# Investigation for durability of mortar using Dry Sludge Powder

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## ABSTRACT

In recent years, reducing environmental impact is required in all industries. Therefore, the dry sludge powder has attracted a great deal of attention in the construction industry. Dry sludge powder is a method to reuse returned concrete. It is hoped that this can be reuse as alternative cement. In the previous studies, it is reported that surface area and density are different in the dry sludge powder according to the processing time at the production. Also, it is reported that strength develops by the hydration. However, few studies have focused on durability.
In this study, authors inspected the durability of mortar using the dry sludge powder which different processing time. Furthermore, authors inspected material permeability to monitor an influence on the durability. Thus, authors performed accelerated carbonation test and salt water immersion test as durability, a water permeability test and mercury intrusion porosimetory. As a result, the carbonation depth of mortar using the dry sludge powder became larger than mortar using Ordinary Portland Cement. On the other hand, the salt penetration depth showed a value smaller than mortar using the Ordinary Portland Cement. Mortar using dry sludge powder had much fine porosity, there was little water penetration. It is thought that water permeability becomes low because there are much fine porosity. The possibility that constituted a complicated porosity network.

## 1. INTRODUCTION

Recently, in the construction industry, the processing of returned concrete is a problem. Figure 1 shows the production process of dry sludge fine powder (hereinafter referred to as DSP). The returned concrete is cleaned and separated into recovered aggregate and sludge water. Recovered aggregate, supernatant water and sludge water satisfying the criteria of sludge solid fraction of 3% or less are accepted for reuse in JIS 5308. This process not only costs a lot of money but also places a burden on the environment. Therefore, a method of using DSP obtained by drying the sludge cake as cement has been studied. It shows the production process of dry sludge fine powder. As shown in the Figure 1, the time from wetting of ready mixed concrete to drying of sludge cake is called processing time. The return con and the remaining con are cleaned immediately at the time of being returned to the ready mixed concrete factory and the drying crushing process from the sludge cake to the DSP is carried out in the same time. For this reason, the difference in processing time refers to the difference in time during which it is stirred as sludge water. In the past research, it is reported that DSP has different density and specific surface area depending on the processing time. This progress of hydration is considered to be due to different by the time the stirred. In addition, it has been reported that the specific surface area of this DSP has correlation with compressive strength. At present it is not yet studied about characteristics and durability of DSP. Therefore, in this study, characteristics of DSP were examined by analysing chemical composition of DSP. Furthermore, we aimed to clear the durability of mortar using only DSP with different processing time. In addition, we investigated mass transfer and pore size distribution affecting salinity penetration resistance.

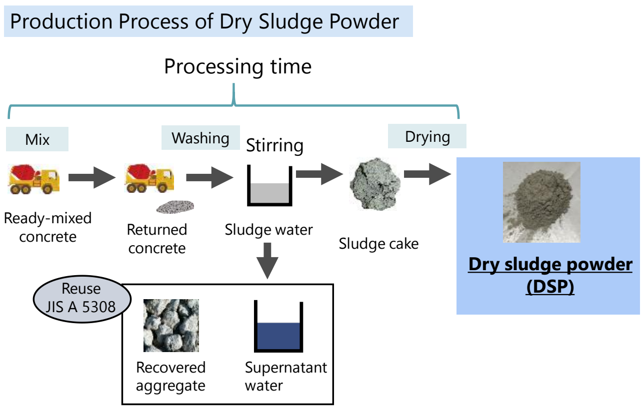



**Figure 1. Process of Washing Method and Production Process of Dry Sludge Powder**

## 2. CHARASTARISTICS OF DSP

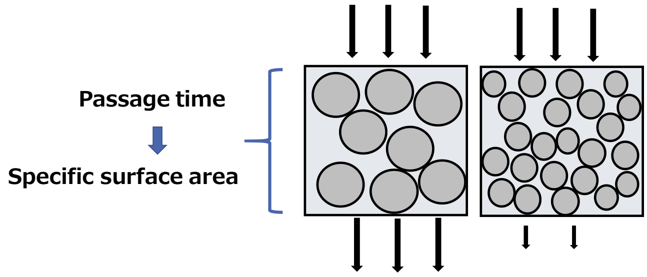
Materials used in this chapter of this study, 3 types of DSP as shown in Table 1. The specific surface area of the DSP is larger than that of general OPC. However, DSP does not perform processing such as fine grinding. Consider why a large specific surface area is measured.

**Table 1. Materials used in this study**

| | DSP- Ⅰ | DSP- Ⅱ | DSP- Ⅲ |
|---|---|---|---|
| Processing Time (h) | 2.5 | 4 | 12 |
| Specific Surface Area ($cm^2/g$) | 6030 | 6070 | 10590 |
| Density ($g/cm^2$) | 2.91 | 2.74 | 2.46 |

### 2.1 Outline of Experiment and Material

The measurement of the specific surface area uses a blaine permeation apparatus. A schematic diagram of the measurement principle of the blaine penetration device is shown in the Figure 2. In the Blaine permeator, the powder is filled in a container having a constant volume and the specific surface area is determined by allowing air to permeate. When the transit time is short, there is a relationship that the particles are large, and if the transit time is long, there is a relationship that the particles are small, so that it is possible to simply measure the powder particle. The measurement of the blaine permeator is based on the assumption that the particle size of the powder is a normal distribution. Therefore, for the purpose of clearing the particle size distribution of DSP. Measurement was carried out using a laser diffraction type particle size distribution measuring apparatus. When a particle is irradiated with a laser, a diffraction phenomenon occurs. Utilizing this diffraction phenomenon, the difference in diffraction angle due to particles is measured.




| Passage time | Short | Long |
|---|---|---|
| Specific surface area | Small | Big |

**Figure 2. Measurement Principle of the Brane Penetration Device**

## 2.2 Result

Figure 3 shows the particle size distribution of DSP–Ⅰ, DSP-Ⅱ, DSP-Ⅲ. When the specific surface area became larger, the peak of the particle of 100 μm became larger. From the above results, it is conceivable that DSP is not a uniform particle diameter. As shown in Figure 4, it is conceivable that particles having a small particle size fill the space in a sparse space generated by particles having a large particle size. In this case, it becomes difficult for air to pass through, and the calculated specific surface area becomes large. From this, it is conceivable that the specific surface area of the DSP cannot be measured by the brane air permeation device.

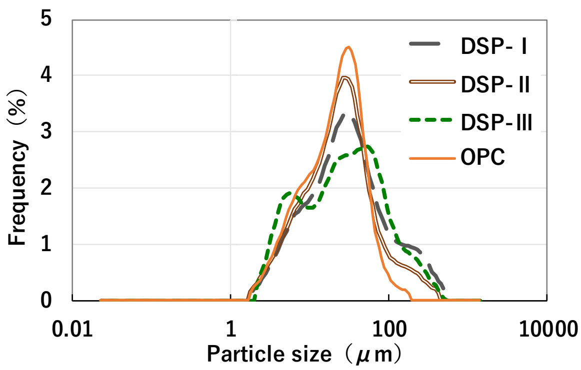



**Figure 3. Particle Size Distribution**

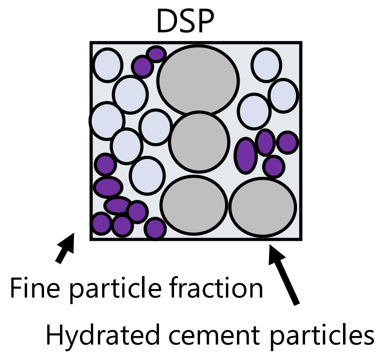



**Figure 4. Container Filled with DSP**

## 3. STRENGTH AND DURABILITY OF MORTAR USING DSP

## 3.1 Outline of Specimens and Materials

Materials used in this chapter of this study, 4 types of DSP on processing times (respectively DSP-A, DSP-B, DSP-C, DSP-D) as shown in Table 1. For comparison, Ordinary Portland cement (OPC) was used. Mix proportion was 1: 3 mortar with reference to the cement strength test of JIS R 5201, demolished on the date of injection and sealed curing was carried out for 28 days in a constant temperature and humidity environment (temperature 20 degree Celsius, humidity RH60%).

**Table 2. Materials used in this study**

| | DSP-A | DSP-B | DSP-C | DSP-D |
|---|---|---|---|---|
| Processing Time (h) | 5 | 9 | 12 | 24 |
| Specific Surface Area ($cm^2/g$) | 7410 | 8920 | 10590 | 11400 |
| Density ($g/cm^2$) | 2.81 | 2.58 | 2.46 | 2.45 |

### 3.2 Outline of Experiment

#### 3.2.1 Strength Test

Bending and compressive strength test of mortar after curing period was conducted according to JIS R 5201.

#### 3.2.2 Pore Measurement Test

A sample of about 40 × 40 × 30 mm was taken from the mortar specimen. Hydration stopped by accetone. After put in a drying oven at temperature 40 degree Celsius, measuring the mass in an absolutely dry state, saturated in a vacuum state, and the saturated water mass and the mass in water were measured. The porosity was calculated by the Archimedes method using these values.

#### 3.2.3 Accelerated Carbonation test

After 28 days of sealing curing, open the one side except casting side, specimen was placed in accelerated carbonation test equipment (Carbon dioxide concentration 5%, temperature 20 degree Celsius, humidity RH60%). Carbonation depth was measured at by 7, 14, 28, 42days brown part using phenolphthalein solutions in split area. Then, it was calculated the coefficient of carbonation ratio using these results.

#### 3.2.4 Salt Water Immersion Test

After 28 days of sealing curing, the specimen coated with epoxy resin except casting side, specimen was put into the NaCl 10% solution. The saltwater dipping period were 7, 14,28,42 days. After each immersion periods, splitting was performed and an aqueous silver nitrate solution was sprayed on the split face. The depth from the surface to the point where it turned white was measured, and the number of points to be measured was set to 4 points. These measured values were averaged and taken as the salt penetration depth.

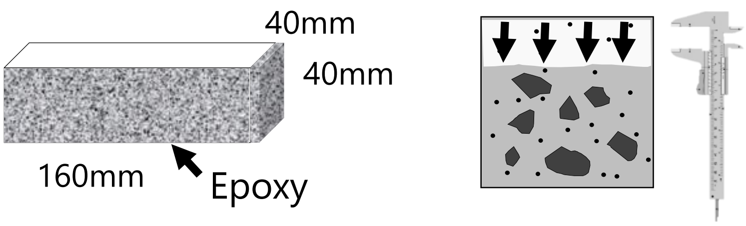



**Figure 5. Salt Water Immersion Test Method**

#### 3.2.5 Water Permeability

It specimens using cylindrical specimens φ100 × 50mm, it was immersed in acetone to be in a vacuum state and the hydration reaction was stopped. It was absolutely dry state in a drying oven at temperature 40 degree Celsius. Put a certain amount of water with stand pipe graduated to calculate the permeated water actually specimen from a height of reduced water under pressure. Incidentally, was measured time measured up to 30 minutes each and then permeability started after 3 hours. The loading pressure was carried out in two patterns of 0. 6 MPa and 0.05 MPa, both outflow side pressure was 0.1 MPa.

### 3.2.6 Mercury Intrusion Test

Since the pore structure greatly affects the substance permeability, mercury penetration test was carried out using a mercury intrusion porosimeter for the purpose of grasping the pore diameter distribution. Using a mortar sample cut to about 5 × 5 × 5mm, the pore size distribution was measured with a mercury intrusion porosimeter.

## 3.3 Results and Discussion

### 3.3.1 Results of Strength and Porosity

A strength test was conducted to confirm the strength development of DSP. Figure 6 shows the bending strengths at 7 and 28 days of curing and Figure 7 shows the compressive strength at 7 and 28 days of curing. In general, DSP does not reach the strength of OPC. Similarly, to the previous studies, DSP with a long processing time has low strength development, and as the processing time becomes shorter, the strength development of DSP becomes higher. Figure 8 shows the results of the porosity test. Porosity of mortar using DSP became larger than mortar using OPC. Figure 9 shows the relationship between compressive strength and porosity after 28 days of sealing curing. DSP-C and DSP-D showed virtually equal porosity and compressive strength. Also, the higher the porosity, the lower the compressive strength.

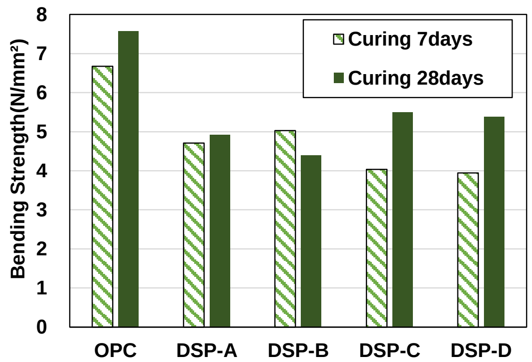



**Figure 6. Result of Bending Strength**

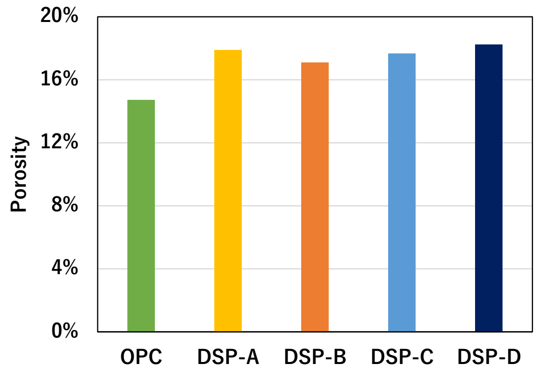



**Figure 8. Result of Compressive Strength**

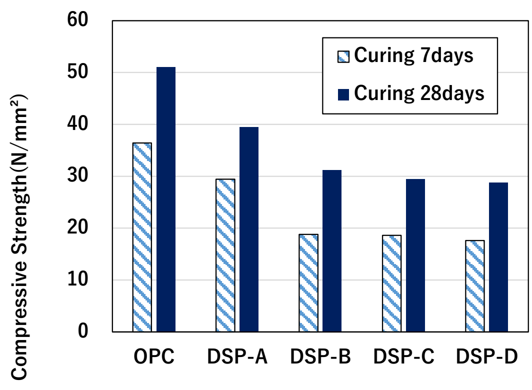



**Figure 7. Result of Porosity**

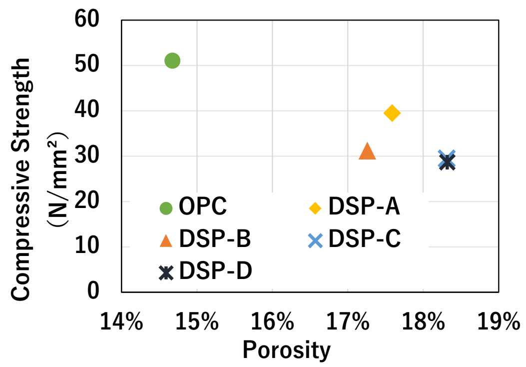



**Figure 9. Relationship between compressive strength and porosity**

### 3.3.2 Accelerated Carbonation Depth

Figure 10 shows accelerated carbonation test. DSP had a large carbonation depth, despite the fact that carbonation hardly progressed in OPC. Furthermore, the neutralization depths of DSP-A and DSP-B and DSP-C and DSP-D show almost equal values at any age. Figure 11 shows the relationship between the porosity and the carbonation depth at 28 days. From this, as the porosity increases, there is a correlation that the carbonation depth increases. Since the porosity increased and the substance permeability of the gas increased, the carbonation resistance decreased.

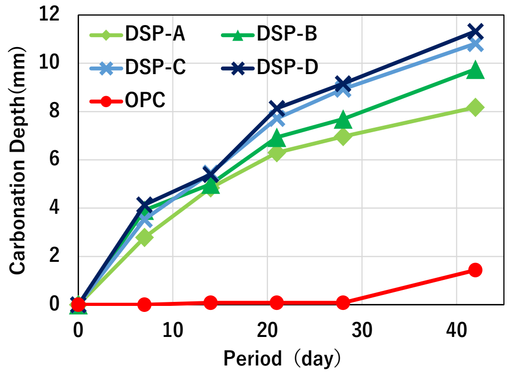



**Figure 10. Carbonation Depth**

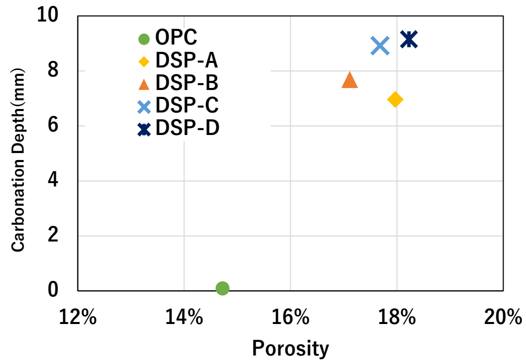



**Figure 11. Relationship between Carbonation depth and porosity**

### 3.3.3 Chloride ion Penetration

Figure 12 shows the results of the salt water immersion test. Salt penetration depth of DSP-A and DSP-B became smaller than OPC at any age. On the other hand, DSP-C and DSP-D showed the same value as OPC. Figure 13 shows the relationship between the porosity and the salt penetration depth at the salt water immersion period of 28 days. Compared with OPC, the DSP has a low salt penetration depth despite the high porosity in general. From this, there was no relationship between porosity and salt penetration depth.

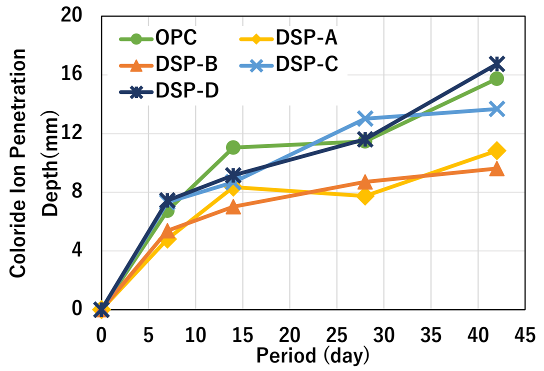



**Figure 12. Chloride ion Penetration**

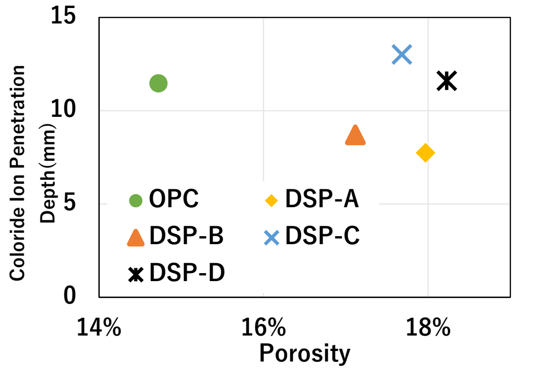



**Figure 13. Relationship between Chloride Ion Penetration and porosity**

Figure 14 shows the results of permeability tests conducted loading pressure in 0.05 MPa and Figure 14 shows the results of loading pressure in 0.6 MPa. When a pressure of 0.05 MPa was applied, the amount of permeated water of OPC and DSP was almost same amount. When applying a pressure of 0.6 MPa, the amount of permeated water was much lower than mortar using OPC for mortar using DSP. Furthermore, mortar using OPC significantly exceeded the amount of permeated water of 0.05 MPa when applying a pressure of 0.6 MPa, but the mortar using DSP did not change in the amount of permeated water of 0.6 MPa and the amount of permeated water of 0.05 MPa. 15 and 16 show the relationship between the porosity and the water permeability. The porosity was taken on the horizontal axis and the water permeability was taken on the vertical axis. Figure 15 shows the result of the applied pressure being 0.05 MPa, and Figure 15 shows the result of the applied pressure being 0.6 MPa. When the applied pressure was 0.05 MPa, there was no difference in the water permeability despite the difference in porosity. On the other hand, when the applied pressure was 0.6 MPa, the OPC with low porosity was the most permeable and the DSP with high porosity had low water permeability. From this result, DSP has lower moisture permeability than OPC. In addition, the mortar using DSP did not change the amount of permeated water due to pressure change, it can be inferred that mortar using DSP has constructed a pore structure different from mortar using OPC.

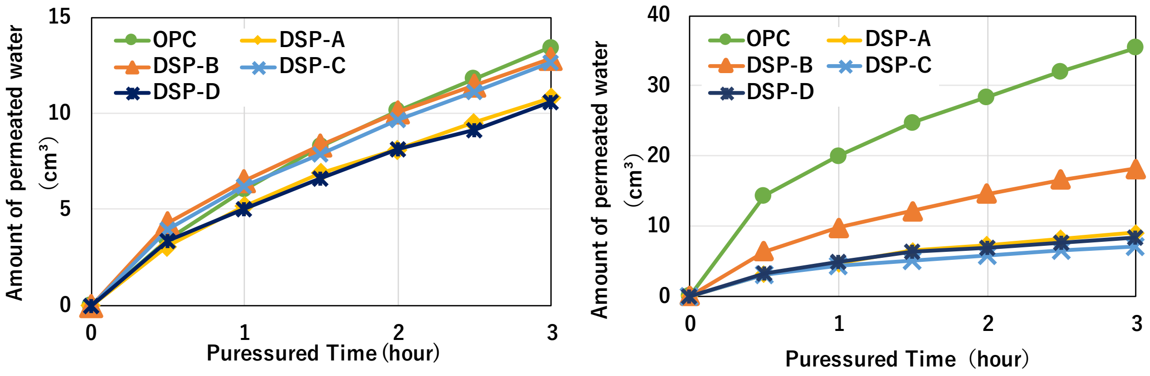



**Figure 14 Amount of Permeated Water**

**(Right : Pressure is 0.05 MPa, Left : Pressure is 0.6 MPa)**

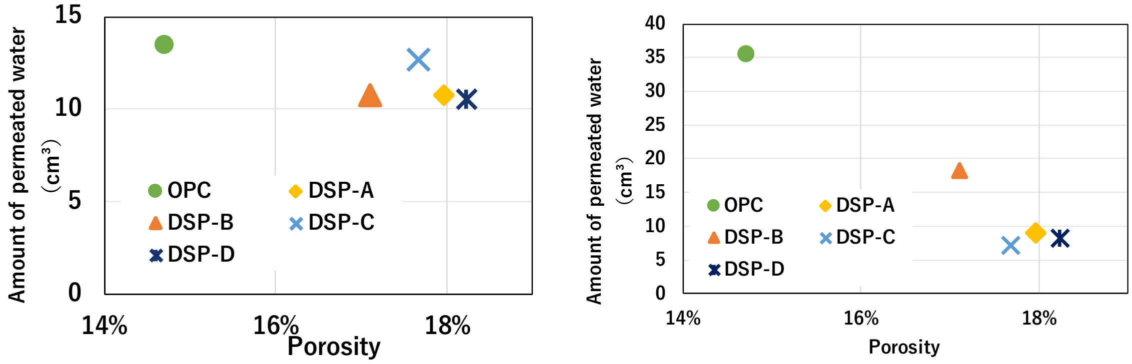


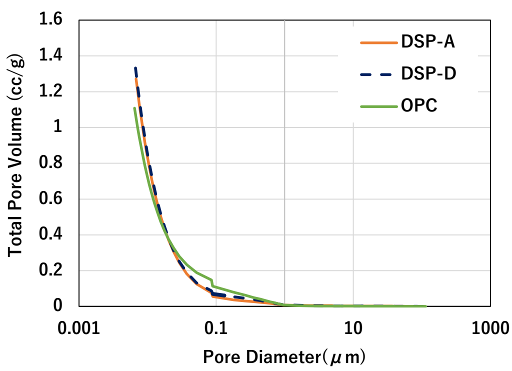

**Figure 15 Relationship Between Amount of Permeated Water**

**(Right : Pressure is0.05 MPa, Left : Pressure is 0.6 MPa)**

### 3.3.4 Mercury Intrusion Test

Figure 16 and Figure 17 shows that similar pore size distribution can be confirmed in DSP-A and DSP-D. It can be seen that mortar using DSP has many smaller diameter pore compared with mortar using OPC. In particular, the difference in the fine pore size of 0.1μm or less is remarkable. From this result, complicated pore network is constructed because mortar using DSP has many micro pore. Furthermore, since a large number of minute pore were measured, it was suggested that a pore having an ink bottle effect was present.

It is thought that mortar using DSP has a structure that liquid hardly intrudes into mortar and therefore greatly reduces moisture permeability.



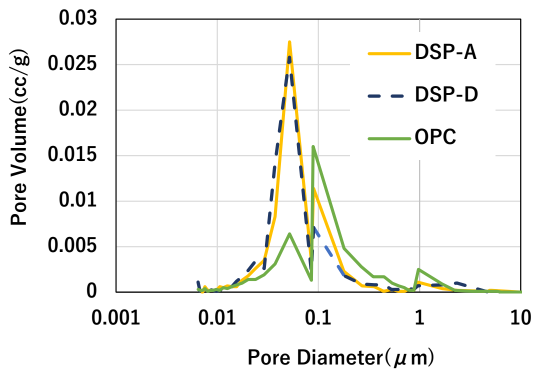




**Figure 16. Total Pore Volume**

**Figure 17. Pore Volume**

## 4. CONCLUSIONS

(1) In the mortar using DSP, the depth of chloride ion penetration was smaller than that of OPC, and there was no correlation with porosity.
(2) As a result of carrying out the permeability test, mortar using DSP was lower in moisture permeability than mortar using OPC.
(3) Since mortar using DSP has more minute pore than mortar using OPC, it can be predicted that the pore network in mortar becomes complicated. Also, a large number of minute pore were measured which has a structure in which liquid hardly intrudes into the mortar.
(4) It is considered that the mortar using DSP has a structure in which the liquid hardly intrudes into the mortar, so that the moisture permeability is greatly reduced and the depth of penetration of the salt has decreased.
(5) We will consider the cause of the complexity of the void structure focusing on the hydration reaction as a future work.

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