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Strength development of cement-treated sand using different cement types cured at different temperatures

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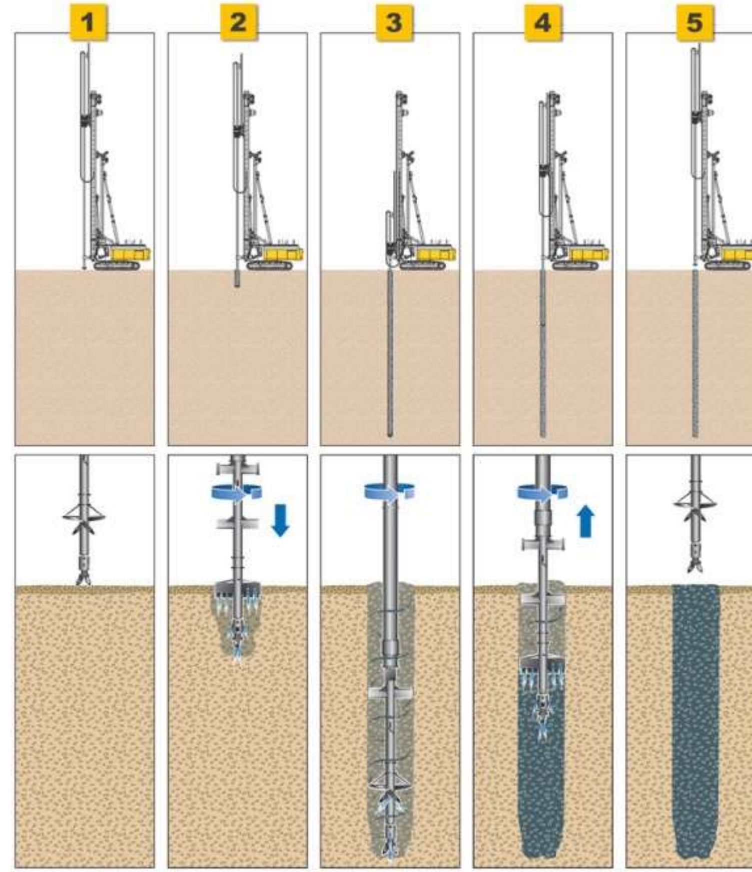
1. Introduction

Cement-treated soils are **composite materials** by mixing soil, cement, and water. Cement-treated soils are used as an improvement method of soft ground such as road-base, dam, air port, other structures etc.

Shallow mixing

Cement-treated soil used to improve the properties for subgrade of pavement
(https://www.martinmarietta.com/products/cement-treated-materials/)

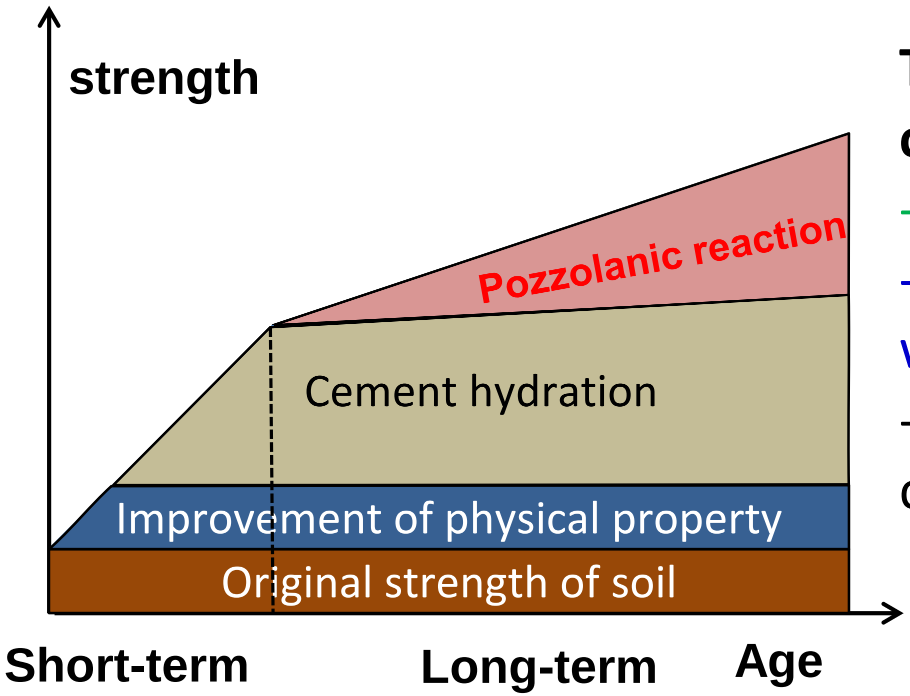
Deep mixing



Cement treated soil used to improve soft ground of dam
(https://www.liebherr.com/en/ita/products/construction-machines/deep-foundation/methods/soil-improvement/ground-improvement.html#lightbox)

1. Introduction

Strength development of cement-treated clay (Kitazume and Terashi, 2013)



There are many factors affect strength of cement-treated soils:

-Material (cement type and soil condition)

-Mix proportion (cement content, water/soil ratio)

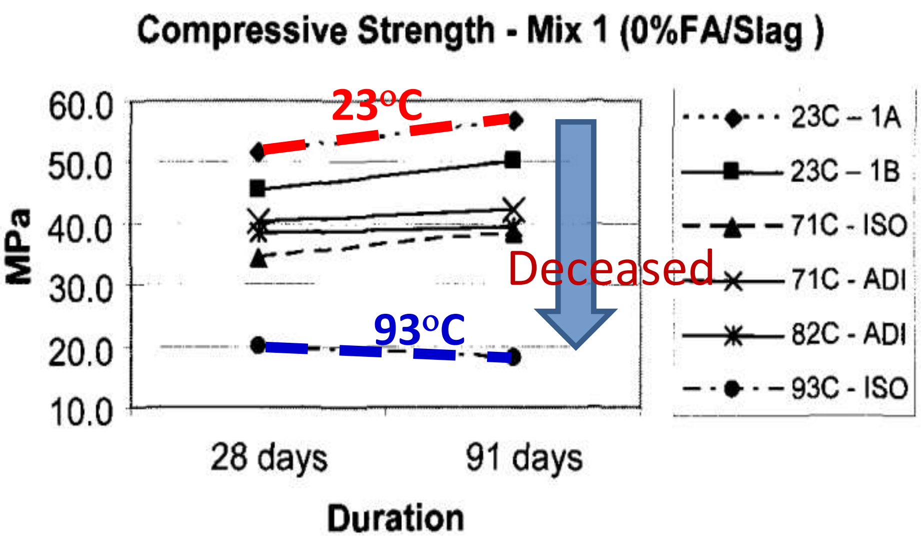
-Construction method (Mixing method, curing , **curing temperature**, age) etc.

Pozzolanic reaction is the reaction between $Ca(OH)_2$ (CH) with clay minerology (SiO_2, Al_2O_3) produces C-S-H, C-A-H, C-A-S-H

1. Introduction

Effect of curing temperature

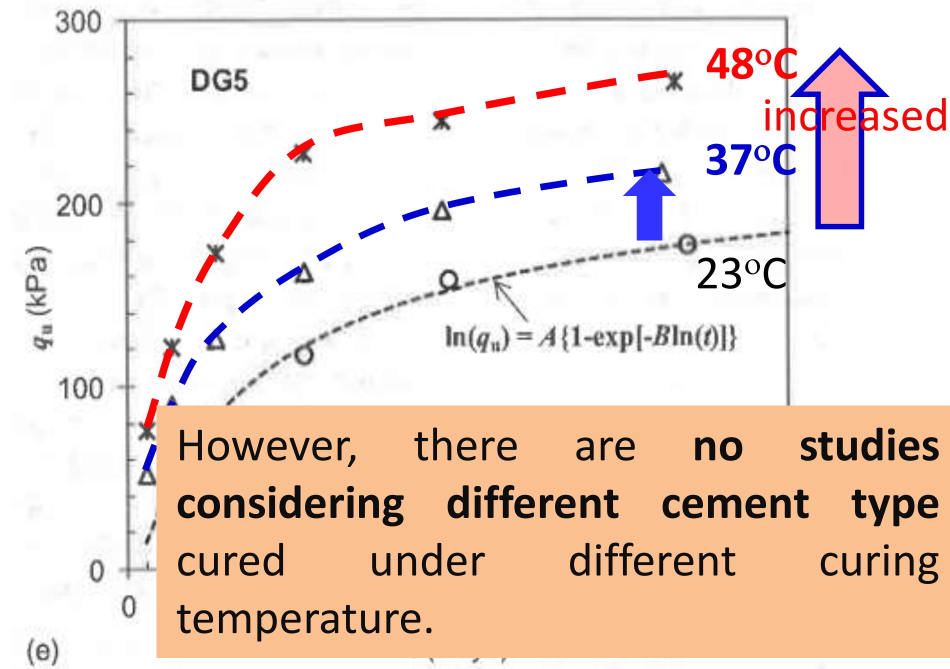
Normal concrete



Compressive strength of concrete under different temperatures (A.R. Chini and L. Acquaye, 2005)

Lime/cement treated soils

Upper marine clay; cement/dried soil=11.8%



However, there are **no studies considering different cement type** cured under different curing temperature.

Strength development over time under different curing temperature (D. Wang et al., 2016)

Purpose

This study investigated strength development of cement-treated sand using different cement types cured at different temperatures.

2. Methods and measurements

Specimen preparation

Mix proportions:

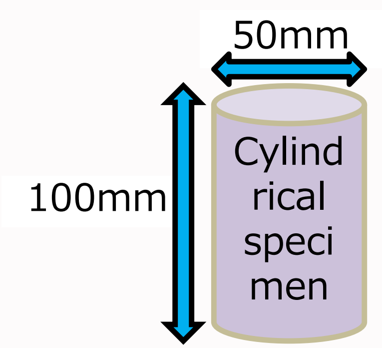
Cement: ordinary Portland cement **(OPC),** high early Portland cement **(HPC), and** moderate heat Portland cement **(MPC)** were used to discuss **effects of cement type.**

Sand mixture: Cement/sand=0.08, W/C=1.0, to discuss effects of curing temperature and cement type on strength development of cement-treated soils (high porosity).

Mortar with W/C = 1.0: Cement/sand = 0.25, W/C = 1.0, to create the mixture with the same W/C ratio (high porosity -similar to cement-treated soils) for explaining strength development.

Mortar with W/C = 0.5: **Cement/sand = 0.5, W/C = 0.5**, to discuss strength development of mortar with dense structure for comparing.

specimen size



Compaction

The sand mixture specimens

Hammer 1.5kg

3 layers

12 times/layer;

Mortar: Tapping

curing condition

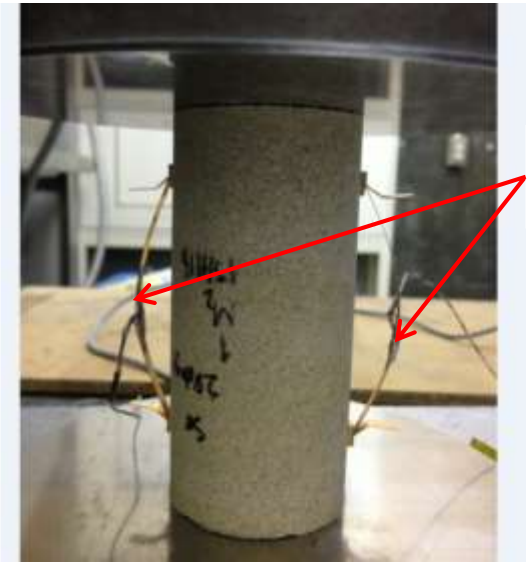
Sealed at **20°C, 40°C**

2. Methods and measurements

Measurements

➢ Unconfined compression test

The tests were performed at a constant loading rate of **0.1 mm/min** for both mortar and cement-treated sand.



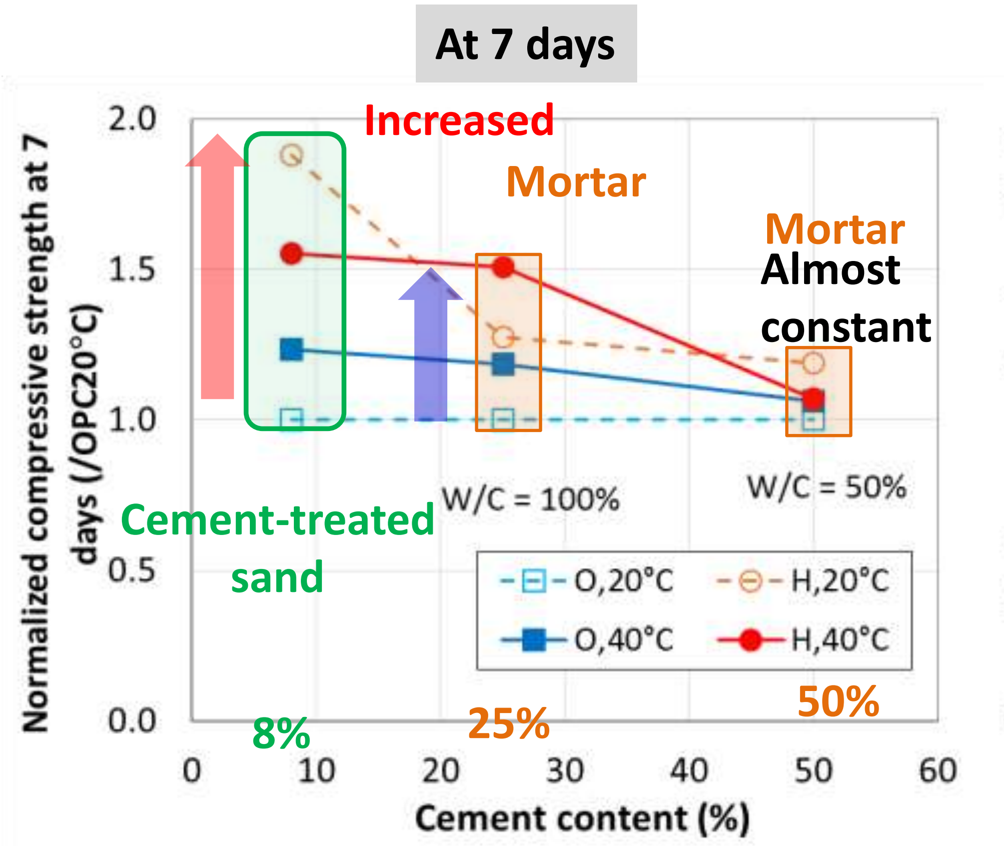
LDTs placed at centers

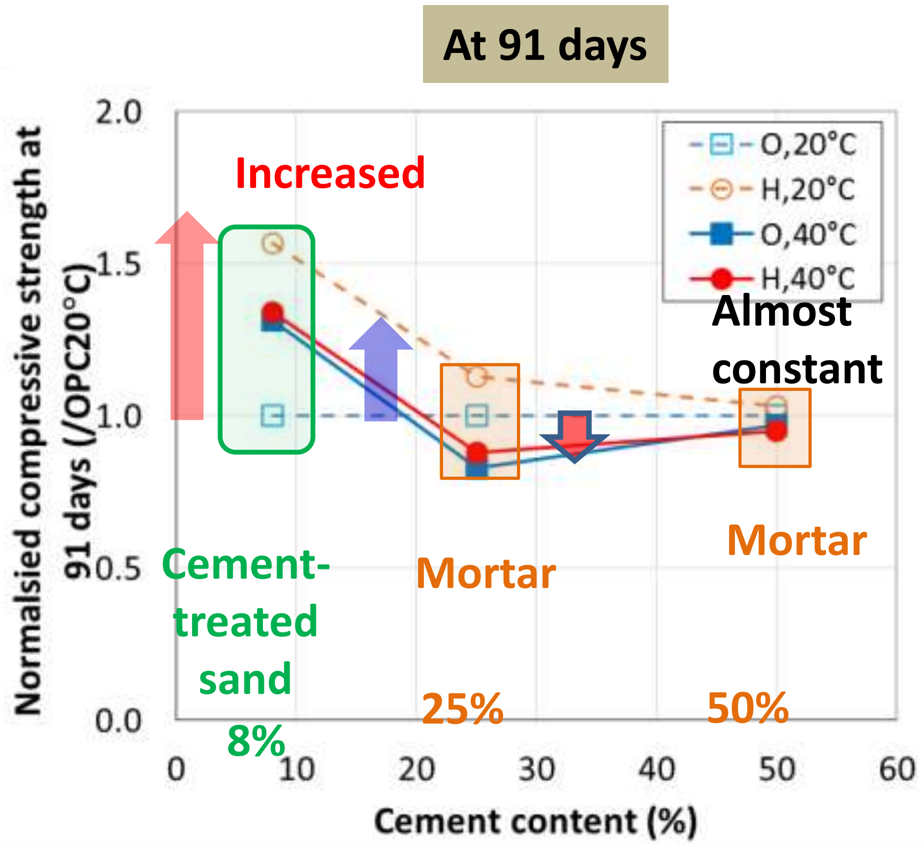
➢ Thermal analysis test

The amounts of chemically bound water and $Ca(OH)_2$ (CH) were determined by thermal analysis (TG-DTA) to evaluate the degree of hydration and pozzolanic reaction.

3.1 Compressive strength

Effect of cement content

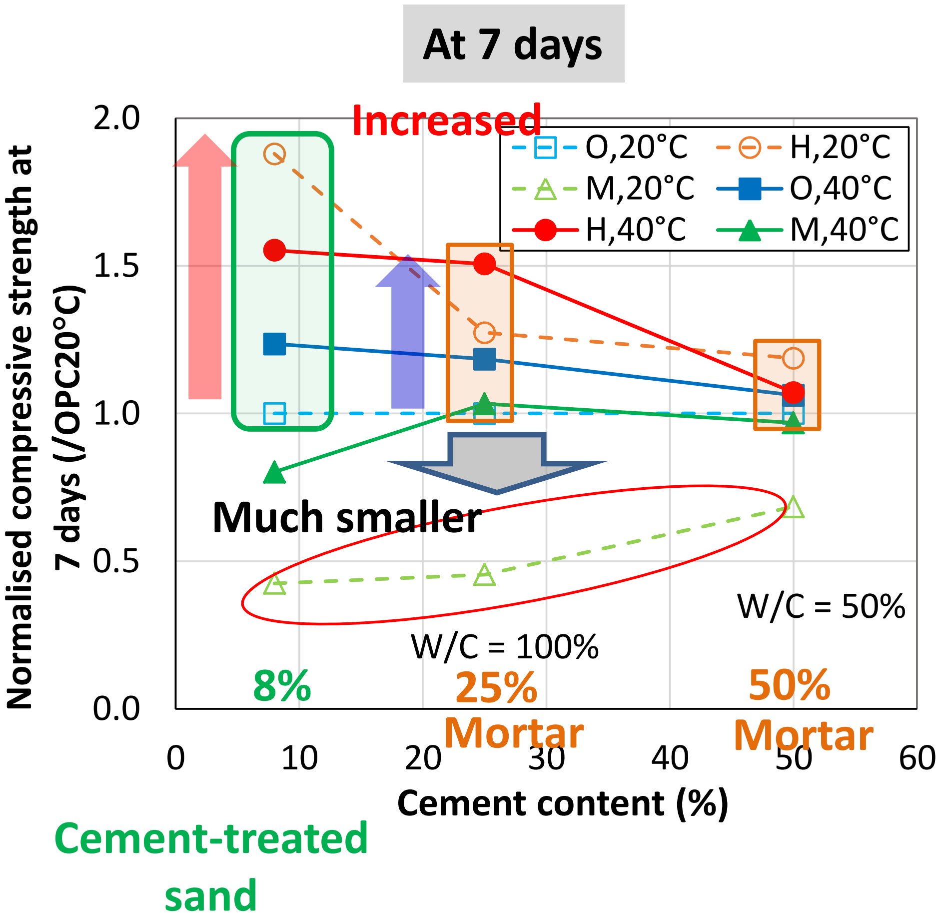


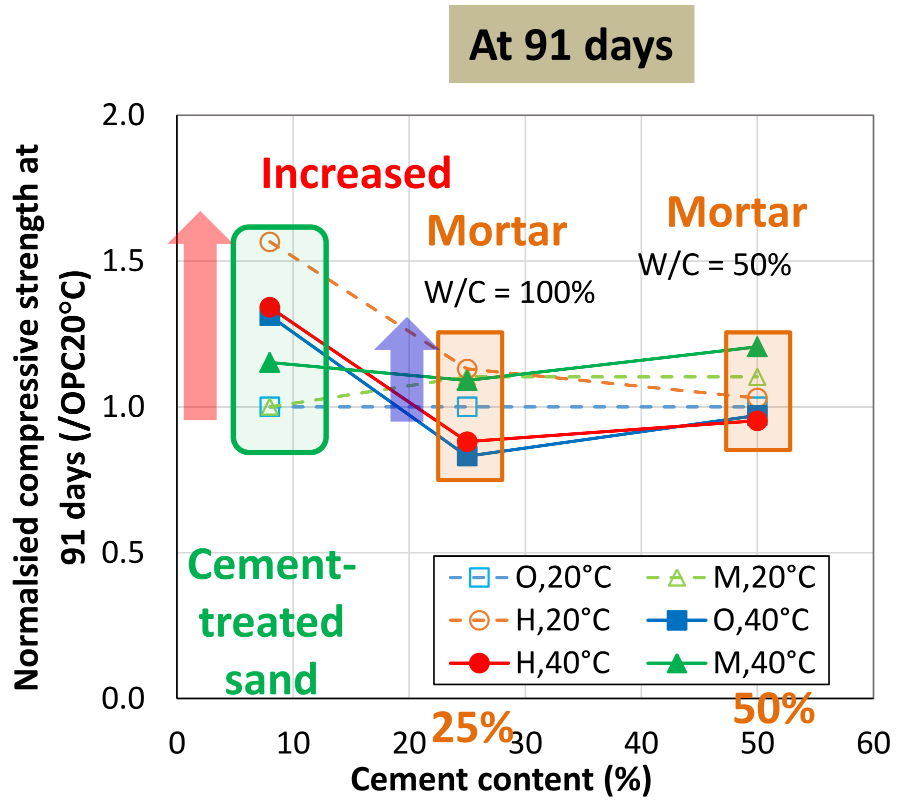


3. Results and discussion

3.1 Compressive strength

Effect of cement content

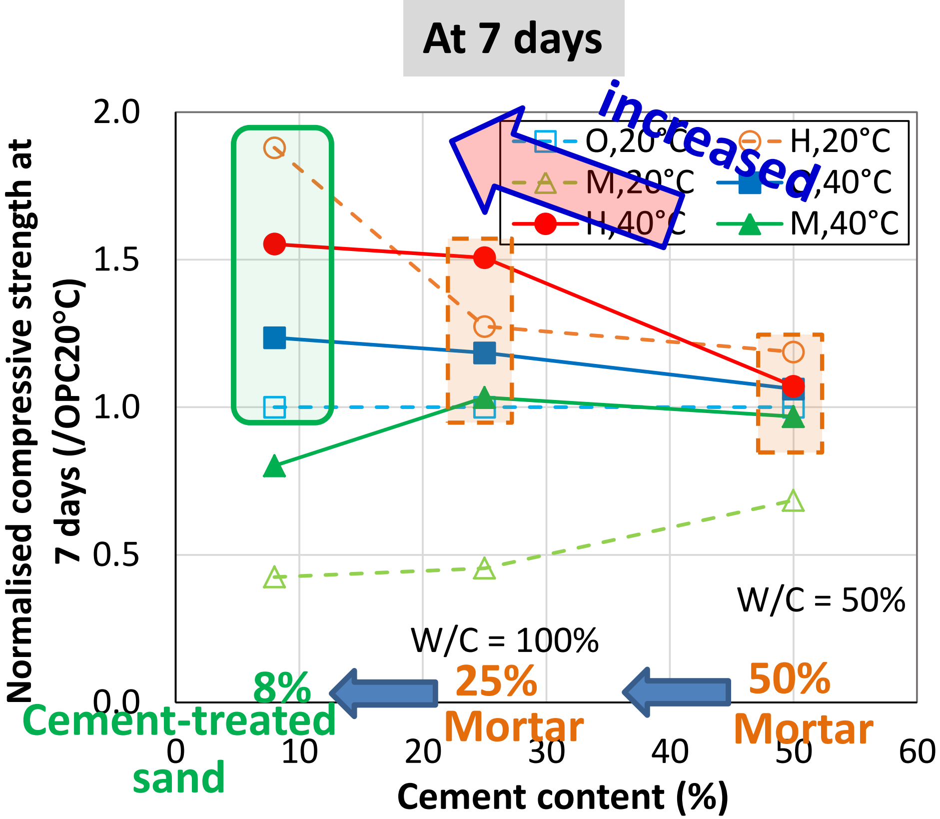


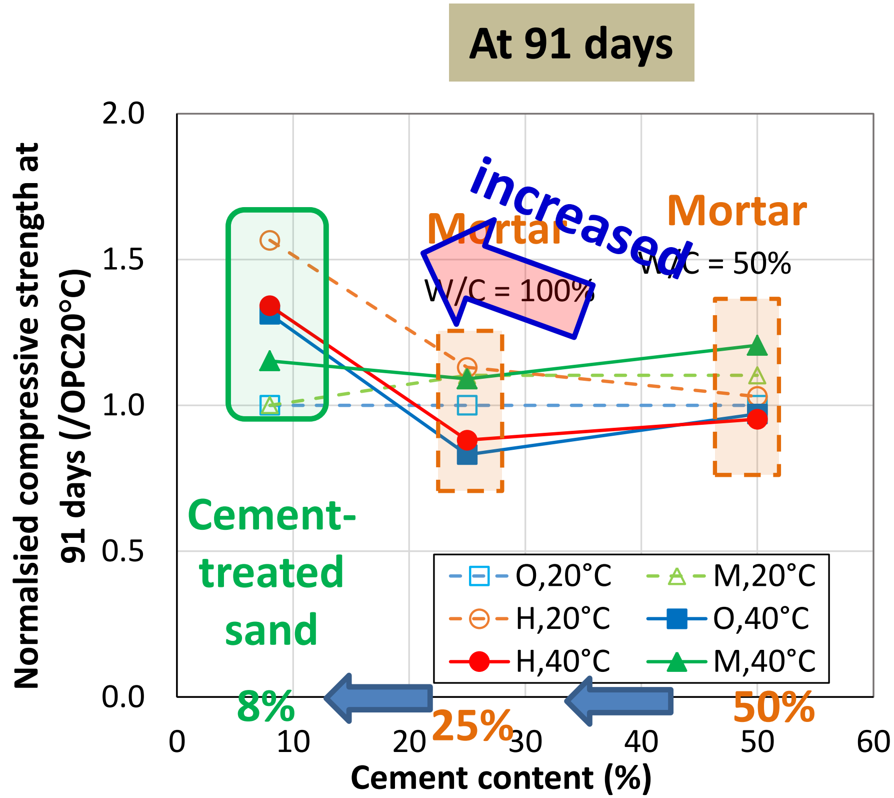


3. Results and discussion

3.1 Compressive strength

Effect of cement content



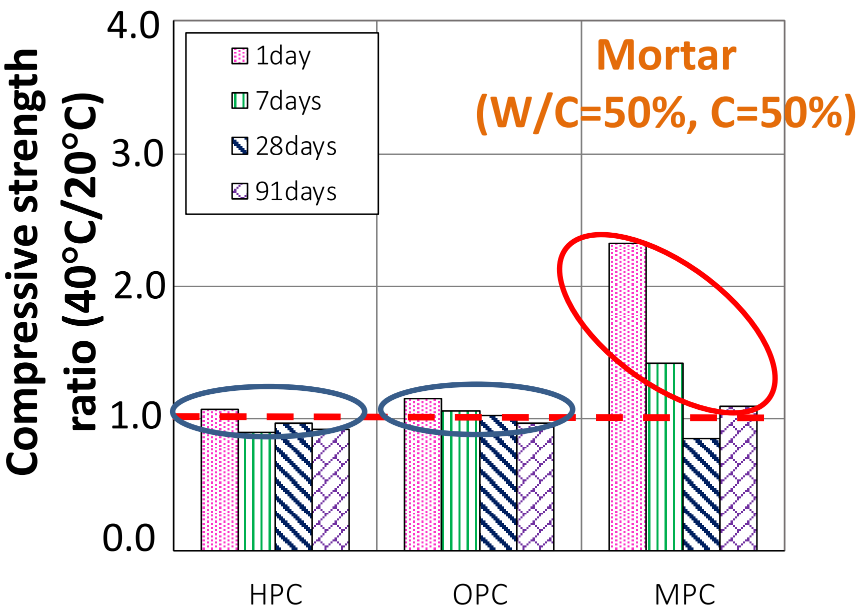


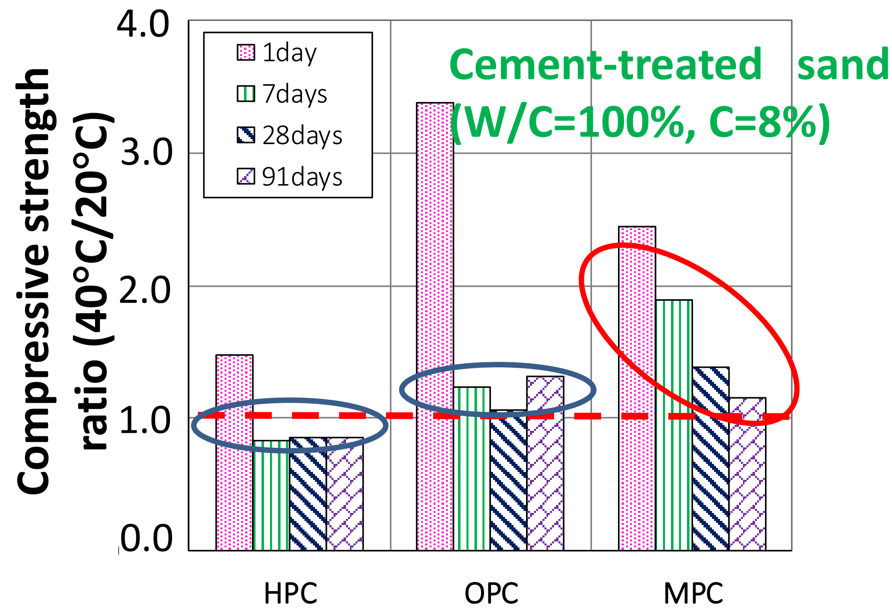
- When **cement content decreased** and **sand content increased**, the effects of **cement content** and **curing temperature** on strength development **increased** both short and long term in HPC and OPC at 40°C

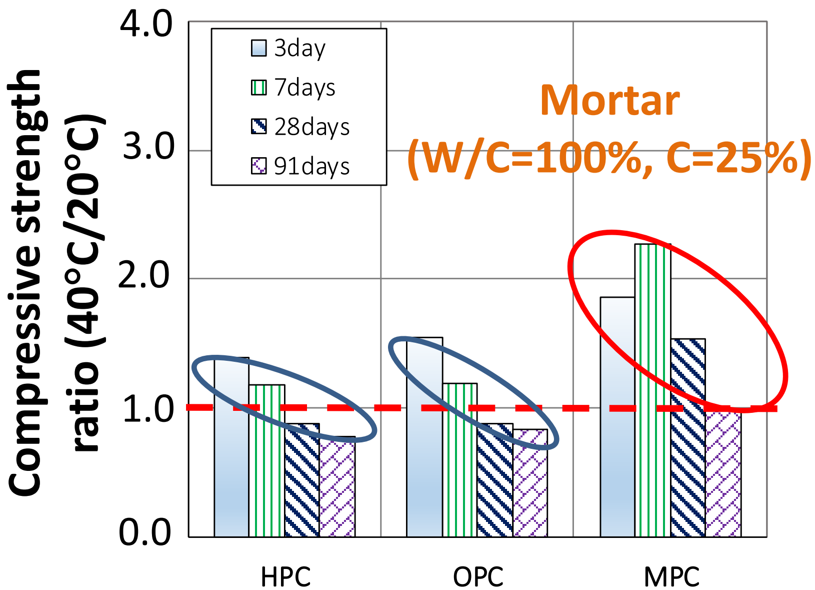
3. Results and discussion

3.1 Compressive strength

Comparison of cement type







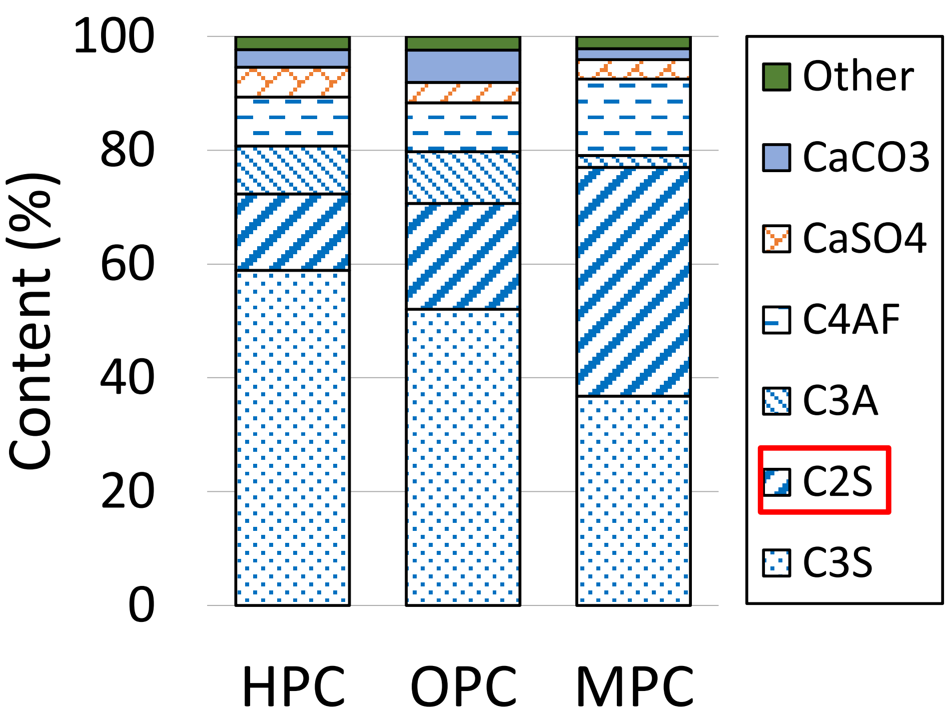
For both mortar and cement-treated sand

→ **the strengh ratio increased in order of MPC > OPC >HPC**

3. Results and discussion

3.1 Compressive strength

Comparison of cement type



C_3S : mainly contribute to early strength development

C_2S : mainly contribute to long-term strength development

Effect of temperature on strength
MPC >> OPC > HPC

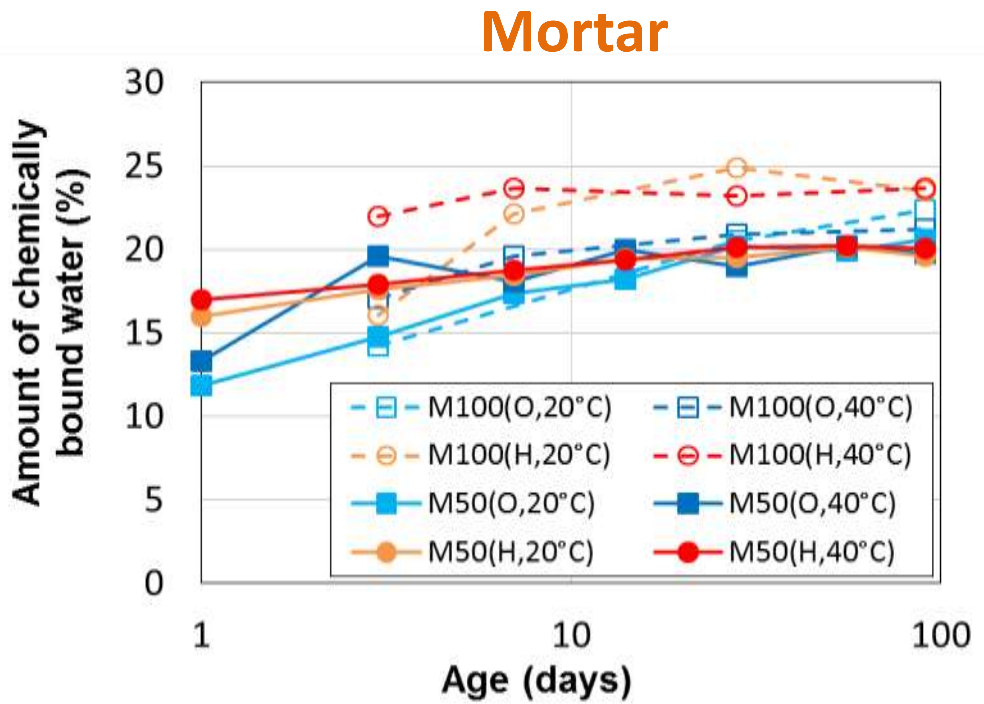
Suggest that

When $C_2S > C_3S$
Effect of temperature on cement mineral reactions:
MPC >> OPC > HPC or C_2S can reduce negative effect of high curing temperatures

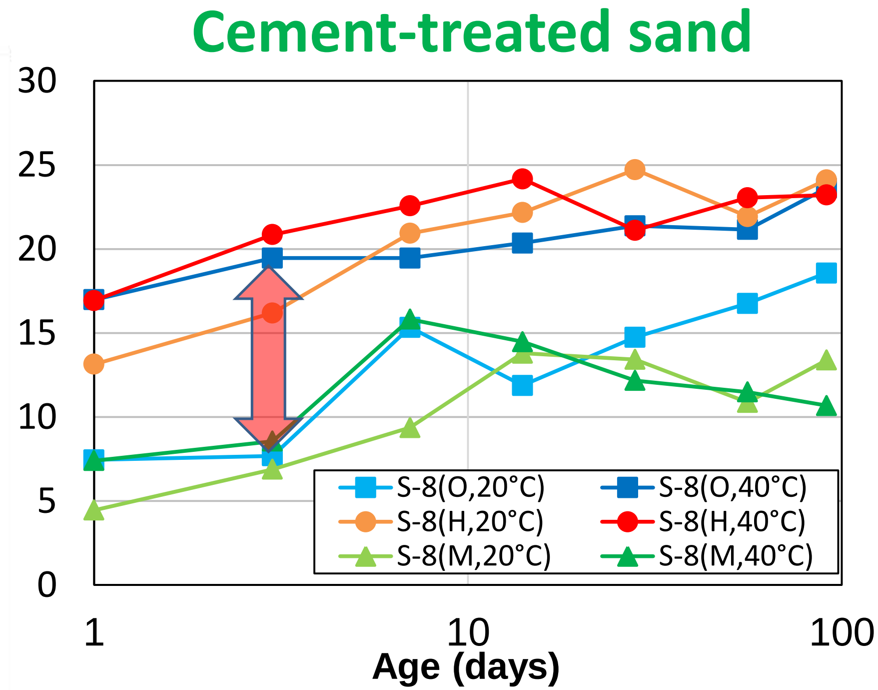
3. Results and discussion

3.2 Amount of chemically bound water

Strength development mechanism of cement-treated soil



Amount of chemically bound water over time of mortars.



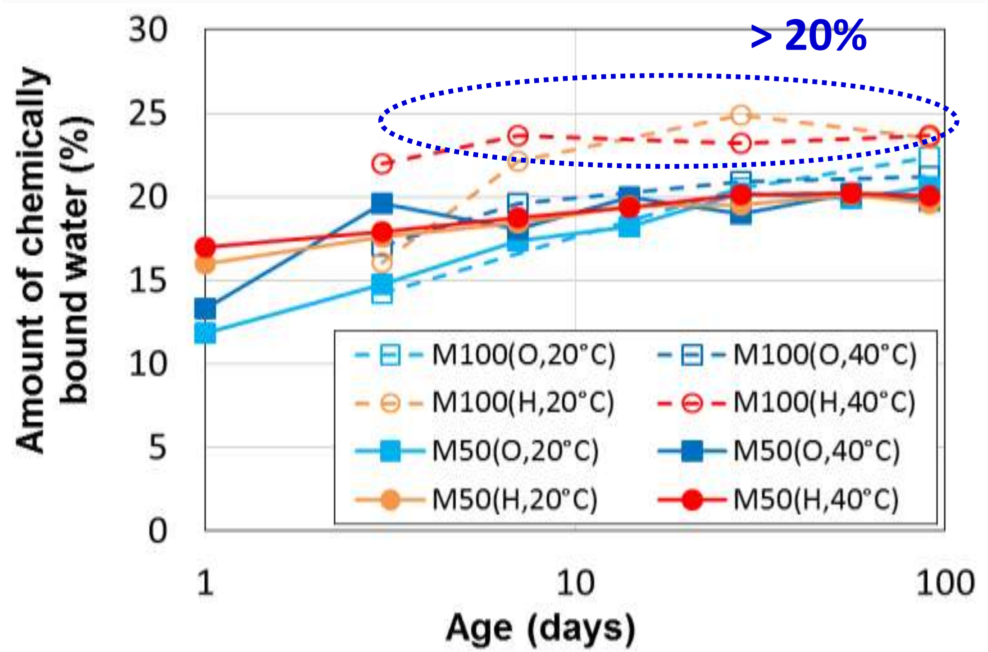
Amount of chemically bound water over time of cement-treated sand.

3. Results and discussion

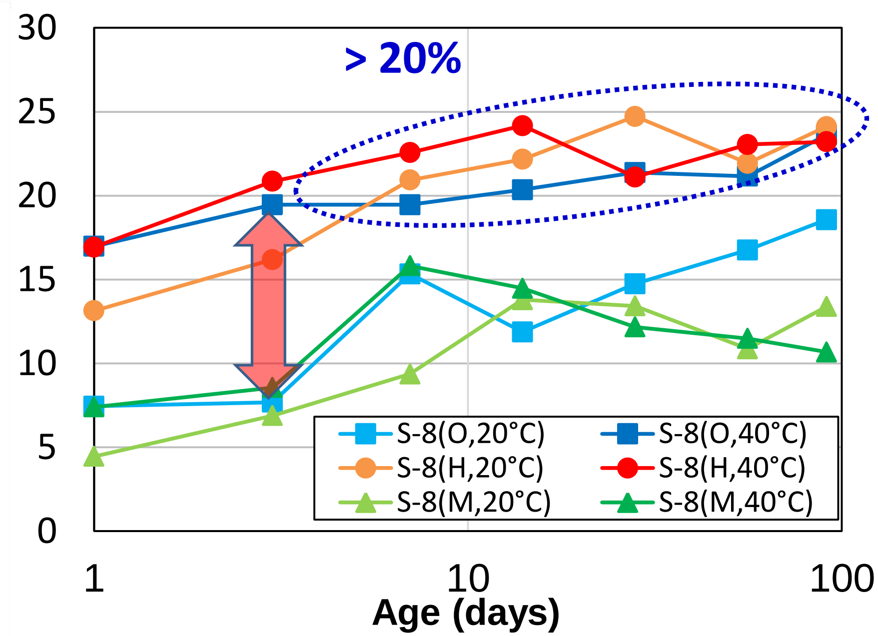
3.2 Amount of chemically bound water

Strength development mechanism of cement-treated soil

Mortar



Cement-treated sand



The **high water cement ratio** caused **the increase in amount of chemically bound water** from the early age due to cement type (HPC) and curing temperature (40°C)

3. Results and discussion

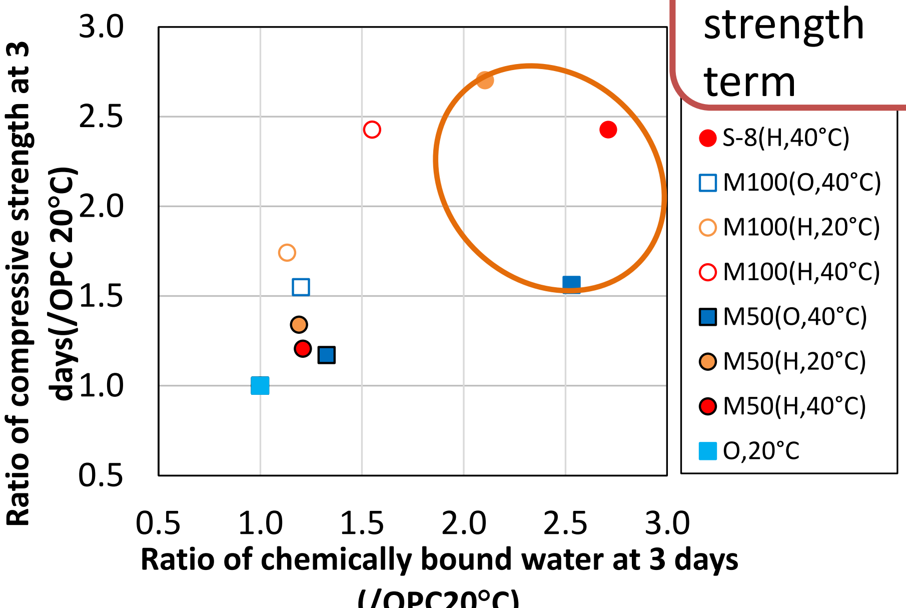
3.3. Relationship between amount of chemically bound water and strength

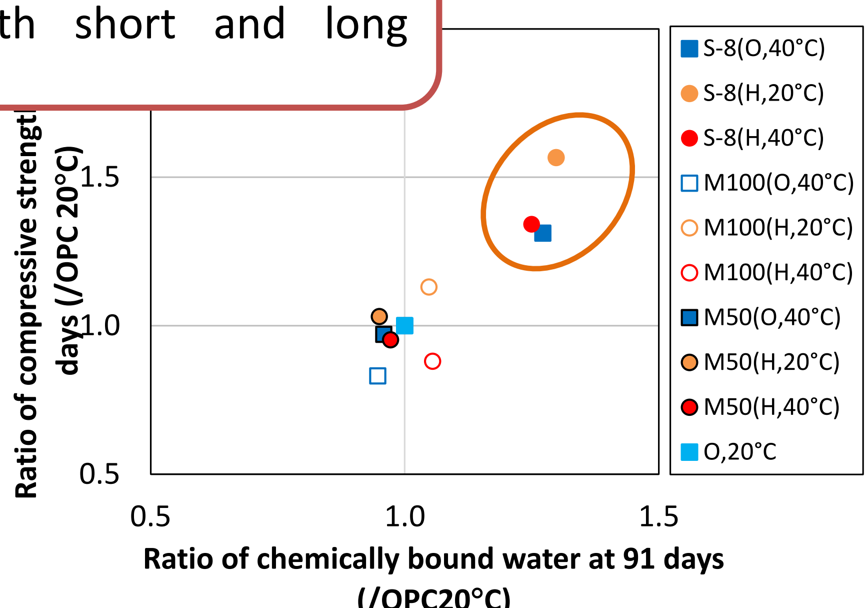
Strength development mechanism of cement-treated soil

3 days

The increase of chemically bound water led to the increase in strength both short and long term

91 days





The strength increase by curing temperature in cement-treated soil was influenced greatly by cement type, and the strength increase both short and long term was caused by the increase in amount of chemically bound water

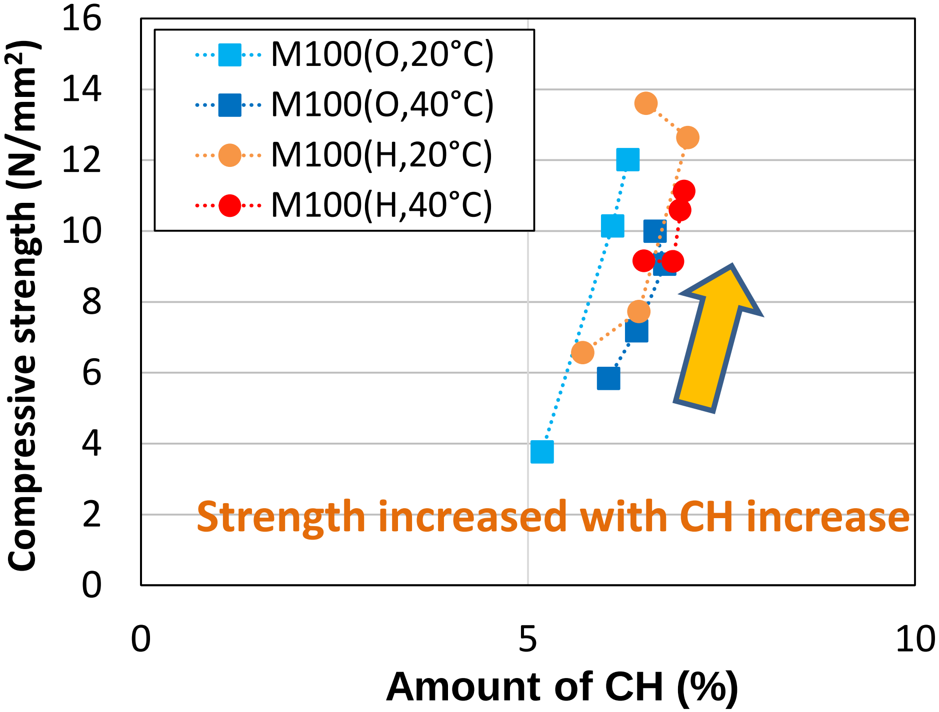
This phenomenon may be caused by a high water cement ratio and a large amount of sand

3. Results and discussion

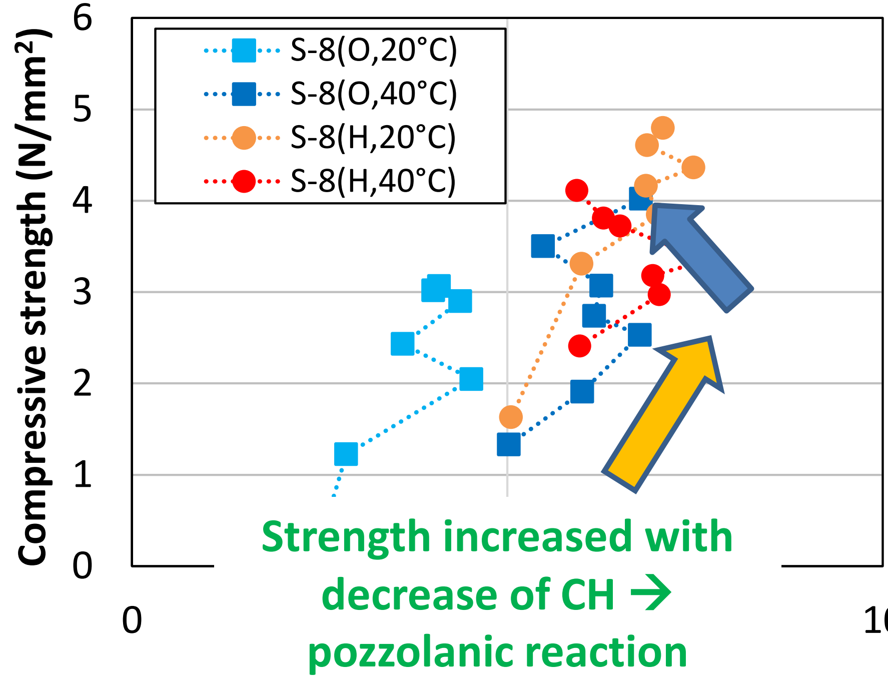
3.3. Relationship between amount of chemically bound water and strength

Strength development mechanism of cement-treated soil (pozzolanic reaction)

Mortar W/C =100%



Cement-treated sand



For cement treated sand used OPC and HPC at 40°C, curing temperature increased amount of chemically boud water and accelerated pozzolanic reaction → strength increase

➡ The pozzolanic reaction occurred in the cement-treated sand under high curing temperature caused by a large amount of sand

4. Conclusions

- The results showed that the compressive strength of cement-treated sand **increased in order of MPC, OPC, and HPC** under high curing temperatures.

- The compressive strength of cement-treated sand using HPC was much higher than that using OPC and MPC under 20°C both short and long-term, due to the higher amount of chemically bound water.

- Finally, the pozzolanic reaction was promoted in cases of cement-treated sand using HPC and OPC under high temperature. **This may be related to the high percentage of sand in the mixtures.**

References

1. https://www.martinmarietta.com/products/cement-treated-materials/
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5. D. Wang, R. Zentar, N.E. Abriak, (2016). Temperature-Accelerated Strength Development in Stabilized Marine Soils as Road Construction Materials, Journal of Materials in Civil Engineering, 04016281.

Thank you for your kind attention!