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Stabilization of PFAS in Contaminated Soils Using Fluoro-Sorb® 100: A Bench-Scale Study

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ABSTRACT

Studies on PFAS (per and polyfluoroalkyl substances) remediation are of prime importance owing to the carcinogenic effects of these substances on humans. However, the recalcitrance and persistence of PFAS make effective remediation extremely challenging. Ordinary Portland Cement (OPC) and Fly Ash are commonly used for ISS applications as binders, however when they react with water, they produce highly alkaline Ca(OH)2 (calcium hydroxide), which can reach a pH of 12 or higher. Such an alkaline environment decreases the contribution of electrostatic interaction in the sorption of PFAS onto soil particles and hence increases their mobility in groundwater. Therefore, in-situ soil stabilization techniques based on adsorption/partitioning of PFAS away from soil and water can be a more effective alternative. In this study, we utilized a novel sorption agent (Fluoro-Sorb® 100) and evaluated its effectiveness in trapping PFAS. Specifically, our objective was to determine an optimal mix proportion for PFAS adsorption. US Environmental Protection Agency (EPA) Methods were utilized with modifications for studying the transfer of PFAS from soil matrix to water. The compressive strength of remediated soils was also measured to check for any deleterious interaction between the sorption agents and cement hydration. The soils were tested for 32 different PFAS analytes via High-Performance Liquid Chromatography Mass Spectrometry (HPLC-MS). The addition of 5% Fluor-Sorb® 100 by dry mass of soil was sufficient to reduce PFAS leaching to water from 150 ppb to less than the Health Advisory Limit (HAL) of 70 ppt. The compressive strength data revealed an increase in compressive strength from 50 kPa with 1% cement to 3000 kPa with 10% cement, which makes FluoroSorb® 100 attractive for PFAS soil remediation.

Keywords: PFAS, Soil Stabilization, Contamination, organoclay, FluoroSorb® 100

1 INTRODUCTION

Per- and polyfluoroalkyl substances (PFAS) are a class of synthetic chemicals that have been widely used in a variety of industrial, commercial, and consumer products (Prevedouros et al., 2006; Buck et al., 2011; Wang et al., 2017). A major source of PFAS release into the environment is through the use of Aqueous Film Forming Foams (AFFFs) in municipal, airport, and military firefighting training facilities (Backe et al., 2013; McGuire et al., 2014; Anderson et al., 2019; Nickerson et al., 2020). PFAS can remain in the soil matrix through various processes, including sorption, partitioning, and complexation (Wei et al., 2019; Zhang et al., 2019). Due to their persistence and potential adverse health effects, PFAS have become a major environmental concern. In situ stabilization is an emerging technology for treating PFAS-contaminated sites, which involves adding amendments to the contaminated soil or groundwater to immobilize the PFAS and prevent their migration.

Several types of amendments have been used for in situ PFAS stabilization, including activated carbon-based materials, clay, lime, and alumina. Activated carbon-based materials, such as powdered activated carbon (PAC) and granular activated carbon (GAC), have been shown to be effective in adsorbing PFAS onto their surface and preventing their migration. A study by Zhang et al. (2020) found that Granular activated carbon (GAC) could reduce the concentration of PFAS in groundwater by up to 99% after 6 months of treatment. Barth et al. (2021) conducted a two-phase study to evaluate the use of chemical

stabilizing agents along with cement solidification for treating PFAS contaminated soils. In the first phase, six PFAS compounds were diluted in a water solution and sorbed using five different sorbents. GAC was found to be the most effective sorbent. The second phase involved using GAC as a chemical stabilizing agent and adding cement as a physical binding agent to solidify soils obtained from two sites that were contaminated with PFAS. Results showed that GAC substantially reduced the leachability of PFAS compounds from the contaminated soil samples, with overall immobilization of detectable PFAS analytes ranging from 87.1% to 99.9%. Navarro et al. (2023) investigated the effectiveness of carbon-based sorbents in immobilizing/stabilizing soils contaminated with PFAS over a period of four years and under various laboratory leaching conditions. Out of five sorbents tested, two powdered activated carbon (PAC) sorbents and one biochar were able to reduce PFAS leaching in soil by at least 95% one week after treatment. After four years, the PAC and colloidal AC sorbents' performance did not significantly change while biochar was found to be affected by aging and were at least 22% less effective in reducing PFAS leaching across a range of leaching conditions

Zhang and Liang (2022) investigated the effectiveness of different stabilizing agents, including biochar, GAC, RemBind® 100, and RemBind® 100X, in reducing the leaching of 10 types of PFAS in soil. Results indicated that GAC, RemBind® 100, and RemBind® 100X reduced the water and acidic water leachable PFAS by 99%, regardless of the PFAS chain length, compared to unamended controls. Aging of the sorbents in the soil did not cause any release of stabilized PFAS. Biochar, when added to the same soil at the same dose, significantly decreased the leaching of long-chain PFAS. However, the stabilization of short-chain PFAS, such as PFBS, PFHxA, GenX, and PFHpA, by biochar was considerably lower than other sorbents. Interestingly, the sorption of these short-chained PFAS to biochar was significantly enhanced by increasing contact time.

Lime-based amendments, such as calcium hydroxide and magnesium hydroxide, have been shown to be effective in immobilizing PFAS by changing the pH of the soil or groundwater. A study by Ok et al. (2019) found that the addition of calcium hydroxide to PFAS-contaminated soil could reduce the leaching of PFAS by up to 88%. Additionally, aluminum hydroxide and aluminum sulfate have also been investigated for in situ PFAS stabilization and were found to reduce the leaching of PFAS by up to 96% (Cho et al., 2019).

Clay-based amendments have also been used for in situ PFAS stabilization. These amendments work by adsorbing PFAS onto their surface and preventing their migration. A study by Zhang et al. (2020) found that the addition of bentonite to contaminated soil could reduce the leaching of PFAS by up to 90%. Li et al. (2020) reached similar observations when investigating the use of chitosan-modified bentonite for in situ stabilization of PFAS in contaminated soil.

This paper presents the results from an investigation to evaluate the use of a modified clay (Fluoro-Sorb® 100) for PFAS insitu stabilization. Bench-scale experiments were performed to simulate the field leaching process on silty clay soil sampled from the hotspot before and after treatment. Different formulations of Fluorosorb 100®, water, and Ordinary Portland Cement (OPC) with soil were prepared. The PFAS concentrations in the eluate extracted from these treated soils were compared to the ones sampled from untreated soils. It is also essential to ensure that the structural integrity of the soil is not compromised during the remediation process. Hence, the unconfined compressive strength of the mixes was also determined experimentally and compared to existing standards in practice to arrive at an optimal mix proportion of a chemical grout that reduced the soil PFAS levels to a safe threshold (USEPA Health Advisory Limit, HAL) and also met a minimum strength recommendation.

2 MATERIALS AND METHODS

2.1 Site location and sample collection

Soil samples were collected from the decommissioned Wurtsmith Air Force Base (WAFB) located in Michigan, USA. The WAFB was established in 1923 and was decommissioned in 1993. Based on the data collected using the open-source database available on the Web Soil Survey (NRCS, 2017), an area of interest was established and marked as shown in Figure 1. The site is a PFAS hotspot due to the historic extensive use of AFFF during fire-fighting training exercise. The soil was sampled from different locations across the site as per proper PFAS sampling protocols and randomly sampled into seven High-Density Polyethylene (HDPE) buckets, each approximately weighing 23 Kg of wet soil. The

soil was then sieved to remove gravel and matter greater than 9.5 mm. The soil from the seven buckets were emptied and mixed together to homogenize the sampled soils before placing again in the buckets and sealing them with an air-tight HDPE lids.



Figure 1. *Satellite image of the Wurtsmith Airforce base with PFAS impacted area marked.*

2.2 Initial soil characterization

All standard testing were modified to ensure that all material used at any stage of testing were made out of non-interfering material, since PFAS is so widely used in many laboratory equipment. The raw soil is classified as a poorly graded sand, based on ASTM D2487-17 Standard Practice for Classification of Soils for Engineering Purposes (Unified Soil Classification System). The gravimetric water content of the soil was measured, in general accordance with the ASTM D2216-19 Standard Test Methods for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass.

The pH of the soil was measured, in general accordance with the ASTM D4972-19 standard test method, adopting Method A, wherein the pH of the soil was determined in ion-free, hence pH neutral, water. A three-point calibrated pH electrode was used (pH buffers as pH=4,7,10). The soil sample was sieved through a No.10 sieve (2.0mm), and air dried. Air drying the samples at ambient temperature has been proven to significantly increase the leachable PFAS content (Lange et al., 2021). In a previously cleaned and decontaminated glass beaker,10mL of nano-pure water was added to 10g of sieved and air-dried soil. The 1:1 slurry was left undisturbed for 1 hour before an electrode probe was immersed in the slurry with minimal disruption of the sedimented soil particles. In an attempt to address any variability, samples for measuring water content (and pH) were collected from the top, middle and bottom of each bucket.

The average water content and pH of the raw soil from different buckets and locations within each bucket was 1.3% ± 0.1%, and 7.63 ± 0.4, respectively. The small variability in both values suggests that the soil has been thoroughly homogenized. The soil maximum dry density and optimum moisture content were determined, in general accordance with the ASTM D698-12 Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Standard Effort. The compaction curve of the native soil, over a range of water content levels from 3% to 16%, was nearly flat, with a maximum dry density of 17.8 kN/m^3 at a water content of 3.1% (Figure 2). Pocket Penetrometer values, where available, indicated a negligible unconfined compressive strength (UCS) with a maximum value of 50 kPa for all compacted specimens. Therefore, it was deemed that the soil had to be amended with OPC to meet minimum EPA strength requirement of 345 kPa for amended soils.

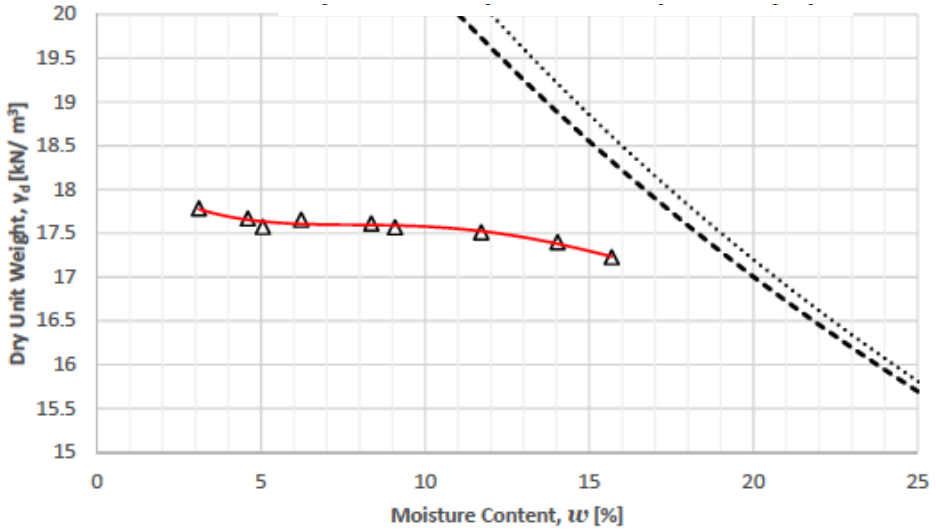


Figure 2. *Dry density versus water content from Standard Proctor Test*

2.3 Specimen preparation for Unconfined Compression testing

Soil contaminated with PFAS was collected from bucket number 7 and stored in sealed polypropylene weighing buckets. A portion of the soil sample was used for baseline leaching characterization of the raw material, and moisture content was measured again to account for any changes during storage. The pre-determined amounts of Ordinary Portland Cement, adsorbent, and nano-pure water were weighed according to a particular proposed mix design. The OPC was mixed with half the volume of water for 10 minutes at high speed, and the remainder of the adsorbent was added intermittently during mixing. The soil and water were added to the slurry, which was then mixed for 15 minutes at medium speed before being blended manually. Four empty polypropylene cylindrical molds were weighed, labeled, and filled layer by layer with the mixture, which was then compacted by tapping the mold 300 times in total. After compaction, the molds were weighed and stored in a humidity-controlled chamber for 28 days. A total of 10 different mixes were prepared in addition to the natural material.

At the end of 28 days, the molds were demolded by blowing compressed air through the drainage hole at the bottom. Monoliths were designed to have sufficient density and UCS to be demolded without disintegrating. The monoliths were carefully demolded while ensuring that PFAS-free apparatuses, materials and surfaces were used throughout. The sample ID, weight, multiple measurements of the height and diameter, and moisture content (from trimmings) were recorded. The average height was recorded to be 101.6mm and average diameter was 50.8mm. The average weight of each of the monoliths was 400g, and the average moisture content was 10%. After this, the monoliths were stored in a clean airtight container, before being loaded for measuring the unconfined compressive strength (Figure 3-a).

2.4 Leach testing methods

LEAF is a leaching evaluation framework designed to estimate the release of constituents of potential concern (COPCs) from solid materials. It is comprised of four leaching tests (U.S. EPA Methods 1313, 1314, 1315 and 1316), data management tools, and scenario assessment approaches (U.S. EPA, 2017). LEAF tests consider the effect that key environmental conditions and material properties have on leaching. With LEAF, the fraction of the total mass of the COPC in the solid phase that will partition in the liquid phase and rate of the soil-to-liquid partitioning through waterborne pathways are estimated. In this paper, only results from Method 1313 (without pH adjustment) are included due to limited space.

U.S. EPA Method 1313 (U.S. EPA, 2017) is initially designed to characterize the leaching potential of inorganic constituents, semi-volatile organic constituents, and non-volatile organic constituents in solid materials. A liquid-solid partitioning (LSP) curve is obtained at a liquid to solid ratio (L/S) of 10 for a wide range of pH values. For this study, the pH of the prepared solutions was maintained at the soil's neutral state since other studies (Kabiri et al. 2021; Rayner et al. 2022) reported that variation in the leachable content due to the increase in pH beyond 7 was not significant.

The Method 1313 batch tests were performed on random pieces collected from the Unconfined Compression specimens after shearing. The test was conducted in general accordance with LEAF Method 1313 with a few modifications to comply with PFAS-specific testing guidelines. After collecting the broken pieces of the Unconfined Compression specimen, the pieces are crushed with a hammer, whose head is wrapped with a Nitrile powder-free glove or other inert material. The crushed treated soil is then sieved through sieve No. 10 (2 mm) to remove any larger particles. A sample of the crushed material is dried in the oven to determine its moisture content. Based on the measured water content, a total wet mass of sieved material is collected such that it contains 40g of dry material. The collected material is then mixed with reagent grade water (total volume of reagent water and water already in moist material should add up to 400 mL) in 500mL HDPE extraction vessels with air-tight unlined PP lid. The sieve and all equipment/surfaces used were cleaned with Deionized water and 1.0% Alconox detergent solution to minimize interferences and cross-contamination between runs.

For the untreated raw soil, a similar approach is used to prepare the suspension in the extraction vessel. The only difference is that the untreated soil is directly sieved through sieve No. 10 (2 mm) to remove any larger particles. Then, the moisture content of the sieved soil is measured to determine the exact wet mass of soil to be used to obtain 40g of dry soil. The soil or crushed treated soil suspensions were agitated for 48h at 28rpm in a top-over-end shaker (rotary tumbler, Figure 3-b) The extraction vessels were allowed to stand for 30 min after halting the shaking to allow for phase separation through natural sedimentation. 50mL of the eluate supernatant were then decanted from the top of the extraction vessels and added to 50mL HDPE vials for centrifugation at 10,000rpm rpm for 15 min. Lastly, 7mL of the eluate supernatant were decanted from the top of the centrifuged vials and added in 10mL HDPE vials. The vials were stored in cold humid room (fridge) at 4°C until they were shipped to Colorado School of Mines for analytical testing. pH measurements were carried out for the remainder eluate of the 50mL vials, past centrifugation. Serological pipets with pump were used for eluate sampling.



a) UCS testing b) LEAF 1313 testing

Figure 3. *Experimental setups: a) Unconfined Compressive Strength (UCS) testing and b) US EPA Method 1313 testing.*

2.5 Analytical testing

Analytical testing was performed for all the extracted eluates at Colorado School of Mines targeting a suite of 32 PFAS listed in Table1. In each experiment, an aliquot was collected after selected reaction time intervals filtered through a 0.2 micrometer (µm) nylon syringe filter, first diluted into calibration range using HPLC-grade water for UPLC-QToF-MS analysis. At the final step, 0.1 ml of the diluted sample was added to a 2 ml vial and reconstituted with 2 ng (50 microliters [µl] of 40 nanograms per milliliter [ng/ml]) of injection standard, 450 microliters (µl) of 100% methanol, and 1 ml of liquid chromatography water (Fisher Chemical) before injection. All the parallel extraction leach tests were carried out in triplicates. A blank sample of nano-pure water (used a reagent) was subjected to the same conditions as the triplicates for confirming the analytical testing results and check for any potential contamination bias in the measurements. The analytes that had a non-detectable concentration were assigned a value

of zero, while the ones with detectable concentrations below the lower limit of quantification (LLOQ), were assigned the LLOQ value to be on the conservative side.

Table 1. *List of PFAS analytes evaluated in this study*

PFAS Chemical Group (abbr.)	PFAS analyte (abbr.)	PFAS name (CAS No.)
Perfluoroalkyl Carboxylates or Carboxylic Acids (**PFCA**)	PFBA	Perfluorobutanoate (45048-62-2) or. Perfluorobutanoic acid (375-22-4)
	PFPeA	Perfluoropentanoate (45167-47-3) or. Perfluoropentanoic acid (2706-90-3)
	PFHxA	Perfluorohexanoate (92612-52-7) or. Perfluorohexanoic acid (307-24-4)
	PFHpA	Perfluoroheptanoate (120885-29-2) or. Perfluoroheptanoic acid (375-85-9)
	PFOA	Perfluorooctanoate (45285-51-6) or. Perfluorooctanoic acid (335-67-1)
	PFNA	Perfluorononanoate (72007-68-2) or. Perfluorononanoic acid (375-95-1)
	PFDA	Perfluorodecanoate (73829-36-4) or. Perfluorodecanoic acid (335-76-2)
	PFUdA	Perfluoroundecanoate (196859-54-8) or. Perfluoroundecanoic acid (2058-94-8)
	PFDoDA or PFDoA	Perfluorododecanoate (171978-95-3) or. Perfluorododecanoic acid (307-55-1)
	PFTrDA	Perfluorotridecanoate (862374-87-6) or. Perfluorotridecanoic acid (72629-94-8)
	PFTeDA	Perfluorotetradecanoate (365971-87-5) or. Perfluorotetradecanoic acid (376-06-7)
	PFHxDA	Perfluorohexadecanoate (N/A) or. Pefluorohexanodecanoic acid (67905-19-5)
	PFODA	Perfluorooctadecanoate (N/A) *or*. Pefluorooctadecacanoic acid (16517-11-6)
Perfluoroalkyl Sulfonates or Sulfonic Acids (**PFSA**)	PFPrS	Perfluoropropane sulfonate (N/A) or. Perfluoropropane sulforic acid (423-41-6)
	PFBS	Perfluorobutane sulfonate (45187-15-3) or. Perfluorobutane sulfonic acid (375-73-5)
	PFPeS	Perfluoropentane sulfonate (NA) or. Perfluoropentane sulfonic acid (2706-91-4)
	PFHxS	Perfluorohexane sulfonate (108427-53-8) or. Perfluorohexane sulfonic acid (355-46-4)
	PFHpS	Perfluoroheptane sulfonate (NA) or. Perfluoroheptane sulfonic acid (375-92-8)
	PFOS	Perfluorooctane sulfonate (45298-90-6) or. Perfluorooctane sulfonic acid (1763-23-1)
	PFNS	Perfluorononane sulfonate (NA) or. Perfluorononane sulfonic acid (474511-07-4)
	PFDS	Perfluorodecane sulfonate (126105-34-8) or. Perfluorodecane sulfonic acid (335-77-3)
	PFDo(D)S	Perfluorododecane sulfonate (N/A) or. Perfluorododecane sulfonic acid (79780-39-5)
Perfluorooctane Sulfonamides (**FOSA deriv.**)	FOSA	Perfluorooctane Sulfonamide (N/A)
	MeFOSA	N-Methyl Perfluorooctanesulfonamide (N/A)
	EtFOSA	N-ethyl Perfluorooctance Sulfonamide (N/A)
Perfluorooctane Sulfonamido Acetic Acids (**FOSA**	FOSAA	Perfluorooctanesulfonamido acetic acid (N/A)
	MeFOSAA	N-Methyl Perfluorooctanesulfonamido acetic acid (N/A)
	EtFOSAA	N-Ethyl Perfluorooctanesulfonamido acetic acid
Fluorinated Telomer Sulfonic Acids (**FTS**)	4:2FTS	4:2 Fluorotelomer sulfonic acid (N/A)
	6:2FTS	6:2 Fluorotelomer sulfonic acid (N/A)
	8:2FTS	8:2 Fluorotelomer sulfonic acid (N/A)
	10:2FTS	10:2 Fluorotelomer sulfonic acid

3 RESULTS AND DISCUSSION

Table 2 shows the design mixes evaluated in this study. All percentages are calculated based on dry weight ratio of amendment to soil. For each mix design, triplicate specimens were prepared and tested. The untreated soil was only tested for PFAS leaching since the soil didn't have enough cohesion to form monolith for Unconfined Compression testing without any cement treatment.

3.1 Unconfined Compressive Strength

The Unconfined Compressive Strength (UCS) results are presented in Figure 4. For 1% OPC with 1% and 3% Fluoro-Sorb® 100, the specimens broke apart when being removed from the mold and no UCS

values were recorded for them. However, portions of each sample was still collected and processed for leach testing. All mixes except the ones with 1% OPC and the 3% OPC and 0% Fluoro-Sorb® 100 exceeded the minimum strength of 345 kPa. UCS increased with increase of total treatment level (%OPC and % Fluoro-Sorb® 100 combined); however, the impact of %OPC was higher than that of Fluoro-Sorb® 100 (5%opc+1% Fluoro-Sorb® 100 had higher UCS than 3%OPC and 3% Fluoro-Sorb® 100).

Table 2. *Different design mixes evaluated in this study.*

FluoroSorb® 100 content (%)	OPC content (%)				
	0	**1**	**3**	**5**	**10**
0	X		X	X	X
1		X		X	
3		X	X	X	
5		X		X	

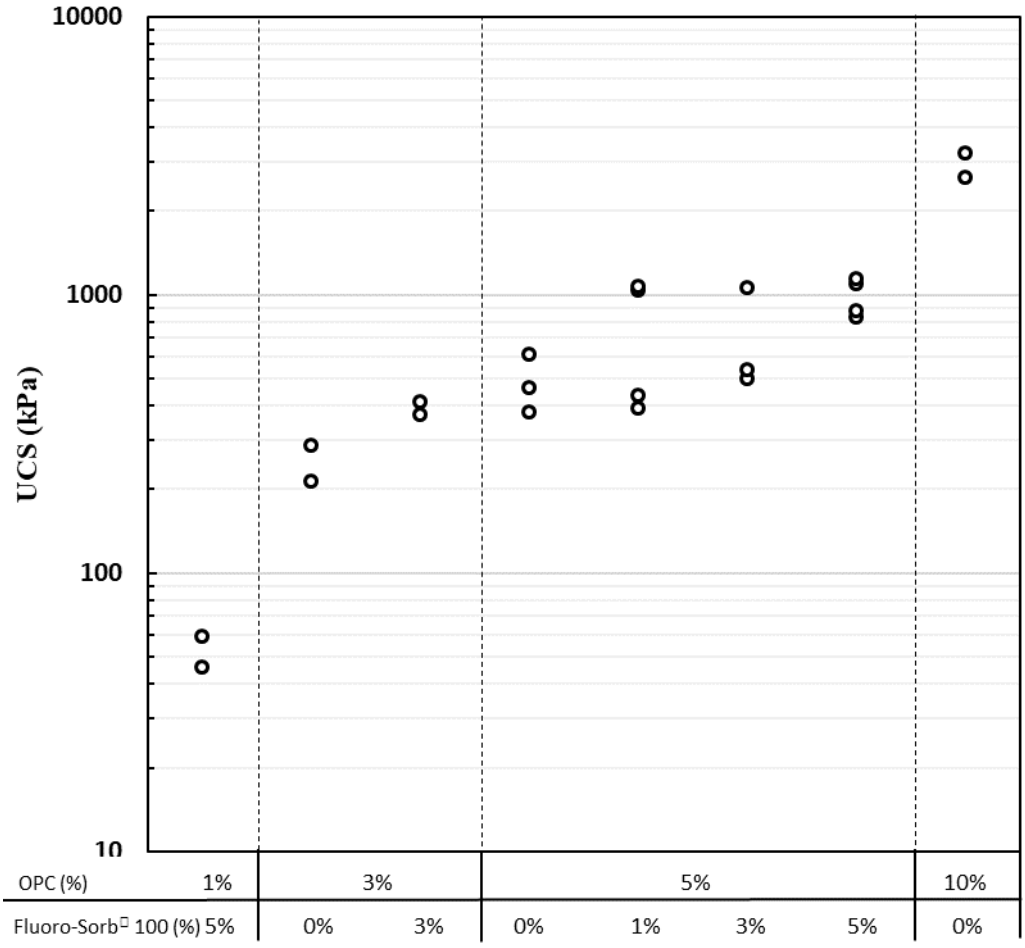


Figure 4. *Unconfined Compressive Strength (UCS) for the different treatment mixes (mixes with 1% OPC and 1% and 3% Fluoro-Sorb® 100 crumbled before testing and were not included in this figure).*

3.2 U.S. EPA Method 1313 for untreated soil

The leachable concentrations (ng/L or ppt) for all 32 PFAS analytes from the untreated soil samples are presented in Figure 5. The average concentrations of the analytes are reported in comparison to the EPA HAL of 70 ppt. More than half of the PFAS analytes concentrations (17 out of 32) are higher than the HAL, with 7 analytes exceeding the limit by more than 10 times. More specifically, PFOA, FOSA, PFHxS, and PFOS exceeded the HAL by a factor of 35 or more. Based on the obtained results, it is noted that the tested soil is highly contaminated with PFAAs and their precursors, which have the potential to transform biologically. It is important to note that these high concentrations are determined based on aggressive leaching testing, and are not the expected concentrations in the groundwater insitu.

3.3 U.S. EPA Method 1313 for treated Soil

Figure 6 presents the total PFAS eluate concentration for each of the 10 mix-designs. The leachable concentration from the untreated soil as well as the HAL are included for reference. The three mixes with only OPC were able to reduce the leachable PFAS by 51% (3% OPC), 92.6% (5% OPC), and 77% (10% OPC) compared to untreated soils. However, the total PFAS concentration with the maximum reduction at 5% OPC was still 160 times higher than the HAL. On the other hand, adding 1% to 5% Fluoro-Sorb® 100 reduce the leachable PFAS by at least 99.8%, and up to 99.97% with 5% Fluoro-Sorb® 100. Both mixes with 5% FluoroSorb® 100 reduced the leachable concentrations to below the HAL, regardless of OPC content.

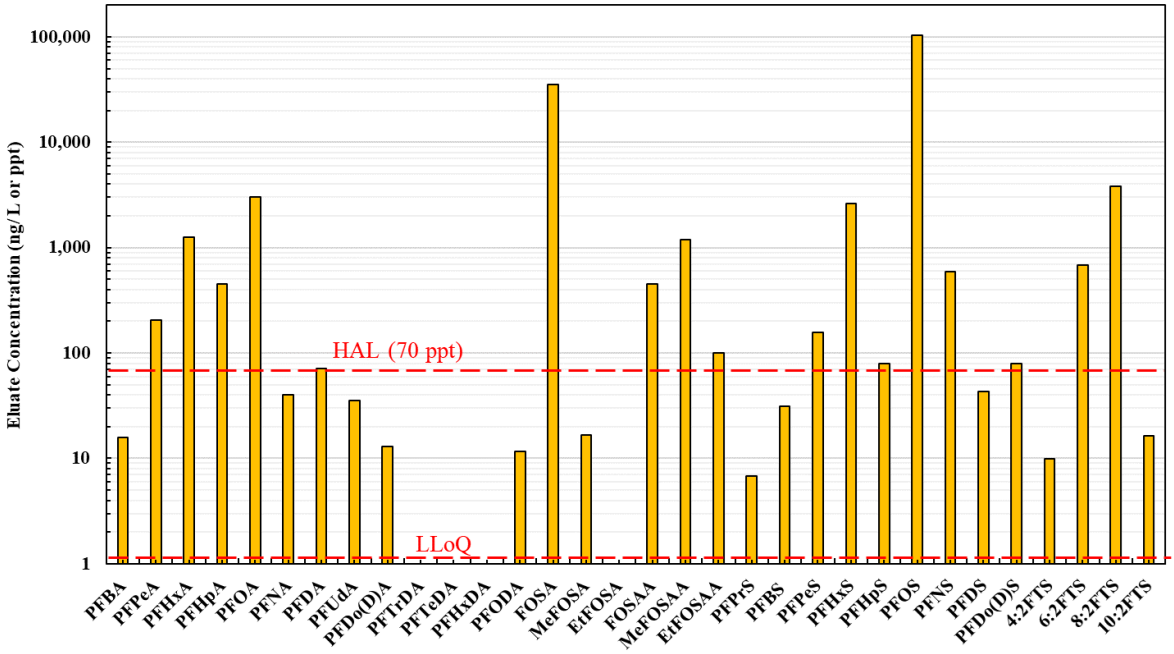


Figure 5. *Leachable PFAS Concentrations from Method 1313 (neutral pH) for untreated soil*

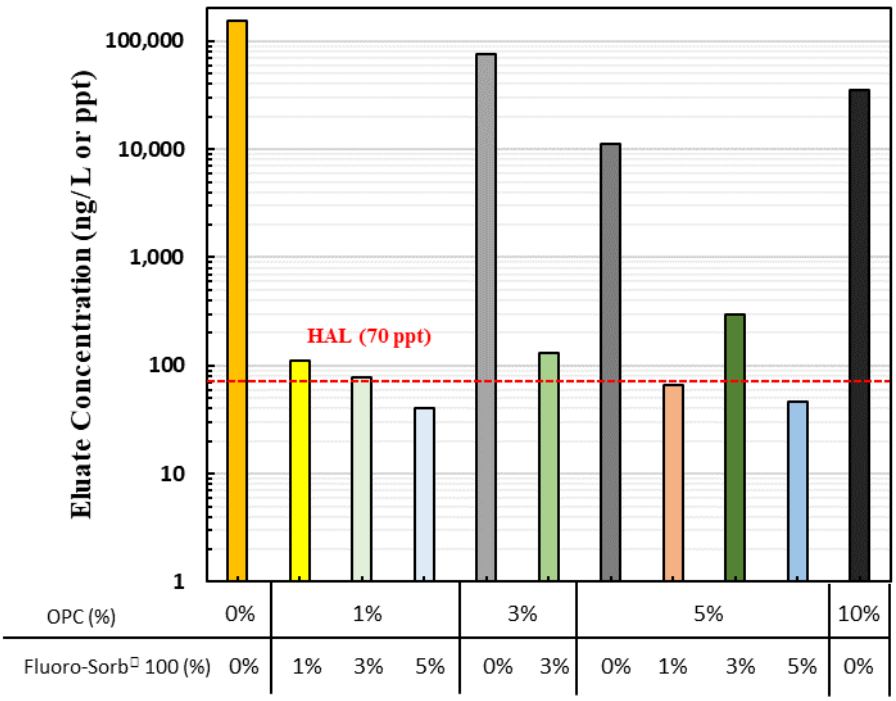


Figure 6. *Leachable PFAS Concentrations from Method 1313 (neutral pH) for treated soil mixes*

The eluate concentrations (ng/ L or ppt) for the four prominent analytes (leached concentrations exceed the HAL by more than 35 times for untreated soil) are shown in Figure 7 for the different design mixes. The leachable concentration of PFOA, PFHxS, FOSA, and PFOS from the untreated soil as well as the HAL are also included for reference. Adding Fluoro-Sorb® 100 reduced leachability below the HAL, even at a dosage as low at 1%, with PFOA leachability reduced to non-detectable limits. to very low levels in all mix designs, while cement alone did not show the same effectiveness. Conversely, high levels of PFOS and Fluorinated Telomer Sulfonates were found when low percentages of Fluoro-Sorb® 100 and high OPC were used, as compared to just the soil itself.

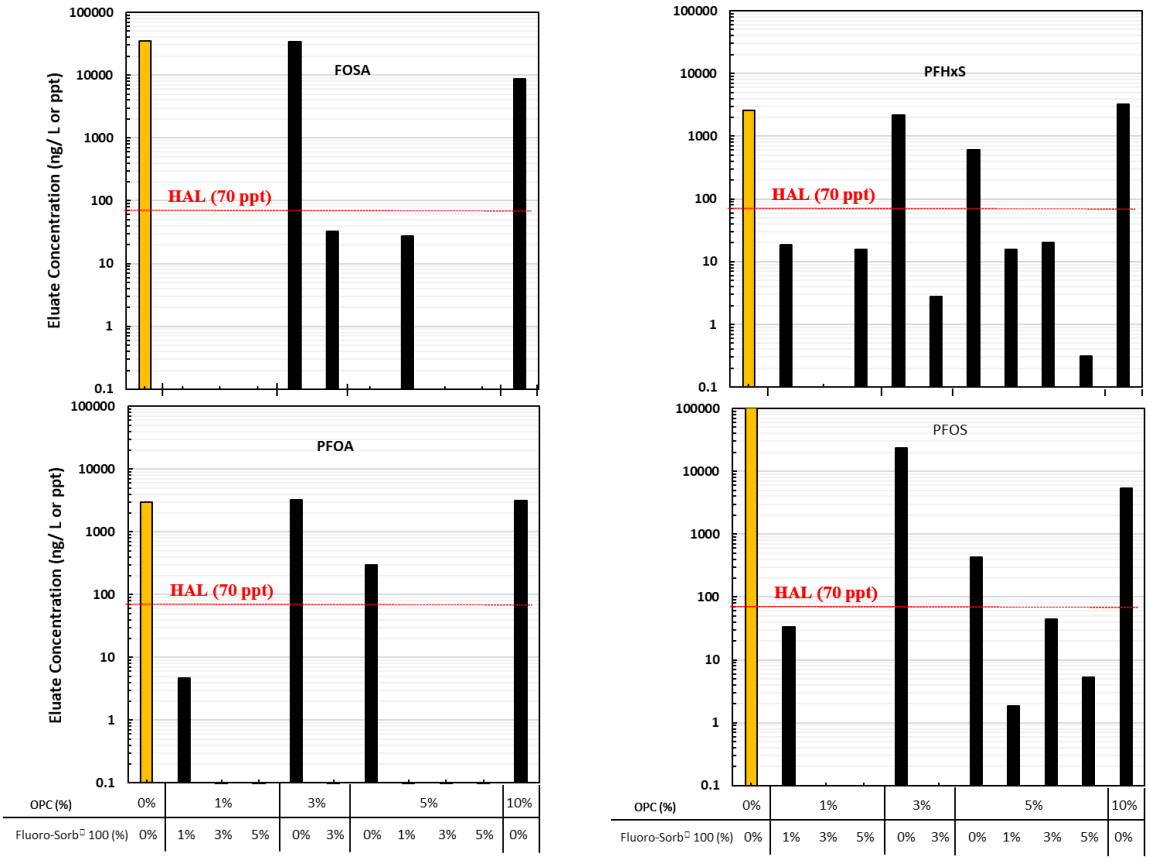


Figure 7. *Leachable FOSA (top left). PFHxS (top right), PFOA (bottom left), and PFOS (bottom right) Concentrations from Method 1313 (neutral pH) for treated soil mixes*

3.4 Optimal soil treatment design

Figure 8 presents the eluate concentrations of the Total PFAS Load for all mixtures. The results are grouped based on the Fluoro-Sorb® 100 dosage and plotted as a function of OPC content. The results for mixes of 1% OPC with 1% and 3% Flouro-Sorb® 100 are identified with black solid markers since they didn't meet the strength criteria; however, their results are included to provide a more complete picture of change in leachability with OPC and Fluoro-Sorb® content.

In the absence of Fluoro-Sorb® 100, the total leachable PFAS first decrease as OPC goes from 0 to 3% and 5% but then increases with adding more OPC (10%). This is likely due to the presence of two competing mechanisms: stabilization of PFAS by adding OPC and destabilization of PFAS due to increase in pH, which enhances the mobility of PFAS. The best performance is seen at OPC = 5% (pH_average = 11.74), where an optimal balance is reached between the two mechanisms. At OPC = 3% (pH_average = 11.56), there is not enough OPC to maximize stabilization, while at OPC = 10%, there is more OPC than needed to stabilize the PFAS, resulting in an increase in pH (pH_average = 12.05) and higher enhancement in PFAS mobility than stabilization.

A significant reduction in leaching potential and stabilization is accomplished by using Fluoro-Sorb® 100, even if only 1% is used. However, at such low dosage of Fluoro-Sorb® 100, the influence of OPC cannot be disregarded as the 1% Fluoro-Sorb® curve show a similar trend of decrease then increase in leachable PFAS as OPC content increases, albeit all being at two orders of magnitude lower PFAS concentrations.

On the other hand, the treatment with Fluoro-Sorb® 100 become independent of OPC content as the clay treatment dosage increase to 3% and above. Treatment with 5% Fluoro-Sorb® 100 produces the least leaching, with an average Total PFAS concentration of 46 ppt, which is lower than the EPA HAL threshold of 70 ppt.

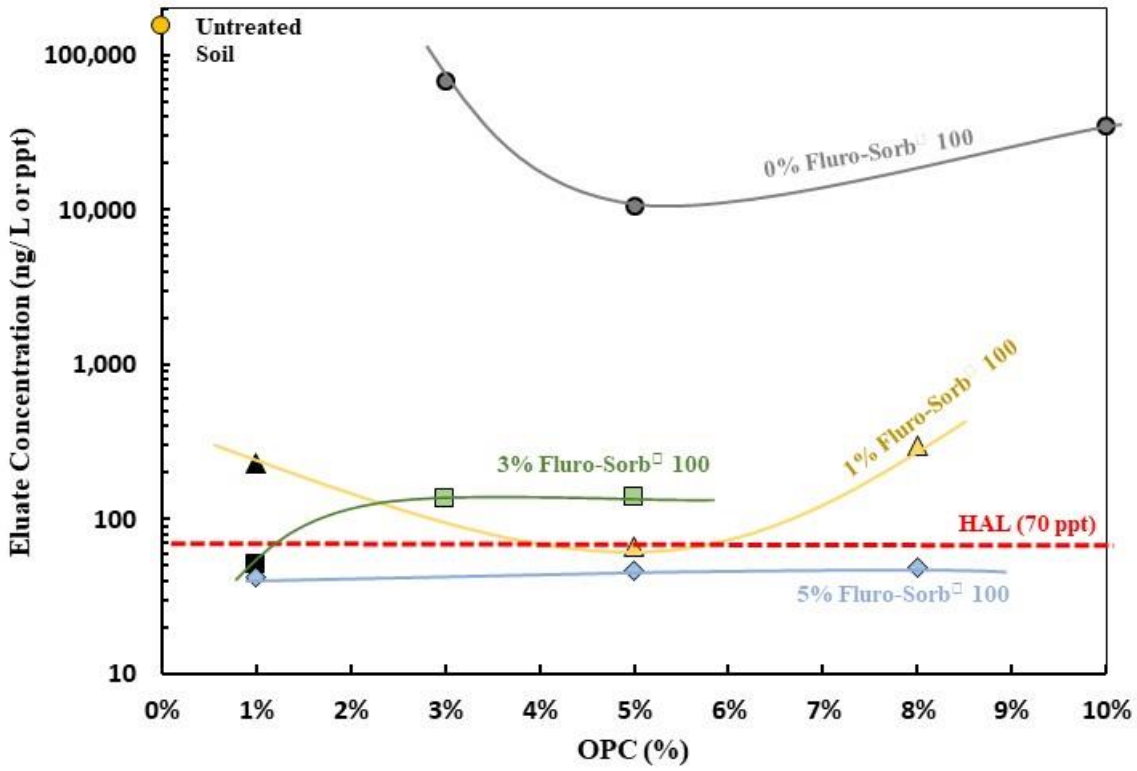


Figure 8. *Change in Fluoro-Sorb® 100 stabilization effectiveness with OPC content.*

4 CONCLUSIONS

This paper presented the results from an investigation to evaluate the use of a modified clay (Fluoro-Sorb® 100) for PFAS insitu stabilization. Bench-scale experiments were performed to simulate the field leaching process on silty clay soil sampled from PFAS hotspots before and after treatment. Different formulations of Fluorosorb 100®, water, and Ordinary Portland Cement (OPC) with soil were prepared. The PFAS concentrations in the eluate extracted from leaching tests (Method 1313 at natural pH) on these treated soils were compared to the ones sampled from similar tests on untreated soils. The main conclusions from this study are summarized below:

1- Using OPC only for stabilizing the PFAS contaminated soils resulted in a decrease in leachable PFAs concentrations up to 92.6% (at 5% OPC) compared to untreated soils. However, the total PFAS concentration with the maximum reduction at 5% OPC was still 160 times higher than the HAL.
2- Adding OPC creates a highly alkaline environment, resulting in an increase in the mobility of PFAS analytes. Adding OPC beyond the minimum required dosage to stabilize PFAS will have a negative impact and results in increased leaching.
3- Using 1% to 5% Fluoro-Sorb® 100 reduced the leachable PFAS by at least 99.8%, and up to 99.97% with 5% Fluoro-Sorb® 100.
4- The impact of OPC dosage was observed in 1% Fluoro-Sorb® 100 mixes, but not after increase the clay content to 3% of higher.
5- Using 5% FluoroSorb® 100 reduced the leachable concentrations from over 150K ppt to below the HAL (70 ppt), regardless of OPC content.
6- The compressive strength of remediated soils was also measured to check for any deleterious interaction between the sorption agents and cement hydration. The compressive strength data

revealed an increase in strength with increase in total amendment for the different mix proportions.

Additional testing is underway to compare the performance Fluoro-Sourb® 100 to Granular Activated Carbon, which is commonly used for treating PFAS in practice.

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