

Geosynthetic sorption sheet—Another function of geosynthetics?

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ABSTRACT: This paper discusses a novel geosynthetics sorption sheet that provides both sorption and traditional geosynthetic functions. In particular, the geosynthetic sorption sheet facilitates both water drainage and chemical barrier function. In this paper, batch sorption tests are used to evaluate the sheet's attenuation performance. The results of soil tank tests involving a 110 x 80 x 12 cm tank are also discussed. A key finding was the higher sorbed extent of arsenate compared with arsenite. The sheet absorbed more than 80% of the arsenic when it was contacted for 15 minutes with 0.1 mg/L of arsenate. Based on the soil tank test, ground particles surrounding the sheet are more important to seepage water distribution than the sheet itself.

1 INTRODUCTION

Excavated soils with geogenic contamination such as arsenic (As) or boron (B) are generated from various construction projects since these elements are widely distributed in several geologic strata such as marine clay layers, sedimentary rocks, hydrothermally altered rocks, etc. In Japan, these soils and/or rocks are expected to be used in embankments or other geotechnical applications to reduce the volume of soil disposal as well as to reduce the use of new soil materials. For such application, proper management against geogenic contamination is a primary engineering concern since groundwater contamination due to possible leaching of toxic elements is required to be prevented. Given the importance of developing economical and effective utilization methods for geogenic contaminated soils, effective countermeasures should be established.

Geosynthetic sorption sheets have been developed to contain the toxic elements from geogenic contaminated soils. By being installed below the excavated soils with natural contamination, the geosynthetic sorption sheet is expected to trap the contaminants. It might release the infiltrated water free from contaminants into the base soil layer to prevent groundwater contamination. The geosynthetic sorption sheet consists of sorptive material attached or adhered to the fabric. Several types of sorptive materials, such as hydrotalcite, are applied, and several types of fabric can also be used. Although knowledge has been accumulated on the sorption performance of various kinds of sorptive materials, sorption performances considering the effect of practical conditions, such as preferential flows and overburden pressures, need to be evaluated (Kinoshita *et al.* 2021). Therefore, in this study, the effect of preferential flow in the soil layer overlying the geosynthetic sorption sheet is experimentally evaluated.

2 GEOSYNTHETIC SORPTION SHEET

Utilization of surplus soil is quite important for material recycling. The amount of soil generated from construction work was more than 130 million m³ in 2018 in Japan (MLIT 2020). Since such a large amount of soil is generated, the soil should be utilized as a geomaterial for embankments, fill, etc., while geogenic contaminants are often contained in the excavated soil higher than the environmental standard values (e.g., Kato *et al.* 2023; Tabelin *et al.* 2018). Therefore, proper countermeasures must be taken to prevent contamination of the surrounding environment. However, if such contaminants are of natural origin, the exceeding degree is often within several times the standard value (e.g., Ito & Katsumi 2020; Naka *et al.* 2016). Toward sustainable development, although the standard is exceeded, if the concentration is relatively low, geogenic contaminated soils should be utilized as embankment material with proper countermeasures.

Containment methods using a geomembrane may be an effective way when geogenic contaminated soils are used for embankments. However, the interface between the geomembrane and soils may become a sliding surface. Further, the containment may be an excessive countermeasure, considering the low-concentration toxic chemicals such as the geogenic contaminants.

Geosynthetic sorption sheets have been developed as a promising countermeasure for geogenic contamination (e.g., Kinoshita *et al.* 2021; Miyawaki *et al.* 2022). Herein, the geosynthetic sorption sheet is placed under the excavated soils, as shown in Figure 1. This geosynthetic sorption sheet offers a new function of sorption, in addition to the traditional geosynthetic functions (reinforcement, barrier, drainage, separation, filtration, stabilization). Since the infiltration can be permitted, pore water does not accumulate in the embankment. Furthermore, the upper soil layer can be compacted. Therefore, the stability of the embankment can be maintained. While the sheet is cost-effective and has workability, some challenges remain to be solved. The reliability of the material may decrease in the case of clogging or preferential flow. For instance, when there is preferential flow, a limited area of geosynthetic sorption sheets may be involved in the sorption of toxic chemicals. Furthermore, the sorption kinetics should be investigated since a short contact time is expected for the sheet considering the in-situ condition.

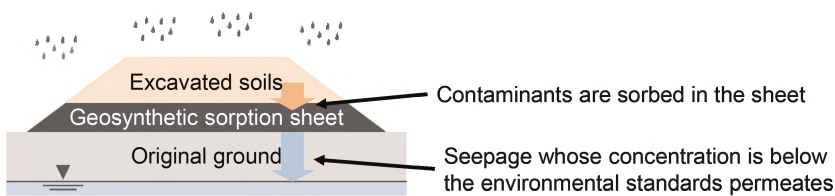


Figure 1. Application of the geosynthetic sorption sheet for geogenic contaminated soils.

3 MATERIALS AND METHODS

3.1 Materials

Figure 2 shows the geosynthetic sorption sheet manufactured by TOYOBO CO., LTD used in this study. One side of the sheet is a hydrophilic long-fiber nonwoven fabric coated with an artificial hydrotalcite compound. The hydrotalcite is adjusted to a nano-size of about 10 nm, and 5.0×10^{-2} kg/m² of hydrotalcite is coated. The thickness of the sheet is 2.8 mm. The

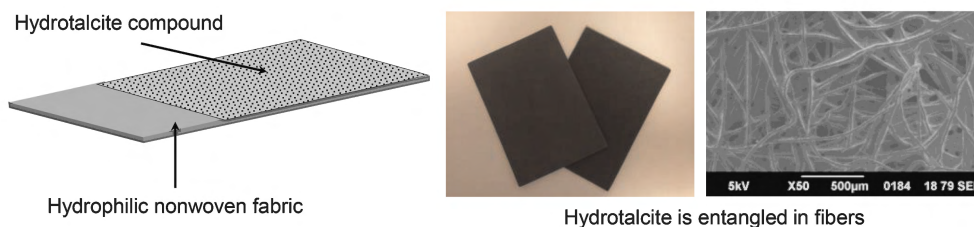


Figure 2. Geosynthetics sorption sheet used in this study.

hydraulic conductivity is 1.7×10^{-3} m/s (JIS A 1218 2009). The pore size range of the sheet was approximately 10–120 μm , and the average pore size d_{50} was 47 μm .

3.2 Batch sorption tests

Batch sorption tests were conducted to evaluate the sorption performance against arsenic (As) contamination under different contact time to evaluate the sorption kinetics. Figure 3 shows the test setup. Since arsenic mainly exists in the solution as either arsenite [As(III)] or arsenate [As(V)] (Mohan & Pittman 2007), As(III) and As(V) solutions were prepared with the sodium arsenite (NaAsO_2) and sodium dihydrogen arsenate ($\text{Na}_2\text{HAsO}_4 \cdot 7\text{H}_2\text{O}$) salts, respectively. The salts were dissolved in distilled water to prepare concentrations between 0.1–20 mg/L. A 200 mL of As solution and the geosynthetic sorption sheet cut to 80 mm \times 50 mm were put in a plastic bottle. Afterward, the bottles were horizontally shaken between 5 minutes and 24 hours at 150 rpm using a mechanical shaker (TAITEC TS-10) under room temperature ($\sim 20^\circ\text{C}$). Three replicate tests were performed for each solution.

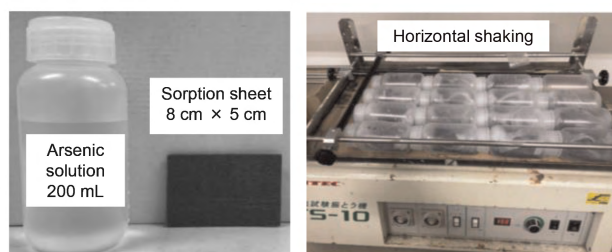


Figure 3. Set up of the batch sorption tests.

After the sample preparation mentioned above, centrifugation at 3000 rpm for 10 min and filtration with a 0.45 μm membrane filter was carried out to separate the liquid from the solid. The pH of the filtrate was measured using a pH/EC meter (Horiba F-54). The As concentrations were measured using an atomic absorption spectrophotometer (Shimadzu AA-6800). The As removal ratio was calculated using equation (1), shown below:

$$R = \frac{C_0 - C}{C_0} \times 100 \quad (1)$$

where R refers to the removal ratio of As (%), C_0 refers to the As concentrations before the batch sorption tests (mg/L), and C refers to the As concentrations after the batch sorption tests (mg/L).

3.3 Water flow conditions using soil tank tests

Soil tank tests were conducted to evaluate the effect of the preferential flow on the performance of the geosynthetic sorption sheet. The tests were conducted using three different silica sands. Table 1 shows the properties of the silica sands. The soil tank employed was 110-cm wide, 80-cm high, and 12-cm deep, as shown in Figure 4(a). The bottom part of the soil tank consisted of six valleys and water sampling holes (drilled in the bottom of the valley), as shown in Figure 4(b). The seepage water was drained from each water sampling port.

Filter paper was installed at the sampling port at the bottom to prevent the soil particle from flowing out of the tank. Then, the soil layer below the sheet was filled. The air-dried silica sand was filled to achieve a compaction degree of 90%, based on the maximum dry density and optimum water content shown in Table 1. The layer was filled to a height of 1.5 cm from the valley's top, as shown in Figure 4(b). Once the soil layer was filled, the horizontality of the surface layer was confirmed using a level. Next, the geosynthetic sorption sheet cut to 108 cm in width was laid on the soil layer. After that, the same silica sand of the bottom layer was compacted on the geosynthetic sorption sheet with a height of 1 cm. After confirming the horizontality of the top surface of the soil sample using a level, a 3 cm × 3 cm non-woven fabric was laid above the water sampling port (C) to prevent disturbing the silica sand.

After filling the tank with sample, the pump was adjusted to spray water with an intensity of 200 mL/h. Water was sprayed directly above the water sampling port (C), assuming the preferential flow. First, the amount of infiltrated water from each sampling port was measured. Once the difference in the discharged water per hour from the port per hour was less

Table 1. Physical and chemical properties of sand specimens.

Parameter	Silica sand No. 3	Silica sand No. 5	Silica sand No. 7	Method of measurement
Particle density	2.66 g/cm ³	2.67 g/cm ³	2.749 g/cm ³	JIS A 1202 (2009)
Particle size distribution				JIS A 1204 (2009)
Average particle size	1.4 mm	0.40 mm	0.18 mm	
Coefficient of Uniformity	2.0	1.8	2.4	
Hydraulic conductivity	3.9 × 10 ⁻³ m/s	1.3 × 10 ⁻³ m/s	1.5 × 10 ⁻⁴ m/s	JIS A 1218 (2009)
Compaction properties				JIS A 1210 (2009)
Optimum water content	12.7%	13.0%	17.1%	
Maximum dry density	2.66 g/cm ³	2.67 g/cm ³	2.749 g/cm ³	

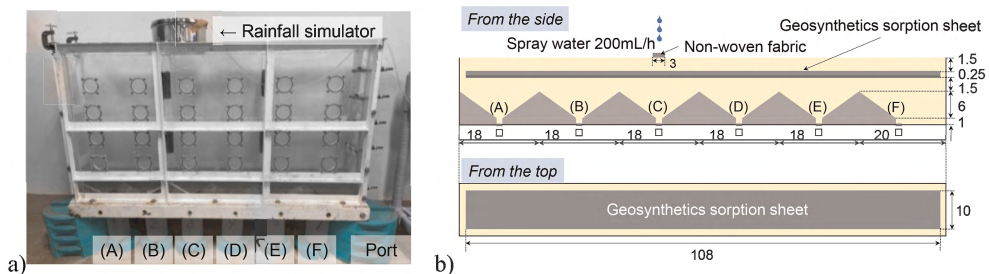


Figure 4. Picture and schematic diagram of the soil tank tests.

than 5%, it was considered that steady state condition was attained. Then, tests were terminated after measuring the amount of water released per hour. The water contents of silica sand near each port were also measured. Each soil tank test was repeated twice.

4 RESULTS AND DISCUSSION

4.1 Arsenic sorption performance

Figure 5 shows the results of the batch sorption tests. The removal ratio of As(V) was higher than that of As(III), as shown in Figure 5(a). This is because more than half of As(III) exists in the neutral region as H_3AsO_3 with no ionic form or H_2AsO_3^- as an anion with a single form (Smedley & Kinniburgh 2002). On the other hand, more than half of As(V) exists in the state of having the divalent anion HAsO_4^{2-} or the monovalent anion H_2AsO_4^- . Since the hydrotalcite compound capture arsenic due to anion exchange (Bhaumik *et al.* 2005), relatively high sorption performance can exhibit for As(V), which shows stronger electric attraction, while the anion exchange was relatively challenging to occur for As(III).

Figure 5(b) shows that the sorption reaction of As reaches nearly equilibrium at 12 hours because almost the same removal ratio is obtained between 12–24 hours. Even though the short contact time is applied, more than 60% of arsenic can be sorbed by the sheet. This result supports the sorption sheet can be one of the promising countermeasures against geogenic contamination. In addition, the higher the initial concentration of arsenic, the lower the removal ratio obtained. Sorption performance of the geosynthetic sorption sheet is affected by the arsenic concentration of leachate, thus the leaching concentration of a given excavated soil should be carefully investigated.

In the case of As(V) with $C_0 = 0.1 \text{ mg/L}$, the removal ratio was higher than 80% at the contact time of 15 minutes. Therefore, if the arsenic contained in the leachate is about 0.1 mg/L of As(V), which corresponds to 10 times the environmental standard value in Japan, enough sorption capacity could be performed even with a short contact time of 15 minutes. This result suggests that sufficient sorption performance can be expected even with a thin geosynthetic sorption sheet that cannot ensure a long contact time with the geogenically contaminated seepage.

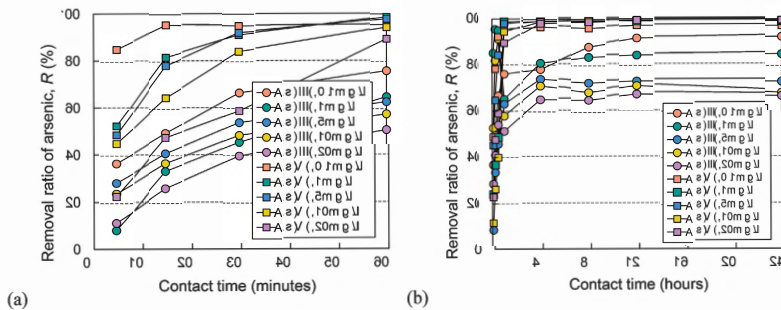


Figure 5. Results of the batch sorption tests of (a) 0–60 minutes, and (b) 0–24 hours.

4.2 Drained seepage from the soil tank tests

Figure 6 shows the amount of drainage per hour from each water sampling port in a steady state when watering is performed. As shown in Figure 6(a), when silica sand No. 3 with a large particle size was used, almost all 200 mL of water sprinkled was drained from the port (C). Judging from Figure 6, the soil tank test was conducted with relatively good

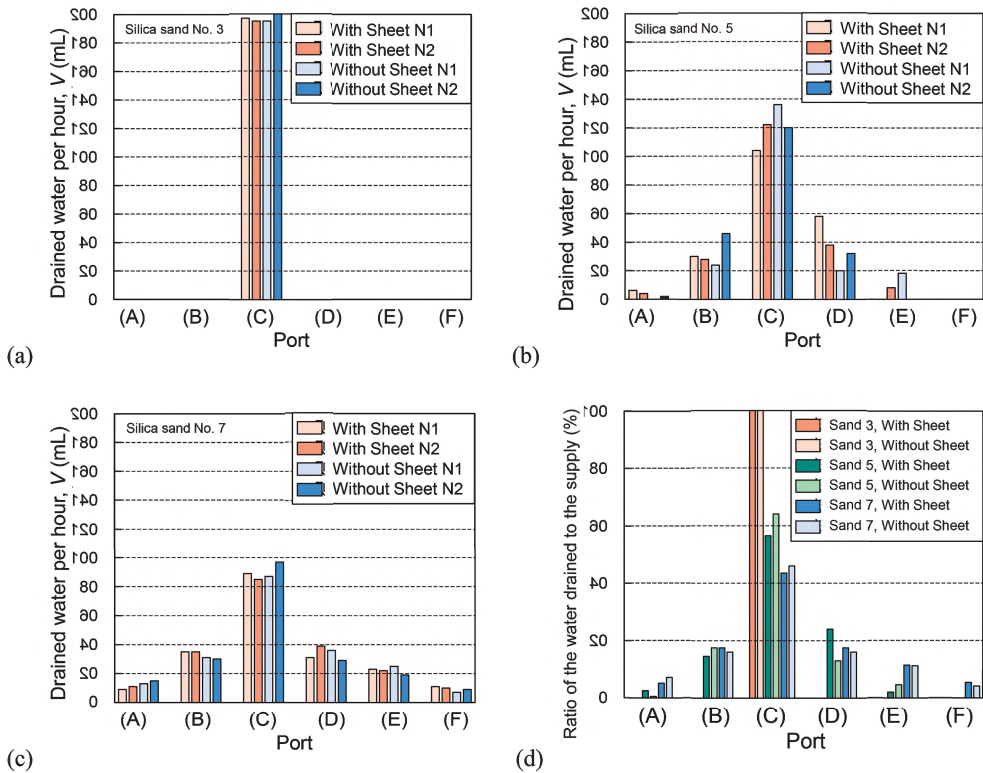


Figure 6. Results of the soil tank tests for (a) Silica sand No.3, (b) Silica sand No.5, (c) Silica sand No.7, (d) comparison of the effect of installing geosynthetic sorption sheets.

repeatability for duplication. When silica sand No. 5, with a smaller particle size than silica sand No. 3, is used, infiltration water was obtained not only under the watering position (C) but also from (A) to (E), as shown in Figure 6(b). The amount of drainage from (C) was the largest. These results confirmed that a certain amount of infiltrated water could be distributed even with silica sand No. 5, which has a relatively larger grain size than No. 7 and is single-grained soil. As shown in Figure 6(c), when silica sand No. 7, which has a smaller particle size than silica sand No. 5, is used, the amount of drainage from directly below the watering position (C) decreases, and (A) and (E) further increased the amount of water discharged. This result suggested that the infiltration water could be more distributed in the ground with smaller grain sizes.

Figure 6(d) shows the ratio of the amount of drained water from each port. The average value of the test results of two repetitions is shown. For example, focusing on port (C) in Figure 6(d), with silica sand Nos. 5 and 7, the amount of water from (C) was slightly affected by the presence of the sorption sheet, but the difference was not significant. The particle size of the ground surrounding the sheet may affect the seepage water distribution more than the presence the sorption sheet.

5 CONCLUSIONS

When applying geosynthetic sorption sheets, materials that can attenuate contaminants in a short time should be selected. This study revealed that the geosynthetic sorption sheet

exhibits high sorption performance for arsenic even under short contact times. Especially in the case of low concentration, such as geogenic contamination, high sorption performance is expected.

The embankment using geogenically contaminated soils should be constructed to permeate seepage water evenly to the sheets. The seepage water was more distributed in the ground with smaller grain sizes. One reason is that the smaller the soil particles, the greater the suction. Therefore, the surrounding soil layer should be sufficiently compacted when installing a geosynthetic sorption sheet. Further, applying fine-grained soil is recommended so that the soil layer retains pore water for longer periods.

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