

Fig.6 The relationship between the period of the injection and q_u

were different at every case depend on the density, the volume, the days to inject the distilled water.

According to Fig.6, the tendency to be more q_u comparatively in the case which the period of the injection was about from 3 days to 6 day was verified. In Case 5 which has only two days as the period of the injection, CaCO_3 precipitation ratio and q_u was less comparatively as shown Fig.3. Presumably, this result is because the time to use the components to precipitate CaCO_3 in the void was not obtained sufficiently, as stated above 2).

Conversely in the cases which have the long period of the injection, q_u was less comparatively, too. It was verified that *Sporosarcina pasteurii* would be most active within about 8 days at first on the past study (Inagaki 2014). It seems the reactions as Eq.(1), Eq.(2) and Eq.(3) became dull because of the decline of microbial functions in the cases which have the long period of the injection.

It is considered desirable that the density of the nutrient salt and discharge would be instituted to put the period of the injection within the period in which the microbial functions is active.

3.4 The Influence of the Density of the Nutrient Salt

In the continuous injection, comparisons between the 2 Cases had the same discharge and the different density of the nutrient salt were investigated on Case 1 and Case 3, Case4 and Case 6 and Case 5 and Case 7.

As stated above Fig.4, q_u in the case of the density 1 (Case 1) was more than it in the case of the density 0.5 with the discharge 0.07 mL/min. Conversely with the discharge 0.14 mL/min and 0.21 mL/min, q_u in the case of the density 0.5 (Case 6 and Case 7) was more than it in the case of the density 1. As shown Fig.7, in Case 1, Case 6 and Case7 the bigger clods remained after the unconfined compression tests than in Case 3, Case 4 and Case 5. If the discharge was faster than 0.14 mL/min, in the case of density 0.5 were effective for the solidification than in the case of density 1.







Discharge 0.07mL/min			
Case 3		Case 1	
Density 0.5		Density 1	
$q_u=6.29\text{kPa}$		$q_u=18.61\text{kPa}$	
			
Discharge 0.14mL/min		Discharge 0.28mL/min	
Case 6	Case 4	Case 7	Case 5
Density 0.5	Density 1	Density 0.5	Density 1
$q_u=53.29\text{kPa}$	$q_u=10.47\text{kPa}$	$q_u=28.91\text{kPa}$	$q_u=7.37\text{kPa}$
			

Fig.7 The appearance of the specimen after the unconfined compression test
 (By the density and the discharge)

Fig.8 instances the change of the density of NH_4^+ in the pore water drained from the void on from Case 4 to Case 7. NH_4^+ occurs with ureolysis shows microbial functions in the void. In the all cases from Case 4 to Case 7, NH_4^+ was found and it seems that ureolysis progressed.

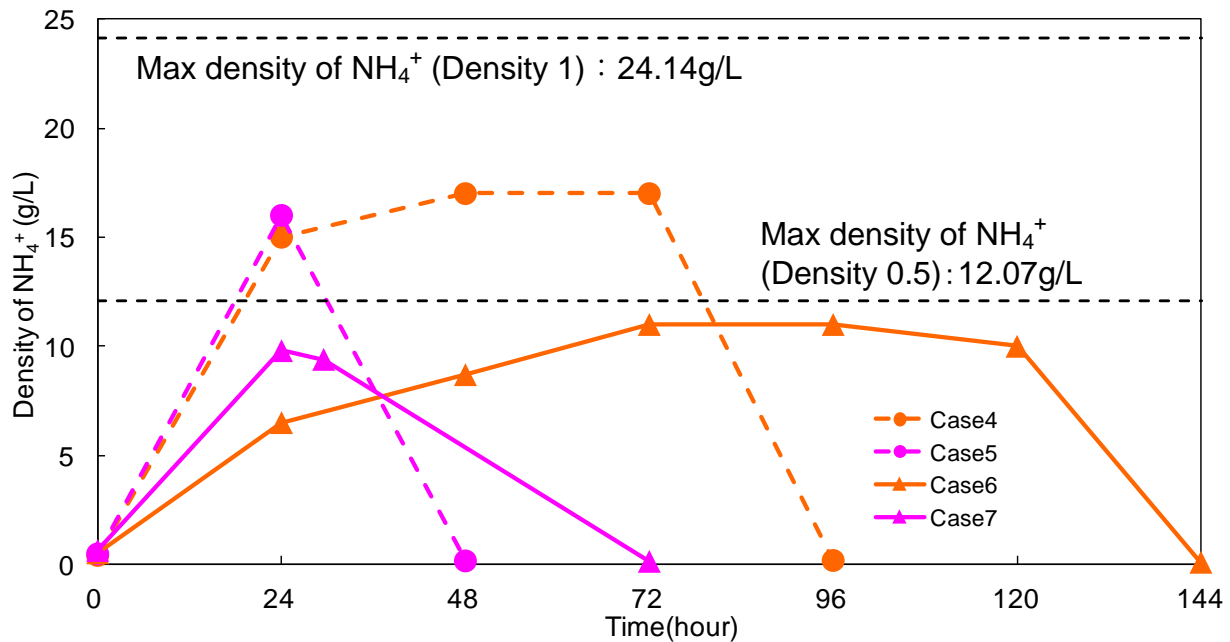


Fig.8 The change of the density of NH_4^+ in the period of the injection

As the difference depends on the density of the nutrient salt, the comparisons were made between Case 4 and Case 6 and between Case 5 and Case 7 respectively. In the Case 6 or Case 7 which is the density of nutrient salt 0.5, the density of NH_4^+ was thinned because the density of urea given was half. But if attention is paid to the ratio density of NH_4^+ to the density of NH_4^+ in the case all urea dissolved, it seems that ureolysis progresses well in Case 6 or Case 7 than in Case 4 or Case 5. In these cases, it is considered that q_u increased, because ureolysis and CaCO_3 precipitation continued longer and more regularly than in the cases of density 1.

It is required that the environmental influence caused by injections of the nutrient salt is decreased when the practical ground is solidified. It is considered that the injection of the thin nutrient salt with much volume can be effective to decrease the density of the ions from the nutrient salt.

3.5 The Influence of the Method of the Injection

As the influence of the method of the injection of the nutrient salt, the results of from Case 8 to Case 11 were compared each other. Pouring of the 200 mL of nutrient salt and leaving were repeated in the intermittent injection of Case 8 and Case 9. In the Case 11, the nutrient salt was injected with fixed discharge. In Case 10, after 200 mL of the nutrient salt was poured and the culture solution was replaced, the 600 mL of the

nutrient was injected with fixed discharge. These 4 cases were carried out at the same time, using the culture solution prepared in the same container.

Fig.9 shows the relationship between the ratio of CaCO_3 precipitation and q_u about these 4 cases. In Case11 which the nutrient salt was injected continuously, the ratio of CaCO_3 precipitation and q_u was small than in the other 3 cases.

Fig.10 shows the states of each specimen after the unconfined compression tests. In Case 8 and Case 9 which the nutrient salt was injected intermittently, each clods were small, but many clods were found comparatively. It seems that the extent solidified was large. In Case 10 or Case11 which the part or all of the nutrient salt was injected continuously, a few large clods were found comparatively. It seems that the extent solidified was small than Case 8 or Case 9.

From these results, it seems that the uniformity of solidification depended on the method of the injection. So that the ratio of CaCO_3 precipitation of the upper and lower parts cut off at the shaping were examined.

Fig.11 shows the comparison about the ratio of CaCO_3 precipitation between the upper or the lower part and specimens. The ratio of the lower part to the specimen and the ratio of the upper part to the specimen about the ratio of CaCO_3 precipitation were expressed on the horizontal axis and vertical axis, each other. If the ratio of CaCO_3 precipitation is equal on the upper part and the lower part, the point is recorded on the dotted line of Fig.11.

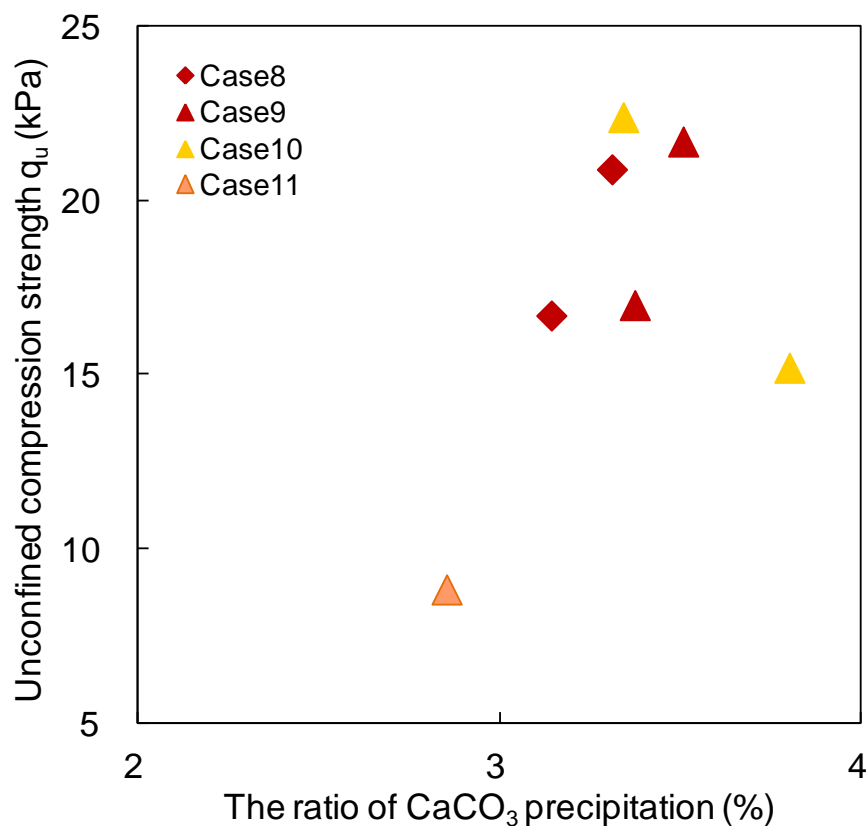


Fig.9 The influence of the method of the injection on the ratio CaCO_3 precipitation and q_u





Case 8	Case 9	Case 10	Case 11
Intermittent (Density 0.25)	Intermittent (Density 0.5)	Continuous after replacement (Density 0.5)	Continuous (Density 0.5)
$q_u=16.7\text{kPa}$	$q_u=21.7\text{kPa}$	$q_u=15.2\text{kPa}$	$q_u=8.83\text{kPa}$
			

Fig.10 The appearance of the specimen after the unconfined compression test
 (By the method of the injection)

In Case 9, the ratio of CaCO_3 precipitation was nearly equal on the specimen, the upper part and the lower part. But in the other 3 cases, the ratio of CaCO_3 precipitation was large in the order of the upper part, the specimen and the lower part. This tendency was remarkable in Case 10 and Case 11 which included the continuous injection. It seems that solidification of sand began in the upper part at first and the remaining components were used to precipitate CaCO_3 in the specimen and the lower part when the nutrient salt were injected continuously. In Case 8 and Case 9, it seems that the pore water was replaced by the nutrient salt poured into at first and the precipitation of CaCO_3 progressed in the all parts when the sand was leaved. Trough the density of the nutrient salt were different, the nearly equal effect on solidification were got in Case 8 and Case 9 (density 0.25 and density 0.5).

It is considered that the continuous injection is adapted to the concentrated solidification to limited extent and that the intermittent injection is adapted to the homogeneous solidification to large extent comparatively.

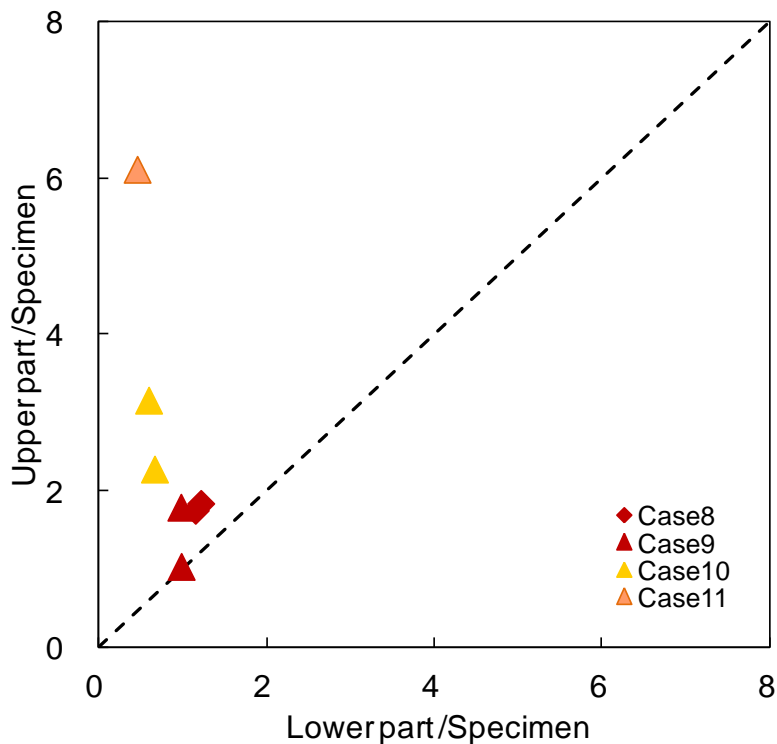


Fig.11 The comparison about the ratio of CaCO₃ precipitation between the parts

3.6 The Influence of Density of the Microbial Individual

The examinations for from Case 8 to Case 11 were conducted using the same culture solution, at the same time. The density of microbial individual in this culture solution was $3.8 \times 10^7/\text{mL}$. Fig.12 shows the relationship between the density of the microbial individual in the pore water at the finish of the period of the injection and q_u .

In all Cases from Case 8 to Case11, the density of microbial individual decreased to from 1-10⁴th to 1-tenth compared with it of the culture solution. Comparatively q_u increased though the density of microbial individual stayed on was small in Case 8 and Case 9 which the nutrient salt was injected intermittently.

This results shows that the rest of many microbial individual is not necessarily advantageous of the solidification. In the case of the intermittent injection, it seems that microbial individual decreases in void because the microbial individual is pushed out of the pore with pore water when the pore water replaces by new nutrient salt poured

It is considered that the intermittent injection can be advantageous of the control of the microbial individual remaining in the pore and the mitigation of environmental influences if the drained pore water is collected and treated appropriately.

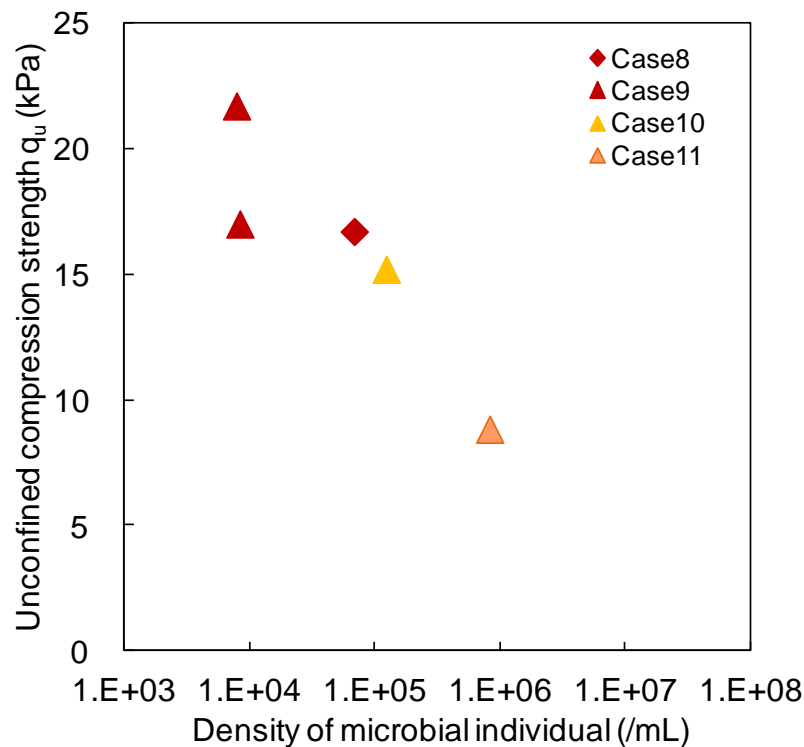


Fig.12 The relationship between the density of the microbial individual in the pore water and q_u .

4. CONCRUTIONS

Studies were conducted about the influences on the solidification of sand by Microbial Carbonate Precipitation of various factors like the density of the nutrient salt, the methods of injection, the discharge in the continuous injection, and so on. The unconfined compression tests were carried out to specimens prepared by the injection of the culture and the nutrient salt.

Followings were investigated under the condition the whole amount of the components was same on the all test cases

- There were the linear relationship between the CaCO_3 precipitation ratio and q_u . With the CaCO_3 more, q_u tended to increase.
- It is considered that the appropriate condition of discharge to not stop and remain in the void for enough time to precipitate CaCO_3 is necessary.
- The period of the injection is not necessarily advantageous of solidification. It is desirable that the period is instituted within the period in the microbial functions is active.
- It is considered that the injection of the thin nutrient salt with much volume can be effective not to decrease the density of the ions from the nutrient salt but also solidification also the mitigation of the environmental influence.
- It is considered that the continuous injection is adapted to the concentrated

solidification to limited extent and that the intermittent injection is adapted to the homogeneous solidification to large extent comparatively.

- The density of microbial individual stays in the pore after the finish of the period of the injection depends on the methods of injection. In the case the nutrient salt supplied by the intermittent injection the density of microbial individual was lower than by the continuous injection. In the case of the intermittent injection, it seems that the microbial individual is pushed out of the pore with pore water when the pore water replaces by new nutrient salt poured.

- The rest of many microbial individual is not necessarily advantageous of the solidification.

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