Improvement of water and air permeability of landfilling sludge by mixing treatment with the other waste

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Abstract

Early stabilization of landfilled waste requires the finish of reaction in landfill layer. The main internal reaction, i.e. mineralization of organic matter and washing out of soluble matter might be accelerated by improvement of mobility of water and gas in landfill layer. In this study, landfilling sludge which causes occlusion of landfill layer was mixed with the other waste, i.e. slag or construction waste in order to improve water and air permeability. The saturated hydraulic conductivity, intrinsic permeability and the other parameters were determined for various mixing proportion of wastes. The saturated hydraulic conductivity and intrinsic permeability did not decrease at 13% and 29% of addition of sludge to slag and construction waste, respectively. Furthermore, water retention curve was determined and the water retention form in waste layer was discussed.

Keywords

Industrial solid waste, acceleration of the stabilization, sludge, mixing, permeability

1 Introduction

In Japan, waste is classified into municipal and industrial waste, and the major part of landfilling industrial waste are construction waste, sludge, slag and dust. Landfilled sludge which has low water and air permeability possibly cause an inhibition of transfer of water and gas in landfill layer. Then, transfer of soluble substance and Oxygen in landfill layer will be insufficient. This may lead a long period for decomposition and exclusion of organic matters.

In this study, improvement of water and air permeability of landfilling sludge was examined by mixing treatment with the other waste for aerobic environment and high reactivity of organic matters in landfill layer.

2 Materials and methods

2.1 Sampled materials

In this study, sludge which has lower permeability and slag and mixed construction waste which have higher permeability were chosen as the target waste material.

Sludge is roughly classified into organic and inorganic sludge. The major part of organic sludge is generated from food processing, stock farming and sewage treatment facility. The major part of inorganic sludge is generated from excavation and construction work of the ground (called “excavation sludge” hereafter), water purification plant and chemical industry. The excavation sludge was chosen as the target sludge. The dewatered and landfilled excavation sludge was colleted as sample (named IW-ES) at a sludge treatment facility.

Slag was collected at melting process of a steel mill (named IW-SG’). Slag contains larger particle, so maximum particle size was 5 cm. The fraction over 16 mm was removed by sieving (named IW-SG) considering the size of experimental apparatus.

Mixed construction waste is generated from construction and demolishing work of the building. The treated residue after hand picking and removing larger fraction by sieving was collected as the sample (named IW-MC).

IW-SG and IW-MC in itself and the mixture with IW-ES were used as the experimental samples.

2.2 Characteristics of samples

Moisture content, ignition loss, bulk density in sampling container and particle density were measured (Table 1). In order to compare and contrast, particle density of Incineration ash (MS-Ash), molten slag (MS-SG) and shredded incombustible residue (MS-SW) of MSW which are major landfilling waste in Japan are also shown in Table 1 (TOJO, 2002). IW-SG had lower organic matter, heavy particle and heavy bulk density. IW-MC had relatively rich organic matter and light bulk density. IW-ES had higher moisture.

The samples were dried at 105˚C for a day and then were subjected to a size fraction analysis as shown in Figure 1. The dried IW-ES was solidified and could not be taken apart (IW-ES’ in Figure 1). Then water was added into IW-ES and the slurry was sieved with flowing water (IW-ES in Figure 1). Slag contains larger particle above 2 mm in large quantities, so the particle size distribution is similar to MW-Ash, SG and SW. On the other hand, IW-MC has smaller particle.

Table 1 Physical properties

Notation	Description	Moisture content ω [%]	Ignition loss - [%]	Bulk density ρ_d, [g/cm^3]	Particle density ρ_p, [g/cm^3]
IW-SG	Slag from steel mill	1.1	0.0	2.0	3.4
IW-MC	Sieved mixed construction waste	7.7	15.6	1.0	2.5
IW-ES	Sludge from construction work	31.0	8.4	1.4	2.6
MW-Ash*	Incineration ash of MSW	-	-	-	3.1
MW-SG*	Molten slag of MSW	-	-	-	2.8
MW-SW*	Shredded incombustible MSW	-	-	-	1.3

*TOJO (2002)

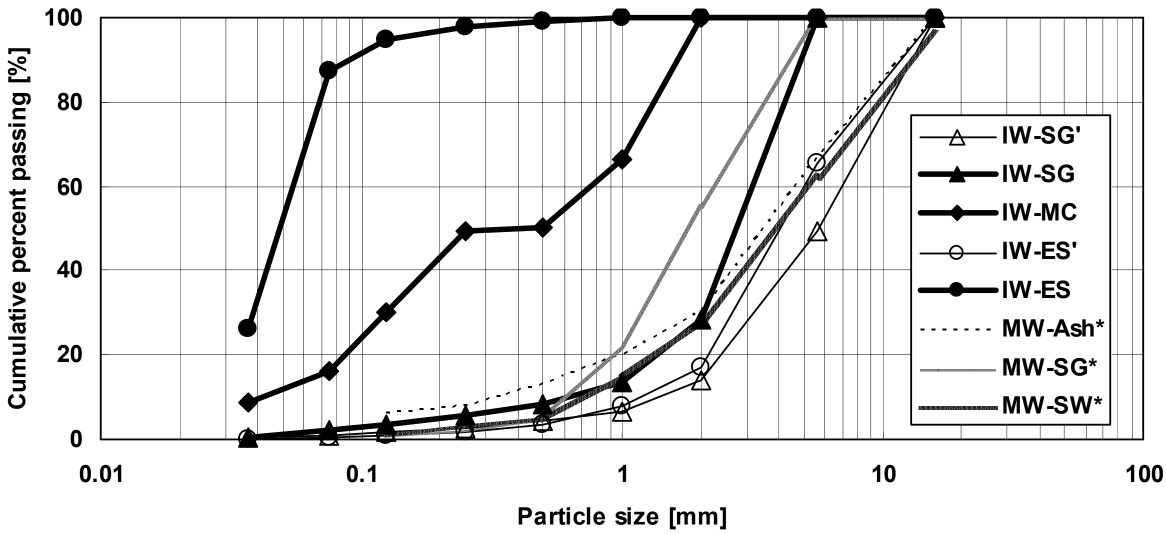

Figure 1 Size fraction analysis

Note: IW-SG' which is original sample was sieved and the particle over 16 mm was removed, so under 16 mm was called IW-SG. IW-ES' was dried sludge and IW-ES was slurry by addition of water.

*TOJO (2002)

2.3 Parameters and experimental methods

2.3.1 Permeability

Permeability controls convective transport of water and gas through a porous media in response to a total pressure gradient. Based on the well-known Darcy's law, it is possible to determine the permeability according to the following relationship expressed by equation (1). Hence, the intrinsic permeability K, which depends only on the gas-filled pore structure, can be estimated using equation (2).

$$K_g = \frac{vL}{P_0 - P_L} \qquad (1)$$

$$K = \mu K_g \qquad (2)$$

where K_g is gas permeability ($m^2Pa^{-1}s^{-1}$); v is Darcy's velocity of the gas (ms^{-1}); L is the distance from the origin (m); P_0 is the pressure at the origin (Pa); P_L is the pressure at the distance L (Pa); K is the intrinsic permeability (m^2) and μ is the gas viscosity (Pas).

Samples were filled and packed densely 50 cm long with a tamper in the column 70 cm long with ID of 15 cm. Water was added into column and filled sample was saturated. Water was supplied into the column and saturated hydraulic conductivity k_H (cm/s) was obtained by measuring water head and flow rate. Water in column was discharged from the bottom drain cock for a day and moisture condition became field capacity. To avoid an aquifer in the bottom layer, column was laid down for several hours. N_2 gas was supplied into the column and gas permeability K_g was obtained by measuring static pressure with manometers and flow rate of N_2. K was estimated with viscosity of N_2 gas used in this work $1.77 \cdot 10^{-5}$ Pas at 20˚C. Sample filling condition is shown in Table 2.

2.3.2 Tortuosity factor and equivalent pore radius

The effective gas diffusion coefficient D_e is proportional to the gas diffusion coefficient in the air D_g^0. For instance one often writes (EVANS and WATSON, 1961):

$$D_e = \frac{\varepsilon}{\xi} D_g^0 \qquad (3)$$

where ε is gas-filled porosity and ξ is tortuosity. The tortuosity ξ is the characteristic of each individual porous medium that must be investigated by experiment (EVANS and WATSON, 1962).

The equivalent pore radius r can be calculated, based upon the following equation:

$$r = \sqrt{\frac{\xi}{\varepsilon} 8K} \qquad (4)$$

The column was filled with only N_2 gas after measurement of K_g. Argon gas was introduced into the head-space of the column. As diffusion occurs, the argon gas fraction increases in the pore space of the waste layer. Tortuosity ξ is obtained by measuring mole fraction of argon in waste layer and elapsed time (KALLEL, TANAKA and MATSUTO, 2004). The equivalent pore radius r was estimated with equation (4).

2.3.3 Van Genuchten parameter

Some water in landfilled waste layer transfer by gravity, surface tension and the other effect, others bond with waste by adsorbing power. The bounding strength between waste and water can be expressed by water retention characteristic, so it is important to evaluate water mobility in waste layer.

Van Genuchten expressed the relationship between matric potential ψ (= $-h$) and volumetric moisture content θ (= ω_v) [-].

$$\theta = \theta_r + \frac{\theta_s - \theta_r}{\left\{1 + (\alpha h)^n\right\}^m} \qquad (5)$$

where θ_r is minimum volumetric moisture content [-]; θ_s is saturated volumetric moisture content [-], and α and n (m = $1-n^{-1}$) is Van Genuchten parameter [-].

Samples were filled and packed densely with a tamper in the ring 5 cm long with ID of 4 cm which were placed upon another with an adhesive tape, so rings were piled to 75 cm. The connected rings were put into a cylinder and water was added from the outside of rings and filled sample was saturated for a day. Water in cylinder was discharged from the bottom drain cock for two days. The moisture content of samples filled in each rings were measured and volumetric moisture contents θ of different height were obtained.

3 Results and discussion

3.1 Permeability, Porosity, Tortuosity factor and equivalent pore radius

Sample filling condition is shown in Table 2. Porosity φ, gas-filled porosity ε and degree of saturation S_r can be calculated (Table 3) using the parameter of Table 1. The porosity φ did not decrease excessively as the dry sludge content increased. But gas-filled porosity ε decreased since volumetric moisture content ω_v and degree of saturation S_r increased, that is, moisture retention capacity increased.

Obtained saturated hydraulic conductivity k_H, intrinsic permeability K, tortuosity ξ and equivalent pore radius r are listed in Table 4. At the condition of sludge addition to Run 3, k_H and K did not decrease excessively. Regardless of the decrease of ε, k_H increased once in RUN2 (Figure 2). There were observable large amount of smaller particles of the filled samples of RUN 1 and it was seen plugging the void space between the larger particles. On the other hand, with a little addition of sludge, the smaller particles were aggregated and much void space could be seen. In this way, a little addition of sludge was effective for keeping void space. The phenomenon of aggregation is illustrated in Figure 3.

Table 2 Sample filling condition

Mixing sample	Run	Dry mixing waste content [%]	Dry sludge content [%]	Moisture content ω [-]	Volumetric moisture content ω_v [-]	Bulk density ρ_d [g/cm^3]	Particle density ρ_p [g/cm^3]
IW-SG	1	100	0	0.04	0.09	2.1	3.4
	2	95	5	0.05	0.12	2.2	3.5
	3	87	13	0.11	0.27	2.1	3.3
	4	78	22	0.17	0.40	1.9	3.3
IW-MC	1	100	0	0.42	0.61	0.8	2.5
	2	88	12	0.37	0.56	1.0	2.5
	3	71	29	0.35	0.56	1.1	2.5
	4	58	42	0.39	0.62	1.0	2.7

Table 3 Porosity condition

Mixing sample	Run	Porosity φ [-]	Gas-filled porosity ε [-]	Degree of saturation S_r [-]
IW-SG	1	0.390	0.303	0.222
	2	0.383	0.268	0.301
	3	0.359	0.089	0.753
	4	0.409	0.006	0.985
IW-MC	1	0.667	0.057	0.914
	2	0.610	0.051	0.917
	3	0.584	0.026	0.956
	4	0.639	0.020	0.969

Table 4 Permeability and pore condition

Mixing sample	Run	Saturated hydraulic conductivity k_H [cm/s]	Intrinsic permeability (by gas flow) K [m^2]	Tortuosity ξ [-]	Equivalent pore radius r [m]
IW-SG	1	3.9E-02	1.9E-10	2.5	1.1E-04
	2	3.9E-02	9.5E-10	1.2	1.9E-04
	3	3.5E-02	2.7E-10	0.7	1.3E-04
	4	1.8E-04	6.5E-13	19.0	1.3E-04
IW-MC	1	1.1E-03	4.4E-12	2.5	3.9E-05
	2	2.4E-03	1.2E-10	3.0	2.4E-04
	3	3.2E-03	3.0E-11	2.9	1.7E-04
	4	3.7E-04	n.a.	n.a.	n.a.

n.a., not analyzed.

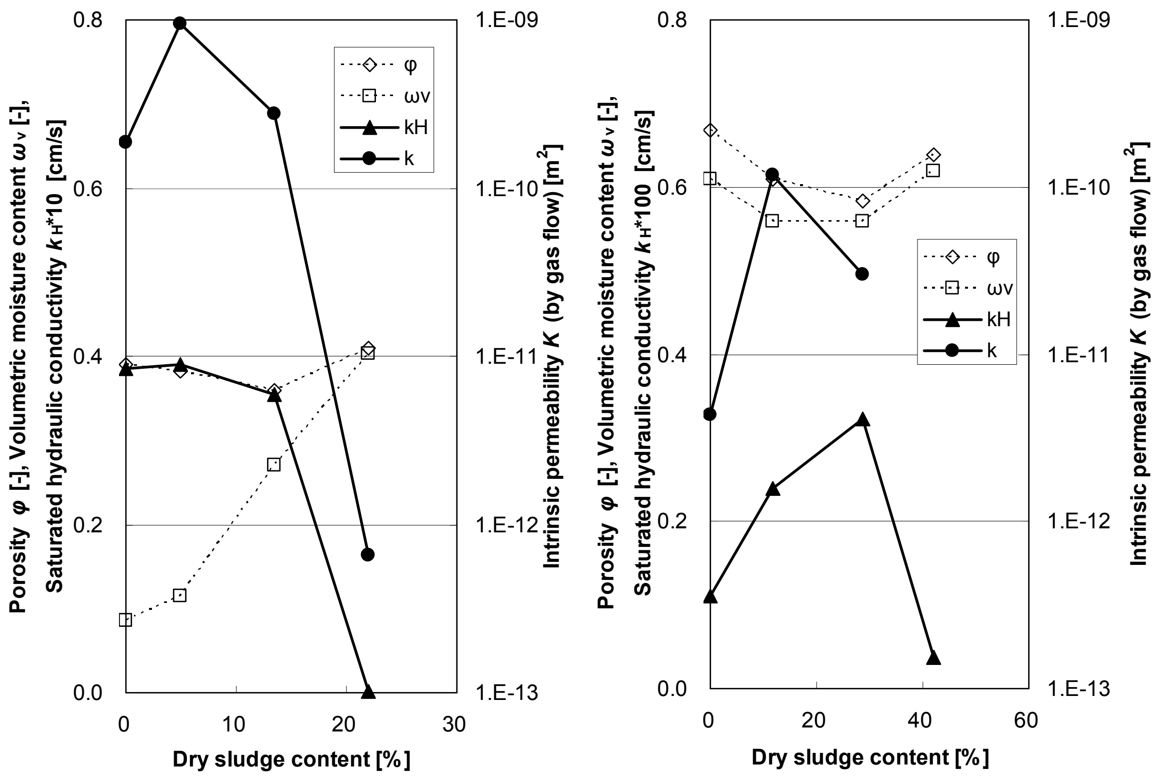

Figure 2 Relationship between dry sludge content and φ, ω_v, k_H and K

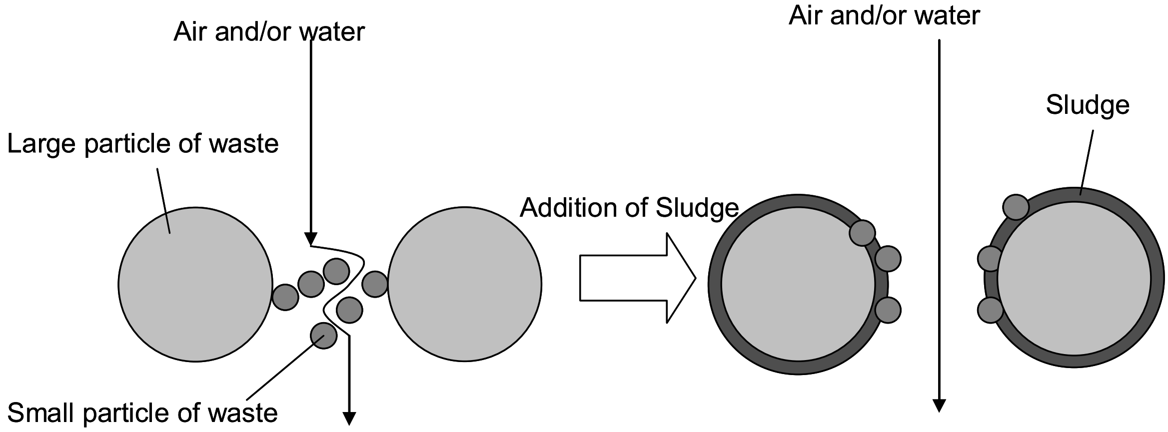

Figure 3 Aggregation and improvement of permeability

3.2 Water retention curve

The obtained water retention curve which illustrates the relationship between volumetric moisture content θ (= ω_v) versus the matric potential $-\psi$ (= h) in this study and literature is shown in Figure 4 and 5. At the condition of sludge addition to Run 3 of IW-SG which contained 13 % of dried sludge, θ was increased a little and no excessive difference was seen. In Run 4 of IW-SG, at 22 % of dried sludge, the θ values became maximum and constant from the bottom to the top. In RUN 1 of IW-MC, there were dewatered moisture in higher rings, but at 12 % and more of dried sludge brought about maximum and constant θ as well as sludge itself.

The Van Genuchten parameters, that is, α and n can be inferred by fitting the measured θ using equation (5) (Table 5). Then, minimum volumetric moisture content θ_r, observed saturated moisture content $\theta_{s\text{-}obs}$ and calculated saturated moisture content $\theta_{s\text{-}cal}$ were regarded as constant moisture content at higher rings, θ at bottom ring and porosity φ, respectively. The water retention and space form are expressed in Table 5 using the parameters of these moisture content. The immobile water, all pore, capillary water were regarded as θ_r, φ and difference between $\theta_{s\text{-}obs}$ and immobile water, respectively. The difference between all pore and $\theta_{s\text{-}obs}$ is assumed the space in which moisture can be dewatered easily, so it is expressed wide pore. The water retention and space form are shown in Figure 6. The height of each bar means all pore. As far as IW-SG, immobile water increased and wide pore decreased along with addition of sludge. On the other hand, immobile water occupied the majority of all pore in RUN 2, 3 and 4 of IW-MC.

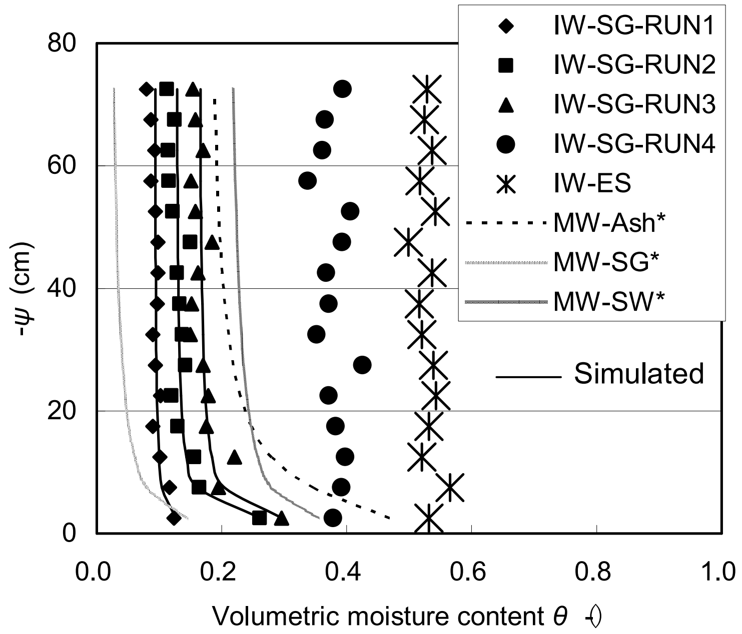

Figure 4 Water retention curves for IW-SG mixed with IW-ES and literature results

*TOJO (2002)

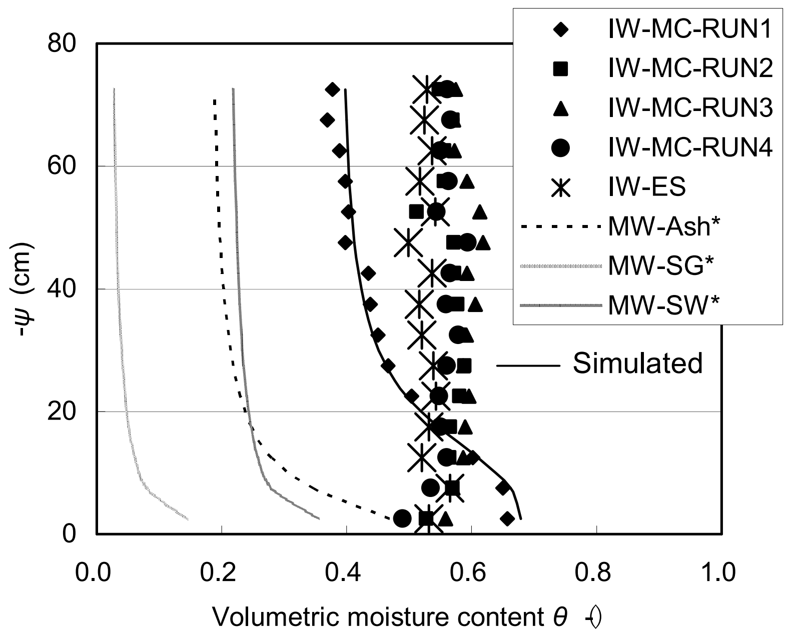

Figure 5 Water retention curves for IW-MC mixed with IW-ES and literature results

*TOJO (2002)

Table 5 Obtained van Genuchten parameters

Sample	RUN	Filling condition: Bulk density ρ_d [g/cm³]	Filling condition: Particle density ρ_p [g/cm³]	Given parameter (Noted in the margin): $\theta_{s\text{-}cal}$ [-]	Given parameter: $\theta_{s\text{-}obs}$ [-]	Given parameter: θ_r [-]	Obtained parameter: α [-]	Obtained parameter: n [-]	Obtained parameter: m [-]	Water retention and space form: Immobile water [-]	Capillary water [-]	Wide pore [-]	All pore [-]
IW-SG	1	1.8	3.4	0.46	0.12	0.09	4.70	1.97	0.49	0.09	0.03	0.34	0.46
	2	1.8	3.5	0.48	0.26	0.13	0.74	2.36	0.58	0.13	0.13	0.22	0.48
	3	1.9	3.3	0.41	0.30	0.16	0.55	2.27	0.56	0.16	0.13	0.12	0.41
	4	2.0	3.3	0.39	0.38	0.38	n.a.	n.a.	n.a.	0.38	n.a.	n.a.	0.39
IW-MC	1	0.8	2.5	0.68	0.66	0.39	0.06	3.25	0.69	0.39	0.27	0.02	0.68
	2	1.0	2.5	0.61	0.53	0.56	n.a.	n.a.	n.a.	0.56	n.a.	n.a.	0.61
	3	1.0	2.5	0.60	0.56	0.59	n.a.	n.a.	n.a.	0.59	n.a.	n.a.	0.60
	4	1.0	2.7	0.63	0.49	0.56	n.a.	n.a.	n.a.	0.56	n.a.	n.a.	0.63
IW-ES		1.2	2.6	n.a.	n.a.	n.a.	0.55	0.53	0.57	0.53	n.a.	n.a.	0.55
MW-Ash*		-	-	-	0.50	0.18	0.19	2.20	0.55	-	-	-	-
MW-SG*		-	-	-	0.31	0.01	1.29	1.65	0.39	-	-	-	-
MW-SW*		-	-	-	0.56	0.20	1.39	1.64	0.39	-	-	-	-

$\theta_{s\text{-}cal}$: Calculated saturated volumetric moisture content
s_{obs}: Observed saturated volumetric moisture content
θ_r: Minimum volumetric moisture content obtained by gravity dewatering
$\theta_{s\text{-}cal}$ = All pore = Porosity
Immobile water = θ_r
Capillary water = $\theta_{s\text{-}obs}$ – Immobile water
Wide pore = All pore – $\theta_{s\text{-}obs}$
n.a., not analyzed
*Tojo (2002)

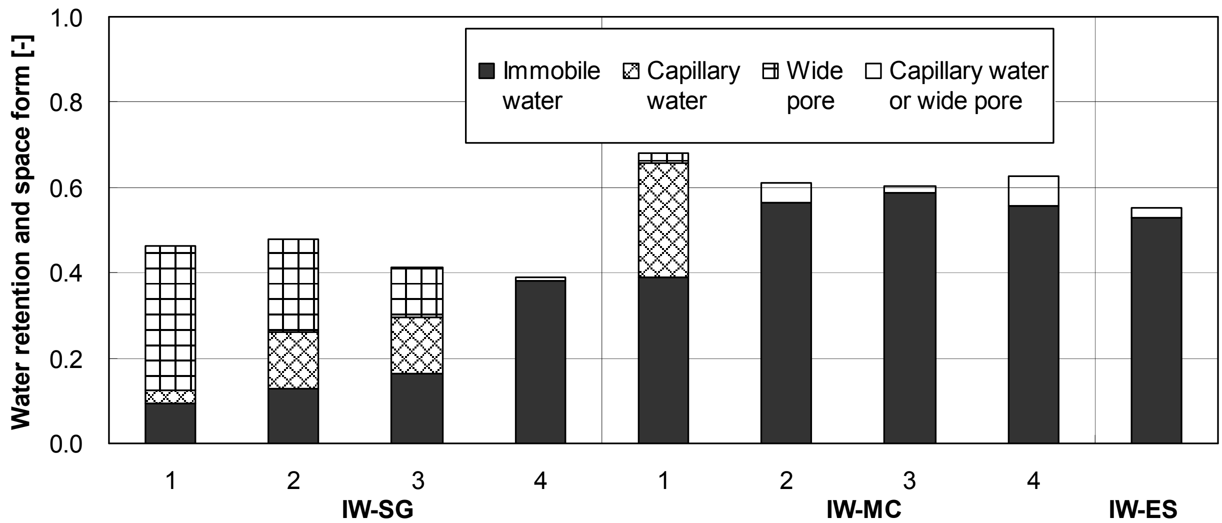

Figure 6 Water retention and space form

4 Conclusion

Landfilling sludge which causes occlusion of landfill layer was mixed with the other waste, i.e. slag or construction waste in order to improve water and air permeability.

The saturated hydraulic conductivity, intrinsic permeability and the other parameters were determined for various mixing proportion of wastes. The saturated hydraulic conductivity and intrinsic permeability did not decrease at 13% and 29% of addition of sludge to slag and construction waste, respectively.

Furthermore, water retention curve was determined and the water retention form in waste layer was discussed.

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