials and lowering long-term maintenance expenses. Stabilized pavements, in particular, show superior performance and durability compared to non-stabilized bases, leading to fewer maintenance issues and extended lifespans. Overall, soil stabilization contributes to sustainable infrastructure development, offering both economic and environmental advantages.

Traditional soil stabilizers like lime and fly ash, while commonly used in construction, face significant environmental sustainability issues. Lime and cement, despite their effectiveness, have notable drawbacks. Lime production emits substantial carbon dioxide and alters soil pH, which can disrupt soil microbiota and harm biodiversity (Tiina, 2022). Excessive use of lime can also affect the pH of nearby water bodies, impacting aquatic ecosystems. Cement production, known for its high energy consumption, releases large quantities of carbon dioxide and causes environmental degradation through resource extraction. These challenges underscore the need for more sustainable soil stabilizers that deliver comparable benefits with reduced environmental impact (Cheng et al., 2023; Environmental Impacts of Concrete Construction and Manufacturing, 2023; Kilns, Calcination & Energy Efficiency, 2022).

This study focuses on evaluating the performance of Solid Earth, a novel soil stabilization product, in enhancing soil properties, addressing dust and erosion as a potential natural paving alternative. This research aims to comprehensively evaluate the performance of Solid Earth as a soil stabilization product on different types of soils. Specific objectives include determining optimal application rates for the diverse soil types to maximize soil strength and durability improvements. Additionally, the study will assess the potential environmental implications of using Solid Earth and develop practical guidelines for its implementation in various soil stabilization projects. By achieving these objectives, this research seeks to contribute to the advancement of soil stabilization practices and inform effective decision-making in infrastructure development. Finally, a Material Safety Data Sheet (MSDS) and a Technical Data Sheet (TDS) were developed and are included in Appendix A and B respectively.

Methodology

Materials

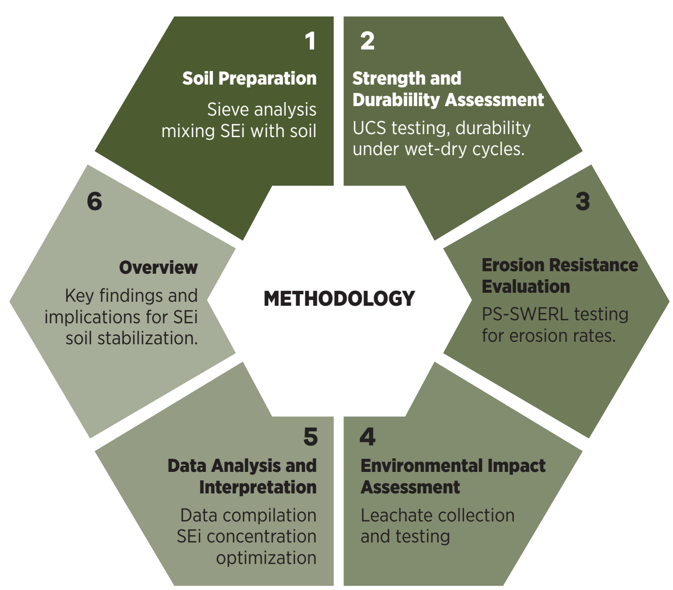
Solid Earth

Solid Earth (SEi) is an eco-friendly liquid polymer soil stabilizer developed by Solid Earth Inc., designed to enhance soil properties while offering several advantages over traditional methods. Key benefits include increased soil strength and durability, reduced dust generation in arid environments, improved moisture and erosion resistance, and an environmentally friendly formulation that preserves the natural soil appearance. As a polymer-water-based solution, Solid Earth uses large polymer molecules to bind and strengthen soil particles. The ratio of polymer to water can be adjusted depending on the desired soil strength.

When applied, the polymer forms a cohesive matrix with soil particles, creating a durable and water-resistant surface. It is particularly effective on granular soils, although its efficacy on fine-grained soils can vary. The application process involves diluting the solution with water, spraying it on the soil surface, and then compacting the soil. The dilution ratio depends on the soil type and application, with lower dilution recommended for structural stability and higher dilution for dust control. Solid Earth's non-heat process reduces maintenance costs, enhances durability, and maintains soil structure even in moist conditions. It is especially beneficial in desert areas for controlling dust.

Soils

Seven different soil types were characterized for Solid Earth stabilization. The Liquid Limit, Plastic Limit and Plasticity Index were determined, followed by the soil size distribution for each. The optimum particle size and Solid Earth content, compressive strength, durability and environmental impacts as well as wind erosion and permeability were evaluated for the different soils acquired (Figure 1). Two dilution ratios were assessed, 10:1 and 20:1 of water to Solid Earth parts. Finally, lime stabilization was tested for strength and durability to compare with Solid Earth stabilized soils.



Methodology

Two soils were sourced from Arizona, and the other five were obtained from different locations in Barbados. A visual representation of the soils tested in this study are shown in Figure 2.

The first soil from Arizona called CF, is a very strong soil made from crushed gravel. It is made of sand with 10% fines. The second soil was sourced from Scottsdale, Arizona, and is made of sand with 2% fines, labelled as “SA”. As for the five soils imported from Barbados, they were sourced from different locations across the island. These soils were labeled as “BG”, “WH”, “RS”, “LS” and “MS”. The last soil was originally made of asphalt pavement millings mixed with aggregates. In general, this soil is made of sand, asphalt millings and very little fines and was labelled as “MS”.

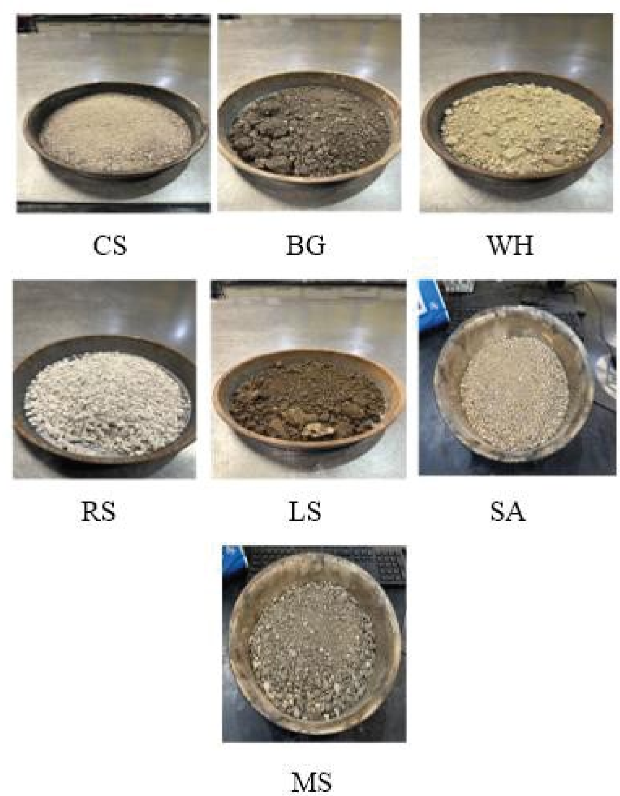


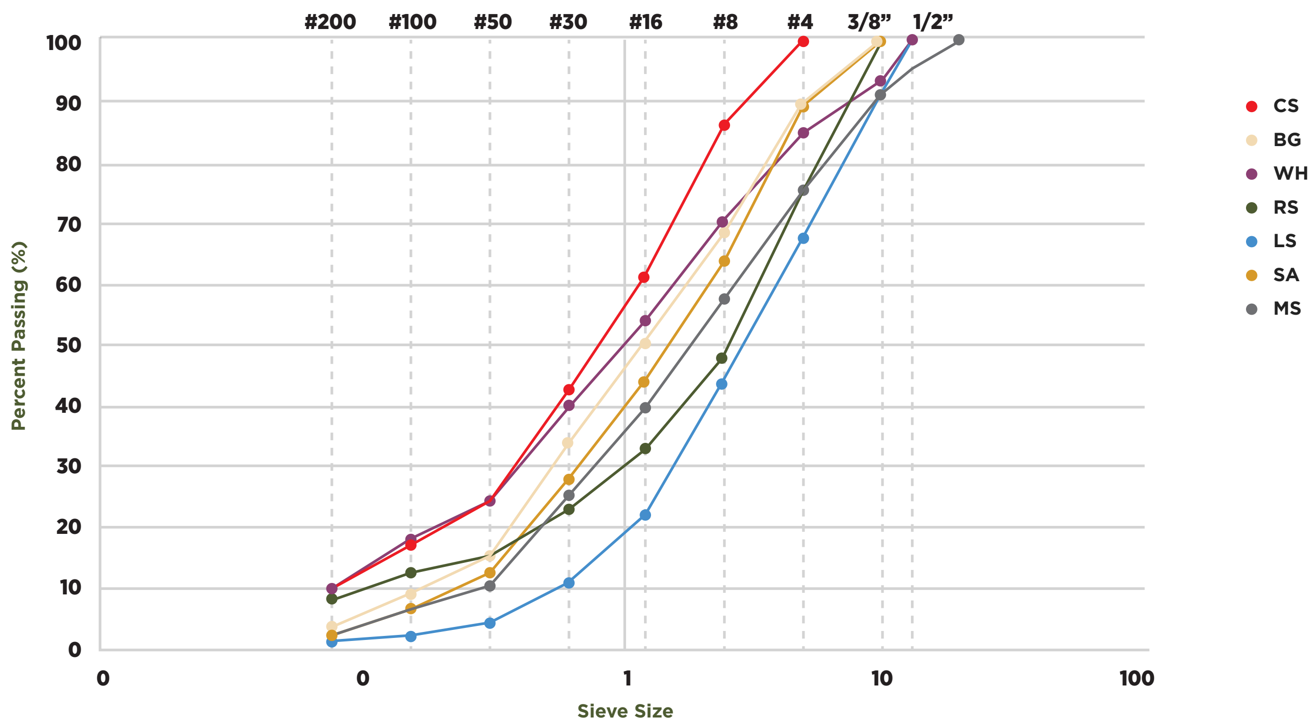
Figure 2.
Visual Representation of the Soils Evaluated

Discussion and Results

Soil Classification

The Liquid limit (LL), plastic limit (PL), and plasticity index (PI) were used to describe the properties of soil and clay (ASTM D4318, 2018), in addition to the grain size distribution analysis (ASTM D6913, 2017).

These methods were used to identify the best aggregate size that will yield larger thicknesses of stabilized soils. The results are shown in Figure 2, where all the soils evaluated in this project were sieved using a stack of sieve from ½'' to #200. The soil was handled as per field conditions and dried before sieving to obtain repeatable and consistent results compatible with the field observations.



Discussion and Results

Soil Classification

The Atterberg Limits of BG, WH and LS were tested in the laboratory, and are summarized in Table 1. The other soils were observed to have a granular behavior, where those parameters could not be tested. According to the Unified Soil Classification Standard (USCS) (Howard, 1986), the soils were classified as containing sands, silts and clays, where the WH soil is highly plastic, and LS and BG have medium plasticity.

After multiple trials, it was determined that the optimum aggregate size for sample stabilization of thicknesses less or equal to 100 mm (or 4 inches), aggregates passing sieve #4 showed the best results. If thinner thicknesses are desired, larger aggregate sizes could be used.

Table 1.
Liquid Limit, Plastic Limit and Plasticity Index of Barbados Soils.

PROPERTY	WH	LS	BG
LL	89%	54%	48%
PL	70%	45%	38%
PI	18%	9%	10%
USCS Soil Classification	Highly Plastic	Medium	Medium
	MH&OH	ML&OL	ML&OL
	Inorganic Silts sand and clay	Sandy Silts with clay	Sandy Silts with clay

Modified Proctor Test: ASTM D1557

The modified Proctor test (ASTM D1557-21, 2021) was used to determine the optimal SEi content needed to achieve maximum soil compaction in the field. This testing method is essential for determining the appropriate SEi content for enhancing soil performance and provides valuable information for controlling costs and estimating material quantities for various projects. By quantifying the SEi product required, the test ensures that the desired soil durability and strength are met. Typically, compacting soil at higher water content results in a more dispersed and weaker soil structure, whereas soil compacted with less water forms a denser, stronger structure. The same principle was applied when using SEi instead of water.

Modified Proctor Test: ASTM D1557

Two SEi ratios (10:1 and 20:1) were tested across several soil types, with SEi contents ranging from 4% to 20% by weight of dry soil.

For each test, the soil was oven-dried, and the modified soil was compacted in layers using a 2 kg rammer. After compaction, the weight of the soil and its moisture/SEi content were measured. The maximum dry density and corresponding SEi content were recorded, allowing for comparison between SEi and traditional moisture-based compaction methods.

The obtained results are summarized in Table 2 for all soil types. When the SEi solution is used, an additional 1% was noted when compared to regular water.

Table 2.
Optimum Water and SEi Contents for Ratios 20:1.

SOIL TYPE	OPT. WATER CONTENT	OPT. SEi CONTENT
CF	11%	12%
BG	7%	8%
WH	7%	8%
RS	10%	11%
LS	12%	13%
SA	11%	12%
MS	9%	10%

For the 10:1 ratio, the modified proctor test was performed on the CF soil. The results showed an optimum content of 10% of SEi compared to 12% with a ratio of 20:1. In other words, less solution is needed when the dilution ratio is smaller.

Unconfined Compression Strength (UCS): ASTM D2166

The unconfined compression strength (UCS) test (ASTM D2166, 2010) is essential in geotechnical engineering as it measures the compressive strength of soil samples without lateral confinement and gives indication about its load. This test helps determine the soil's load-bearing capacity, which is critical for designing safe and reliable structures like foundations and embankments.

For stabilized soils, the UCS test assesses the effectiveness of stabilization techniques, ensuring improvements in soil performance for applications such as road pavements and embankments. It is also essential for quality control, verifying that treatments meet project specifications and confirming the adequacy of natural soils for construction.

In this study, UCS samples (Figure 4) with a height-to-diameter ratio of 2.5 were tested using six replicates per soil type, with compression applied at a constant strain rate of 1.2%.

To compare the performance of the stabilized soils, control samples were created using water at the optimum water content found in Table 2, whereas SEi stabilized samples were also created using the optimum SEi content found in the same table. The samples were cured under a 250W heat lamp for four hours prior to testing.

The unconfined compression strength test results for all the soils at a ratio of 20:1 are shown in Table 3. Soils treated with SEi at a 20:1 dilution ratio showed significant improvements in UCS for all soil types: for CS and SA, the UCS increase is not as substantial compared to the others but is still significant. As for the WH soil, given that it is a very problematic soil with high plasticity, the addition of SEi did not seem to provide any benefit in terms of strength.
The interesting results to be noted are with reference to MS, with a 324% improvement in UCS. As this soil is a mix of asphalt millings, the strength resulting from the SEi stabilization is interestingly positive. Furthermore, BG soil as well as the LS soil, having clay in their composition, are positively enhanced with the presence of SEi as stabilizer.

Figure 4.
UCS Test Samples.

Unconfined Compression Strength (UCS): ASTM D2166

For the lime-treated soil, UCS was found to be 327 kPa, which is not very promising in terms of strength compared to the control of 706 kPa.

For a different dilution ratio of 10:1 for CS, the UCS was found to be equal to 2,639 kPa, leading to an increase in UCS of 67%, compared to 40% with a ratio of 20:1. This refers to a higher compression strength when using a lower dilution ratio.

Table 3.
UCS Test Results.

UCS (kPa)			
SOIL TESTED	CONTROL	SEI TREATED (20:1) AY OPTIMUM CONTENT	% INCREASE
CS	1579	2206	40%
BG	133	229	72%
WH	249	174	-30%
RS	285	1786	527%
LS	52	119	129%
SA	706	1256	78%
MS	143	608	324%

Tensile Strength Ratio (TSR): AASHTO T283

The Tensile Strength Ratio (TSR) test, as outlined in (AASHTO T283, 2022), is essential for evaluating the moisture susceptibility of asphalt mixtures by measuring how moisture exposure impacts the material's strength. This test is crucial in assessing the durability and potential moisture-induced damage in asphalt pavements, such as stripping and reduced lifespan.

For SEi-stabilized soils, the TSR test was adapted to examine the effects of moisture, as well as freeze-thaw cycles, which are particularly important in wet-freeze regions. Soil samples made from CS were stabilized with optimum SEi content and then subjected to the following procedure:

- Samples were divided into unconditioned (untreated) and conditioned (subjected to moisture and freeze-thaw treatment) groups.
- Moisture conditioning involved submerging samples in water, followed by freezing at - 18°C for 16 hours, and then thawing in a 60°C water bath for 24 hours.
- The specific gravity of the loose SEi-treated soil (similar to the Maximum Theoretical Specific Gravity for asphalt) and the Bulk Specific Gravity of the cylindrical sample were determined. From these values, the air void content was calculated.
- A degree of saturation of 80% was achieved using a vacuum mechanical shaker, ensuring the sample could freeze without damage.

The test involved loading soil samples in the diametrical direction at a rate of 50 mm/min (2 in/min) and at a temperature of 25°C. After conditioning, the samples were still wet, leading to observations based on their moisture state: fully wet, half dried (after a few hours of drying), or fully dried (following moisture, freezing, and thawing).

The strength results for all samples, categorized by their moisture condition, are summarized in Table 4. The Tensile Strength Ratio (TSR) was calculated as the ratio of wet strength to dry strength obtained after failure.

Table 4.
TSR Test Results.

TESTING CONDITIONS	WET STRENGTH (kPa)	DRY STRENGTH (kPa)	TSR
Half Dry	78.5	266.4	29%
Fully Dry	192.1	194.6	99%
Fully Wet	9.41	194.5	5%

Tensile Strength Ratio (TSR): AASHTO T283

The results showed that SEi-stabilized soil samples gained strength as they dried. Initially, the fully wet samples exhibited minimal strength, but strength increased from the half-dried to the fully dried state. This behavior suggests self-healing properties, indicating that SEi-stabilized soils retain their strength as they dry in the field. A Tensile Strength Ratio (TSR) of 0.80 (80%) is considered acceptable, ensuring sufficient resistance to moisture- induced moisture damage.

Durability Testing and Resistance by Wetting and Drying: ASTM D559

The test for soil-cement durability (ASTM D559, 2023) assesses the resistance of soil- cement mixtures to disintegration, erosion, and physical degradation through cycles of wetting and drying. This simulation of natural environmental conditions helps evaluate the mixture's durability.

In this project, cement was replaced with SEi stabilization. The procedure involved:

- Preparing two samples at optimum SEi content using standard proctor molds and curing them under a heat lamp overnight for complete curing.
- Subjecting the samples to 12 cycles of wetting (5 hours immersion in water) and drying (42 hours in an oven at 71°C or 160°F).
- Inspecting the samples after each cycle for damage such as cracking or scaling. One sample remained unaltered, while the other was brushed 18 times with a wire brush.
- Recording the specimens' weight before and after each cycle to measure material loss due to disintegration.
- Measuring sample dimensions after each cycle to check for volume changes.

Durability Testing and Resistance by Wetting and Drying: ASTM D559

Durability was assessed based on the percentage of weight loss, with lower weight loss indicating higher durability. It was noticed that after 6 cycles the results were not significantly changing. The results are reported in the following tables:

Table 5.
Durability Test Results: Volume Change.

VOLUME CHANGE		
SOIL TYPE	**SAMPLE 1**	**SAMPLE 2**
CF	1%	3%
RS	12%	8%
SA	-1%	-7%
MS	1%	-3%
CF LIME TREATED SOIL	-4%	-18%

Table 6.
Durability Test Results: Weight Change.

WEIGHT CHANGE		
SOIL TYPE	**SAMPLE 1**	**SAMPLE 2**
CF	-1%	-2%
RS	-1%	-1%
SA	-4%	-9%
MS	-1%	-2%
CF LIME TREATED SOIL	-2%	-4%

Durability Testing and Resistance by Wetting and Drying: ASTM D559

The results showed that lime-treated soil experienced the most shrinkage after 6 cycles compared to SEi-stabilized soils. In terms of weight loss, all SEi-stabilized specimens demonstrated high durability, with weight loss under 5% for unbrushed samples and under 10% for brushed ones. According to the Portland Cement Association (PCA), a weight loss under 14% is acceptable, so the SEi-stabilized samples performed very well. The SEi-stabilized samples also exhibited consistent volume changes, indicating good dimensional stability compared to lime- stabilized soil. Attempts to test other soil types, such as BG, WH, and LS soils, were unsuccessful due to the clayey nature of these soils causing shrinkage and sample failure, as shown in Figure 5.

Based on those observations, it was determined that the Solid Earth stabilization is still effective for clayey and silty soils in terms of erosion control. For thinner layers, the stabilization may still work based on the clayey and sand content of the soil, as the shrink-swell behavior was minimized to some extent. For best performance, mixing sand with clayey soils may minimize this effect even further.

Figure 5.
LS (Left) and WH and BG (right) Durability Samples.

Environmental Impact: Leachate Analysis

Nutrients Analysis

Leachate analysis is crucial for determining potential contamination of groundwater and surface water by identifying harmful chemicals. Nutrients in leachate can significantly impact ecosystems, particularly water bodies.

Environmental Impact: Leachate Analysis

Nutrients Analysis

- **Ammonia (NH3).**
  Originates from decomposed organic matter and can be toxic to aquatic life, causing oxygen depletion and contributing to eutrophication. It can also lead to nitrate formation and toxic buildup in tissues (Burton & Watson-Craik, 1998).

- **Nitrate (NO3-).**
  Formed from ammonia oxidation, nitrate is highly soluble and can contaminate groundwater. Excessive nitrate leads to eutrophication, algal blooms, and health issues such as "blue baby syndrome" in infants (Follet, 2012).

- **Phosphate (PO43-).**
  Less mobile but can still leach into groundwater, promoting algal growth and causing oxygen depletion in water bodies, disrupting aquatic ecosystems (Correll, 1998).

- **Chlorine (Cl-).**
  Present as chloride, it can harm both terrestrial and aquatic environments by increasing salinity and affecting freshwater species. Chloride is challenging to remove with conventional treatment methods and can contribute to infrastructure corrosion (Boyd, 2020).

- **Dissolved Organic Carbon (DOC).**
  Indicates the organic load in leachate, impacting water treatment and potentially forming harmful disinfection byproducts. Elevated DOC can affect microbial activity and oxygen levels in aquatic systems (Schwarzenbach et al., 2002).

- **Dissolved Inorganic Carbon (DIC).**
  Includes carbon dioxide, bicarbonate, and carbonate, influencing leachate pH and buffering capacity. It affects water chemistry and helps mitigate acidic conditions (Stumm & Morgan, 1996).

In the study, SEi-stabilized soil samples at ratios 10:1 and 20:1 were soaked in distilled water for one month before testing. Water samples from this soaking process, along with a distilled water sample for comparison, were analyzed for these nutrients. The results and acceptable levels are detailed in.

Table 7.
Leachate Analysis - Nutrients.

NUTRIENTS	CONTROL (mg/L)	10:1 (mg/L)	20:1 (mg/L)	ACCEPTABLE LEVELS
C1-	0.197	30.183	44.9	Maximum safe level in drinking water: 250 mg/L (2019)
3-	0.002	0.072	0.026	Maximum safe level in rivers: 0.1 mg/L (2011)
NH4	ND	1.19	ND	Ammonia Range for safe level in water: 0.25 mg/L to 32.5 mg/L (2017) Maximum safe levels of Nitrite and Nitrate: 1 mg/L and 10 mg/L respectively (2017)
NO2	0.0005	0.0058	0.0024	
NO2+NO3	0.004	0.057	0.011	
DIC	6.087	56.96	37.53	In most surface water 3.5 to 350ppm (Cole et al., 2021)
DOC	0.8272	36.18	50.99	Surface waters typically show thousands of mg/L depending on the source (Chapelle, 2022)

Environmental Impact: Leachate Analysis

Nutrients Analysis

According to the all stabilized samples, with both ratios, are within the safe levels for the nutrients when it comes to surface and drinking waters. For the lower dilution ratio (10:1), where the solution is more concentrated, higher concentrations are observed but still within the acceptable ranges.

Metal Concentrations

Metals in leachate are critical to analyze due to their potential toxicity, mobility, and long- term environmental impact. Both heavy metals and trace metals are commonly analyzed because of their harmful effects and persistence in the environment. Monitoring these metals is essential for assessing risks to human health, groundwater, surface water, and ecosystems.

In this report, only the metals with concentrations higher than those in the control distilled water are presented, along with their acceptable levels, as shown in Table 8.

Table 8.
Leachate Analysis - Metals.

METALS	CONTROL (mg/L)	10:1 (mg/L)	20:1 (mg/L)	ACCEPTABLE LEVELS (MERIDE & AVENEW, 2026)
Ca (Calcium)	0.51	60.25	43.31	In water, high levels can contribute to water hardness and may affect industrial processes and water distribution systems. In soil, excessively high levels can interfere with the uptake of other essential nutrients by plants. Permissible levels: 75 mg/L
K (Potassium)	1.09	4.43	7.33	Not a concern as a pollutant Permissible levels: 12 mg/L
Mg (Magnesium)	0.31	6.78	5.99	Major contributor to water hardness, along with calcium. In water, high levels can contribute to soil salinity and affect plant growth. May need to consider the content in irrigation water to prevent soil degradation. Permissible levels: 50 mg/L
Na (Sodium)	2.1	55.89	58.4	High levels contribute to high salinity. Permissible levels: 250 mg/L

Environmental Impact: Leachate Analysis

Nutrient Analysis

Metal Concentrations

The results in Table 10 indicate that the addition of Solid Earth does not harm surface water, soil, or surrounding vegetation. The metals analyzed showed concentrations similar to those in distilled water, suggesting that they are not harmful to the environment. This includes commonly tested toxic metals such as lead, mercury, cadmium, arsenic, chromium, zinc, and copper, all of which were found at levels comparable to distilled water and thus deemed environmentally safe.

Permeability Test (Ksat): ASTM D5084

The permeability of stabilized soil, specifically its saturated hydraulic conductivity (Ksat), is crucial for managing water infiltration and surface runoff. The Ksat measures how easily water moves through soil, which impacts erosion control and drainage (ASTM D5084, 2016). For this analysis, samples of CF were tested with and without Solid Earth treatment. The soil samples were prepared in standard rings, saturated with degassed water for 24 hours, and then placed in a Ksat device. Water flow through the samples was measured to calculate Ksat using Darcy's Law.

The untreated control sample had a Ksat of 5.3E-6 m/s, while the Solid Earth-stabilized sample had a Ksat 8.5E-7 m/s. This indicates that the stabilized soil has lower permeability, meaning reduced water infiltration and better erosion control. Since water does not easily infiltrate these soils, surface runoff is reduced, decreasing the likelihood of soil erosion caused by water flow. In addition, high permeability resistance can be advantageous for environmental protection. Such soils are effective in containing pollutants and preventing their migration into groundwater. However, it can also pose some challenges as proper drainage must be in place, as excess water may accumulate on the surface rather than infiltrating.

Wind Erosion Resistance Using the Portable In-Situ Wind Erosion Laboratory (PI- SWERL)

The PI-SWERL is a portable device designed for real-time measurement of wind erosion and dust emissions across various environments. It features a wind tunnel with adjustable speeds, sensors for wind speed, dust concentration, soil moisture, and a data logger. The wind tunnel's core component is a circular chamber with a motorized fan and a Rotating Annular Blade (RAB) to simulate wind conditions and assess soil erosion thresholds (Figure 6). The device measures dust particles' concentration, size, and composition, and uses a DustTrak II monitor to detect PM10 particles, which are harmful when inhaled. During testing, soil samples stabilized with water or Solid Earth are placed under a foam seal, and the PI-SWERL gradually increases the blade speed from 0 to 6,000 RPM in 700 seconds to measure soil's resistance to wind erosion and dust emissions.

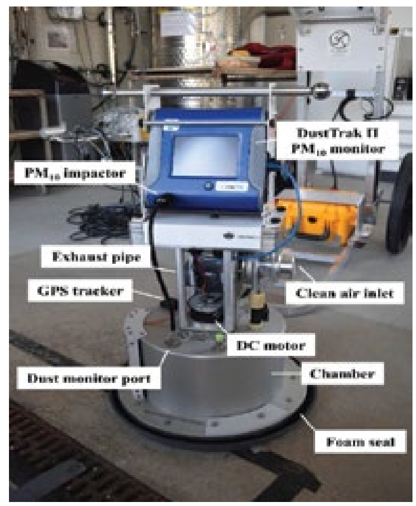


Figure 6.
PI-SWERL Testing Equipment.

The PM10 concentrations for both samples (Control and SEi) were recorded with time. At 12 m/s (about 4000 RPM after 12 minutes), which is considered to be very high wind speed conditions (van Leeuwen et al., 2021), the results are presented in Table 9 below:

Table 9.
PI-SWERL Test PM10 Results.

SOIL TYPE	CONTROL (mg/m3)	SEi (mg/m3)	REDUCTION %
CF	8.7	0.868	90%
RS	0.699	0.652	7%
WH	189	67	65%
LS	7.2	3.74	48%

Wind Erosion Resistance Using the Portable In-Situ Wind Erosion Laboratory (PI- SWERL)

Based on the results observed in Table 9, it can be seen that the stabilization was very effective with respect to wind erosion resistance. A decrease in dust concentration up to 90% was measured. A smaller reduction in dust concentration was measured for the Rayside soil, as it has lower content of fines.

Summary and Conclusions

Soil stabilization improves soil's physical properties, such as strength, durability, and erosion resistance, making it useful for unpaved roads, parking lots, dust control, and erosion management. Traditional stabilizers like Cement and Lime, while effective, have drawbacks including leaching, high energy consumption, and significant CO2 emissions. In contrast, Solid Earth (SEi) offers an eco-friendly alternative by creating a durable, water-resistant surface with minimal environmental impact.

This study evaluated SEi's performance on seven soil types, comparing it with lime stabilization. Key findings include:

- **Strength:** SEi significantly enhanced the unconfined compression strength of most soil types, except high plasticity soils. Optimal strength was achieved with a slower curing method using a heat lamp.
- **Durability:** SEi-stabilized soils showed minimal weight loss and volume change, outperforming lime stabilization.
- **Environmental Impact:** Leachate analysis indicated SEi has minimal groundwater contamination and is environmentally friendly.
- **Wind Erosion:** SEi reduced dust by up to 90%, demonstrating strong erosion resistance.
- **Permeability:** SEi decreased water infiltration, aiding in surface runoff control and pollutant containment.

SEi proved effective, especially with sandy soils, offering higher strength and better erosion control. It also showed some effectiveness with clayey soils, though it is recommended to mix these with sand to improve performance. Overall, SEi is a promising alternative to traditional stabilizers, offering both enhanced soil properties and environmental benefits.

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Appendix A

Technical Report

Implementation of Solid Earth Inc.
for Soil Stabilization, Dust,
Erosion Mitigation and Eco Paving

Appendix A

SOLID EARTH MATERIAL SAFETY DATA SHEET (MSDS)

General Information

PRODUCT NAME	SOLID EARTH®
General names	Soil Solidifier, Soil Stabilizer Dust Control Agent, Dust Inhibitor, Dust Retardant
Manufacturer	Solid Earth® https://www.solidearthinc.com/ 1027 E Curry Rd Tempe, AZ 85288, USA
Associated patents	U.S. Patent No. Pending
Contact	HADAR RAHAV - PRESIDENT hadar@solidearthinc.com Tel: 480.446.9000 Fax: 480.446.9001
Description	Solid Earth is a unique, innovative, eco-friendly liquid polymer soil solidifier installed using existing or imported soil producing durable, long-lasting, water resistant, solid load-bearing roadways, pathways and other solid high compressive strength surfaces. When used to stabilize existing soil on the ground, slopes or embankments, Solid Earth dramatically reduces mud, dust and erosion. Solid Earth surfaces provide exceptional durability and longevity without harming or polluting the environment while maintaining existing indigenous landscapes.

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SOLID EARTH MATERIAL SAFETY DATA SHEET (MSDS)

Hazards Classification

U.S.HAZARDOUS MATERIALS IDENTIFICATION SYSTEM (HMIS) RATING

Health	**0**	No significant risk to health
Flammability	**1**	Non-flammable, but will burn on extended contact to flame or high temperature.
Physical Hazard	**0**	Stable, non-explosive and non-reactive
Personal Protection	**-**	No special hazard in normal use

ACCORDING TO OSHA CRITERION, THIS MATERIAL IS NOT CONSIDERED HAZARDOUS

Appearance	Viscous fluid, white color
Odor	Resinous-almond
Safety Hazards	Nonflammable, but will burn on extended contact to flame or high temperature
Health Hazards	Harmful: may cause lung injury if swallowed and enters air ways
Environmental Hazards	Not classified as hazardous for the environment

HEALTH HAZARDS

Inhalation	In usual conditions of use, this material is not likely to be a primary way of exposure
Skin contact	Repeated or prolonged or skin contact without appropriate cleaning can block the pores of the skin follow-on disorders such as acne
Eye contact	Eye contact
Ingestion	Harmful: may cause lung injury if swallowed and enters air ways

Signs and symptoms

Signs and symptoms, if material enters lungs, may include choking, wheezing, coughing, chest congestion, difficulty in breathing, shortness of breath, and/or fever. The beginning of respiratory symptoms may be postponed for some hours after contact. Ingestion may result in vomiting, diarrhea, and/or nausea.

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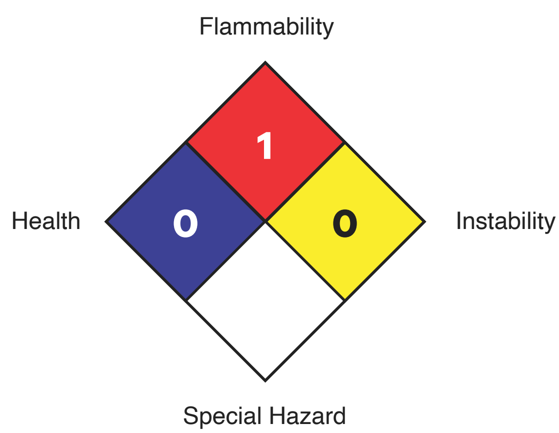
Fire-fighting Measures

Flammability	Non-flammable, but will burn on prolonged exposure to flame or high temperature.
Extinguishing Media	Use foam, water spray or fog. Dry chemical powder, carbon dioxide, sand or earth may be used for small fires only.

SPECIAL FIRE FIGHTING PROCEDURES & PROTECTIVE EQUIPMENT

Do not use water in a jet. Proper protective equipment including breathing apparatus must be worn when approaching a fire in a confined space.

U.S. NATIONAL FIRE PROTECTION ASSOCIATION (NFPA) 704 HAZARD CLASS



Legend:

0 - Minimal
1 - Sligth
2 - Moderate
3 - Serious
4 - Severe

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SOLID EARTH MATERIAL SAFETY DATA SHEET (MSDS)

First-aid Measures

INGESTION	No treatment necessary under normal conditions of use. If swallowed do not induce vomiting. If symptoms persist, request medical attention.
INHALATION	No treatment necessary under normal conditions of use. If breathing difficulties develop move injured party away from source of exposure and into fresh air in a position comfortable for breathing. If symptoms persist, look for medical attention.
SKIN CONTACT	No treatment necessary under normal conditions of use. Remove contaminated clothing. Wash affected area with mild soap and water. If irritation or redness develops and persists, seek medical attention.
EYE CONTACT	If irritation or redness develops from exposure, flush eyes with clean water. If irritation persists, ask for medical attention.

Handling and Storage

STORAGE	Keep container tightly closed in a cool, well-ventilated place. Use properly labeled and closeable containers.
HANDLING	Avoid breathing vapors or mist. Avoid contact with eyes. Avoid prolonged or repeated contact with skin. Wash thoroughly after handling. When handling product in drums, safety footwear should be worn, and proper handling equipment should be used.

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SOLID EARTH MATERIAL SAFETY DATA SHEET (MSDS)

Accidental Release Measures

PROTECTIVE MEASURES	Stop the leak, if possible. Avoid contact with skin and eyes. Use appropriate containment to avoid environmental contamination. Prevent from spread in go entering drains, ditches, sewers, rivers or open bodies of water by using sand, earth or other appropriate barriers.
CLEAN-UP METHODS	Avoid accidents, clean up immediately. Slippery when spilled. Prevent from spreading by making a barrier with sand, earth or other containment material. Reclaim liquid directly or in an absorbent. Soak up residue with an absorbent such as clay, sand or other suitable material and dispose of properly.
ADDITIONAL ADVICE	Local authorities should be advised if significant spillages can't be contained.

Toxicological Information

SKIN IRRITATION	Likely to be slightly irritating.
EYE IRRITATION	Likely to be slightly irritating
RESPIRATORY IRRITATION	Breathing of vapors or mists may cause irritation.
SENSITIZATION	Unlikely to be a skin sensitizer.
REPEATED DOSE TOXICITY	Unlikely to be a hazard.

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SOLID EARTH MATERIAL SAFETY DATA SHEET (MSDS)

Exposure Controls/Personal Protection

EXPOSURE CONTROLS	The level of protection and types of controls necessary will vary depending upon potential exposure conditions. Select controls based on a risk assessment of local circumstances.
PERSONAL PROTECTIVE EQUIPMENT	Personal protective equipment (PPE) should meet recommended national standards.
RESPIRATORY PROTECTION	Respiratory protection is not required under normal conditions of use in a well-ventilated workplace. In accordance with good industrial hygiene practices, precautions should be taken to avoid breathing of material.
EYE PROTECTION	Eye protection is not required under normal conditions of use. If material is handled such that it could be splashed into eyes, wear splash-proof safety goggles or full-face shield.
PROTECTIVE CLOTHING	Skin protection is not required under normal conditions of use or for single, short-duration exposures. For prolonged or repeated exposures, use impervious chemical-resistant boots, gloves and/or aprons over parts of the body subject to exposure.

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SOLID EARTH MATERIAL SAFETY DATA SHEET (MSDS)

Ecological Information

CHEMICAL CONTENTS	CHEMICAL CONTENTS	SIGNIFICANCE	ACCEPTABLE LEVELS
CHLORIDE	**CI**	Presence is salty, corrodes pipes pumps and plumbing fixtures. Not harmful to health.	Maximum safe level in drinking water: 250 mg/L 1
PHOSPHORUS	**PO4**	Presence leads to growth of aquatic algae and plants.	Maximum safe level in rivers: 0.1 mg/L 2
AMMONIA, NITRITE, NITRATE	**NH4 NO2 NO3**	Presence of Ammonia in high levels causes toxic buildup in tissues and blood. Presence of Nitrite and Nitrate in high levels increase heart rate, nausea and headaches.	Ammonia Range for safe level in water: 0.25 mg/L to 32.5 mg/L 3 Maximum safe levels of Nitrite and Nitrate: 1 mg/L and 10 mg/L respectively 3

CHEMICAL	CONTROL (mg/L)	10:1 (mg/L)	20:1 (mg/L)	ACCEPTABLE LEVELS
CI	**0.197**	**30.183**	**44.9**	Maximum safe level in drinking water: 250 mg/L1
PO4	**0.002**	**0.072**	**0.026**	Maximum safe level in rivers: 0.1 mg/L2
NH4	**ND**	**1.19**	**ND**	Ammonia Range for safe level in water: 0.25 mg/L to 32.5 mg/L3 Maximum safe levels of Nitrete and Nitrate: 1 mg/L and 108mg/L respectively 3
NO2	**0.0005**	**0.0058**	**0.0024**	
NO2+NO3	**0.004**	**0.057**	**0.011**	
DIC	**6.087**	**36.18**	**37.53**	In most surface water 3.5 to 350 ppm4
DOC	**0.8272**	**56.96**	**50.99**	Maximum safe level in drinking water: 250 mg/L1

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SOLID EARTH MATERIAL SAFETY DATA SHEET (MSDS)

Ecological Information

CONCENTRATIONS OF IMPORTANCE (PPM)	CONTROL	10 TO 1	20 TO 1	SIGNIFICANCE
Ca (Calcium)	0.51	60.25	43.31	In water, high levels cn contribute to water hardness and may affect industrial processes and water distribution systems. In soil, excessively high levels can interfere with the uptake of other esential nutrients by plants. Permissible levels of Calcium is 75ppm according to WHO for drinking water 7
K (Potassium)	1.09	4.43	7.33	Potassium is not a concern as a pollutant. Permissible levels of Potassium es 12ppm according to WHO fos drinking water 7
Mg (Magnesium)	0.31	6.78	5.99	Major contributor to water hardness, along with calcium. High levels in irrigation water can contribute to soil salinity and affect plant growth. It may be necessary to consider the contect in irrigation water to prevent soil degradation. Permissible levels is 50ppm according to WHO for drinking water 7.
Na (Sodium)	2.1	55.89	58.4	High sodium levels contribute to high salinity. Permissible levels is 250ppm according to WHO for drinking water 7.

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Technical Report

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SOLID EARTH MATERIAL SAFETY DATA SHEET (MSDS)

Disposal Considerations

MATERIAL DISPOSAL	Recover or recycle if possible. It is the responsibility of the waste generator to determine the toxicity and physical properties of the material generated to determine the proper waste classification and disposal methods in compliance with applicable regulations. Do NOT dispose into the environment, in drains or in water courses.
CONTAINER DISPOSAL	Dispose in accordance with prevailing regulations, preferably to a recognized collector or contractor. The competence of the collector or contractor should be established beforehand.
LOCAL LEGISLATION	Dispose in accordance with applicable regional, national and local laws and regulations.

Disclaimer

No warranty of merchantability, fitness for any particular purpose, or any other warranty is expressed or is to be implied regarding the accuracy or completeness of the information provided above, the results to be obtained from the use of this information or the material, the safety of this material, or the hazards related to its use. No responsibility is assumed for any damage or injury resulting from abnormal use or from any failure to adhere to recommended practices. The information provided above, and the material, are furnished on the condition that the person receiving them shall make their own determination as to the suitability of the material for their particular purpose and on the condition that they assume the risk of their use. In addition, no authorization is given nor implied to practice any patented invention without a license.

Appendix B

SOLID EARTH TECHNICAL DATA SHEET (TDS)

This technical data sheet (TDS) of Solid Earth (soil solidifier, stabilizer and dust control product) is a comprehensive document that provides all relevant data about the product to potential customers, engineers, contractors, and other stakeholders. It is designed to give a clear understanding of the product's composition, features, benefits, application methods, safety information, and technical specifications.

Product Name and Description:

Solid Earth is a unique innovative liquid polymer soil solidifier/stabilizer installed using existing or imported soil to produce solid, water-resistant, load-bearing roadways, pathways and other solid, high compressive strength surfaces without adding pollutants to the substrate or ground water. Used to stabilize ground, slope or embankment soil, Solid Earth effectively reduces mud, dust and erosion. Solid Earth's 15 years of successful testing in the field is now supported by a comprehensive study conducted by a team of scientists from the Arizona State University School of Sustainable Engineering and the Built Environment headed by FORTA Professor of Pavement Engineering Kamil Kaloush, Ph.D., P.E.

Physical and Chemical Properties:

ASPECT/ITEM	VALUE/DESCRIPTION
APPEARANCE	White liquid
ODOR	Resinous-almond
PH VALUE	4.58
BOILING POINT/RANGE	98.2 °C
FREEZING POINT/RANGE	-1.25 °C
VISCOSY, LV-3 @ 20RPM	443.9 cps @ 7.4 Torque %
SPECIFIC GRAVITY OR DENSITY	98.62 lb./US gal - 1.032g/ml%
SOLUBILITY	Soluble in water and other solvents

Composition/Information on Ingredients:

- Binder (~85%)
- Blend of mineral oils and non-ionic surfactants (~0.3%)
- Water (~14%)

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SOLID EARTH TECHNICAL DATA SHEET (TDS)

Performance Data:

ASPECT/ITEM	VALUE/DESCRIPTION
EFFICACY DURATION	Durability Resistance: Wetting and Drying (ASTM D559). Weight loss of soils treated with Solid Earth is about 4.9%. The Portland Cement Association establishes a Maximum limit of 14%. Solid Earth duration is about 3 times lower of the maximum limit established for Portland Concrete. Consistent volume change indicates good dimensional stability.
STRENGTH OR STABILITY ENHANCEMENT METRICS	Unconfined Compression Strength Testing (UCS) /(ASTM D2166) shows that soils treated with Solid Earth can reach 319.2PSI. A soil stabilized with Lime 6% can reach 92PSI. Solid Earth can improve the UCS up to 3.5 times more than conventional methodologies.
WIND EROSION CONTROL AND DUST CONTROL EFFECTIVENESS	Wind Erosion Resistance using PI-SWERL (Portable In-Situ Wind Erosion Laboratory). When soils treated with SE are exposed to wind forces simulated in a controlled environment at 12 m/s and 16 m/s, the erosion is reduced in 90% and 84% respectively.
OPTIMAL CONDITIONS FOR USE	Solid Earth should be blended with water in a ratio of 20:1 (Water Solid Earth). Optimal performance can be found in granular soils such us crusher fines, sand, etc. According to the Proctor Modified Test (ASTM D1557), the optimal Solid Earth solution (20:1) is 12% to obtain a maximum density of 19.7kN/m3.

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SOLID EARTH TECHNICAL DATA SHEET (TDS)

Application Instructions:

ASPECT/ITEM	VALUE/DESCRIPTION
Preparation of the surface/soil prior to application (varies with type of application)	Scarify, till or loosen dirt or gravel surface to a depth of 3 to 4 inches if needed. Apply 2 coats of material with pressurized spray equipment until saturation occurs. Allow brief curing, then compact with roller if necessary. Apply the final finish coat and cure until hardens before introducing traffic.
Recommended application rates and methods (varies with type of application)	Solid Earth should be blended with water in a ratio of 10:1 to 20:1 (Water:Solid Earth). Optimal performance can be found in granular soils such us crusher fines, sand, etc.
Curing time and conditions	Curing should be done at environmental conditions. The slower the time of curing the better performance results.
Equipment needed for application (varies with type of application)	Red Fire Hose Nozzle, Skid Steer Loader, Grader (i.e. Gannon), 2-ton Water Truck or Water Buffalo, 2-ton Double Steel Drum Roller.

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SOLID EARTH TECHNICAL DATA SHEET (TDS)

Safety Information:

ASPECT/ITEM	VALUE/DESCRIPTION
Hazard identification	Health Hazards: Categories 1-4 and 2A 
Precautionary statements for handling and storage	Good organization is needed for storage, relocate, usage, and application of this material to avoid leaks and spills.
Personal protective equipment (PPE) recommendations	Insufficient ventilation: wear respiratory protection. Gloves. Protective clothing. Safety glasses or chemical goggles as appropriate to prevent eye contact.
First aid measures	First-aid measures section on the safety data sheet (MSDS) of the product.
Fire-fighting measures	Not considered flammable, however, for eventual incidents use extinguishing media appropriate for surrounding fire. Do not use a heavy water stream. Use of heavy stream of water may spread fire.
Accidental release measures	In the occasion of a spill or leak of material, barrier and absorb material with inert material and scoop up material. As with all spills, diminish material incoming water systems.

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SOLID EARTH TECHNICAL DATA SHEET (TDS)

Environmental Impact:

ASPECT/ITEM	VALUE/DESCRIPTION
Biodegradability and environmental persistence	Major constituents are expected to be willingly biodegradable
Eco-toxicity	Plant and water quality impact expected to be very low.
Precautions for environmental protection	Minimize product runoff during application. Material will dry to a solid binder that is highly resistive to wash out.
Disposal considerations	Dispose of material in following all pertinent federal, state/provincial and local laws and policies. Waste classification and observance with related laws are responsibility exclusively of the waste originator.

Technical Support and Services:

- Hadar Rahav
  President
- hadar@solidearthinc.com
- Office: 480-446-9000
- Cell: 602-625-0954

Packaging:

- 5 Gallon Buckets = 45 lbs.
- 250-gallon Totes = 2350 lbs.
- Tote Dimension = 48”x 40”x 45” (tote sizes vary)

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SOLID EARTH TECHNICAL DATA SHEET (TDS)

Storage and Handling:

Store product in an unopened container in a dry location. Storage information may be indicated on the product container labeling.
Optimal Storage: 8 °C to 21 °C. Storage below 8 °C or greater than 28 °C can adversely affect product properties. Material removed from containers may be contaminated during use. Do not return product to the original container. Solid Earth Inc. cannot assume responsibility for product which has been contaminated or stored under conditions other than those previously indicated. If additional information is required, please contact your local Solid Earth representative.

Conversions
(°C x 1.8) + 32 = °F

Inspect containers and storage area regularly for signs of leakage or damage.
Store in the original, labeled container.
Store in a well-ventilated place. Keep container tightly closed. Keep in a cool and dry area away from direct sunlight.

Transport Information:

UN number	Not applicable
UN proper shipping name	Not applicable
Transport hazard class	Not applicable
Packaging group	Not applicable
Environmental hazards	No
Transport in bluk, if applicable	Not applicable
Special Precautions/provisions	NIL

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- Cell: 602-625-0954
- SOLID EARTH INC.
- 1027 E. Curry Rd.
  Tempe, Arizona 85288,
  USA

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SOLID EARTH TECHNICAL DATA SHEET (TDS)

Disclaimer

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