Investigation on permeability measurement method of investment casting shell molds and influencing factors on permeability.

Ryosuke Naito
Kazuyoshi Chikugo
IHI Corporation

August 24th, 2022

15th WCIC 2022
INVESTMENT CASTING
It's A Small World After All

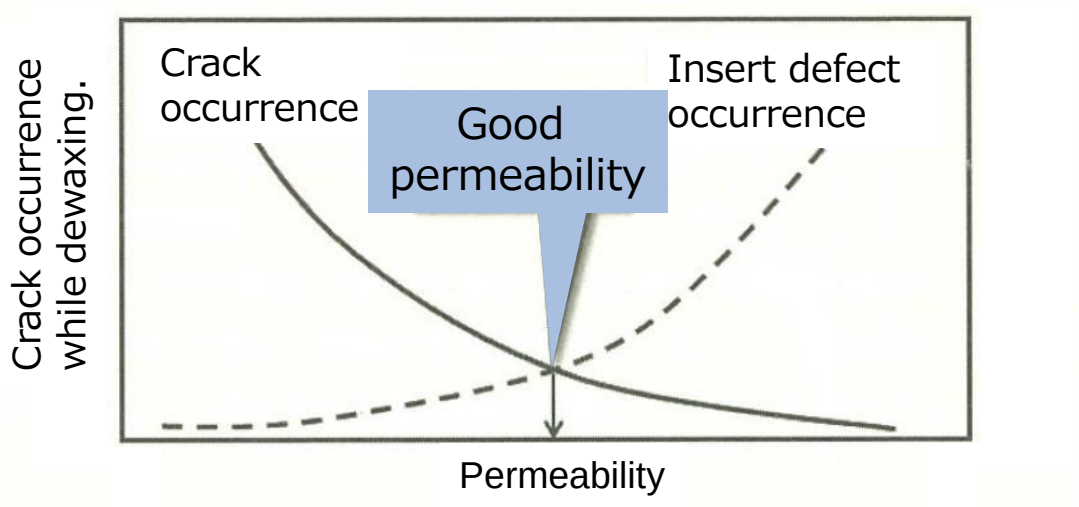
Agenda

- Background
- Purpose
- Permeability measurement method
- Sample preparing method
- Relationship between the condition of shell molds and permeability

1. Background

Shell mold management is important to improve stability of investment casting process and their production. But a shell mold consists of multiple kinds of ceramics and is nonuniform. So, the management of shell molds are very difficult.

On the other hand, shell permeability is evaluated through the primary layer to back up layers even if it is nonuniform.

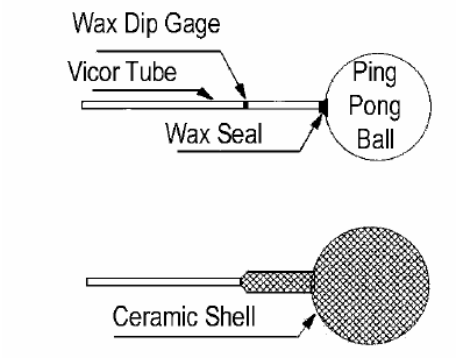
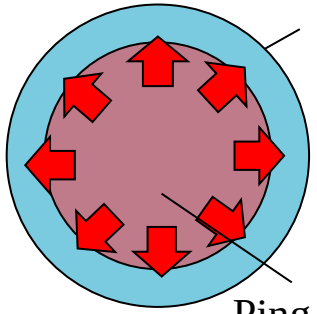
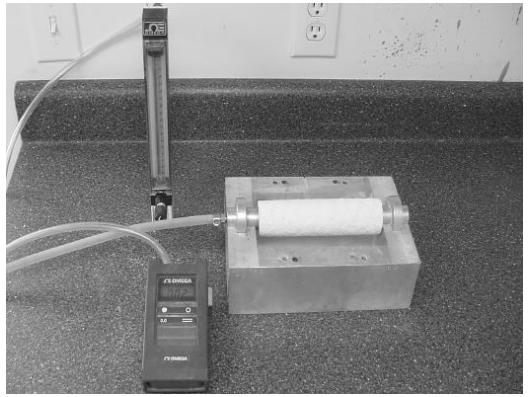
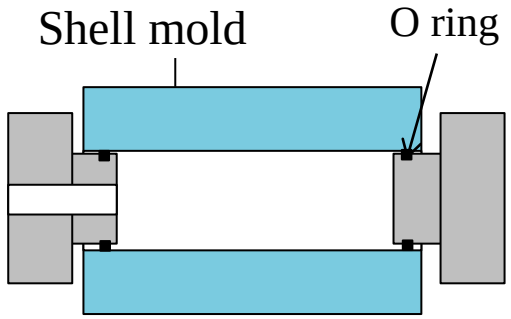
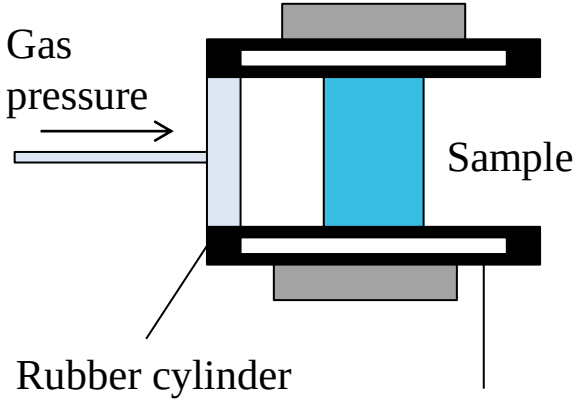


Relationship between permeability and casting defects

Investment castings：Japan Foundry Association (2015)

With good permeability management, the stability of investment castings process can be improved.

1. Background

	Ping Pong ball method	Tube method	Japanese industrial standard method (JISR2115)
	 	 	
Merit	Heat stress measurement	-	<u>Easy to avoid air leaks</u>
Demerit	Shell mold cracking	Air leak from O ring	<u>Not for investment casting molds</u>

2. Purpose

The Final Purpose

・Improve stability of casting production using permeability measurement.

Purpose of this study

① Establishment of sample preparation for JISR2115.

② Investigation of the relationship between shell mold’s condition and permeability value.

3. Measuring method

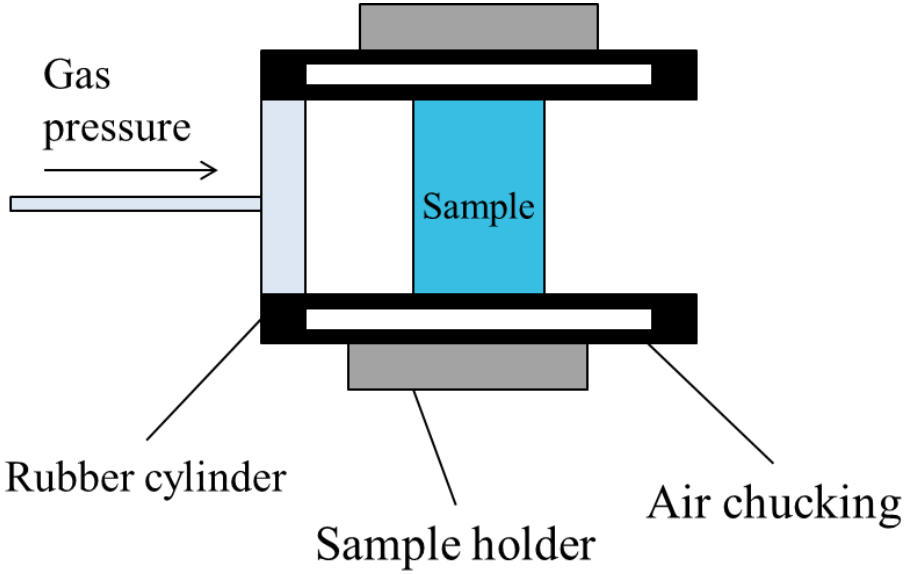
Holder：Rubber Cylinder

Sample：Round Column

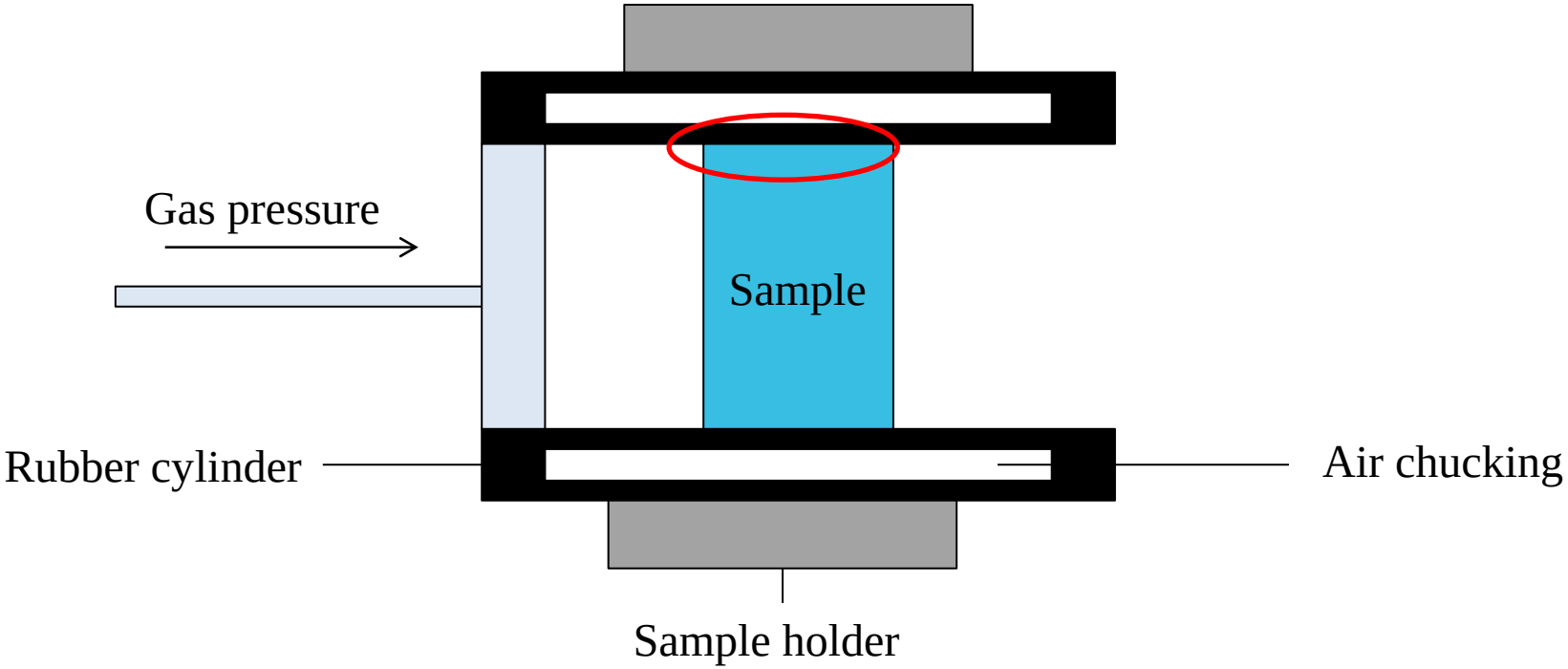
1. Set the round column shaped shell into the cylinder rubber.
2. Apply gas pressure from one side and measure the flow rate of the gas.
3. Calculate permeability value

$$\mu = \frac{V}{t} \cdot \eta \cdot \frac{\delta}{A} \cdot \frac{1}{p_1 - p_2} \cdot \frac{2P}{p_1 + p_2}$$

μ : Permeability (m^2)
V : Gas Volume (m^3)
t : Measuring Time (s)
η : Gas viscosity (Pa・s)
A : Cross sectional area (m^2)
δ : Shell Thickness (m)
P : Atmosphere gas pressure(Pa)
p_1 : Instlusion pressure(Pa)
p_2 : Detatchment pressure(Pa)



4. Sample preparing method



① If there is a gap between the sample and cylinder rubber, the permeability value gets higher and is not the correct value.

⇒Investigation of the condition of the outside shell diameter is carried out

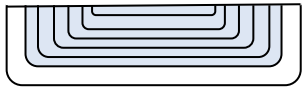
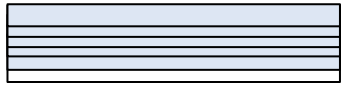
4. Sample preparing method

① Statement of outside diameter

A Shell is coated in a ring. After the coating, the ring is removed

B Board-shaped shell is coated and the shell is shaved down by a machining process.

This study, supersonic machining was chosen.

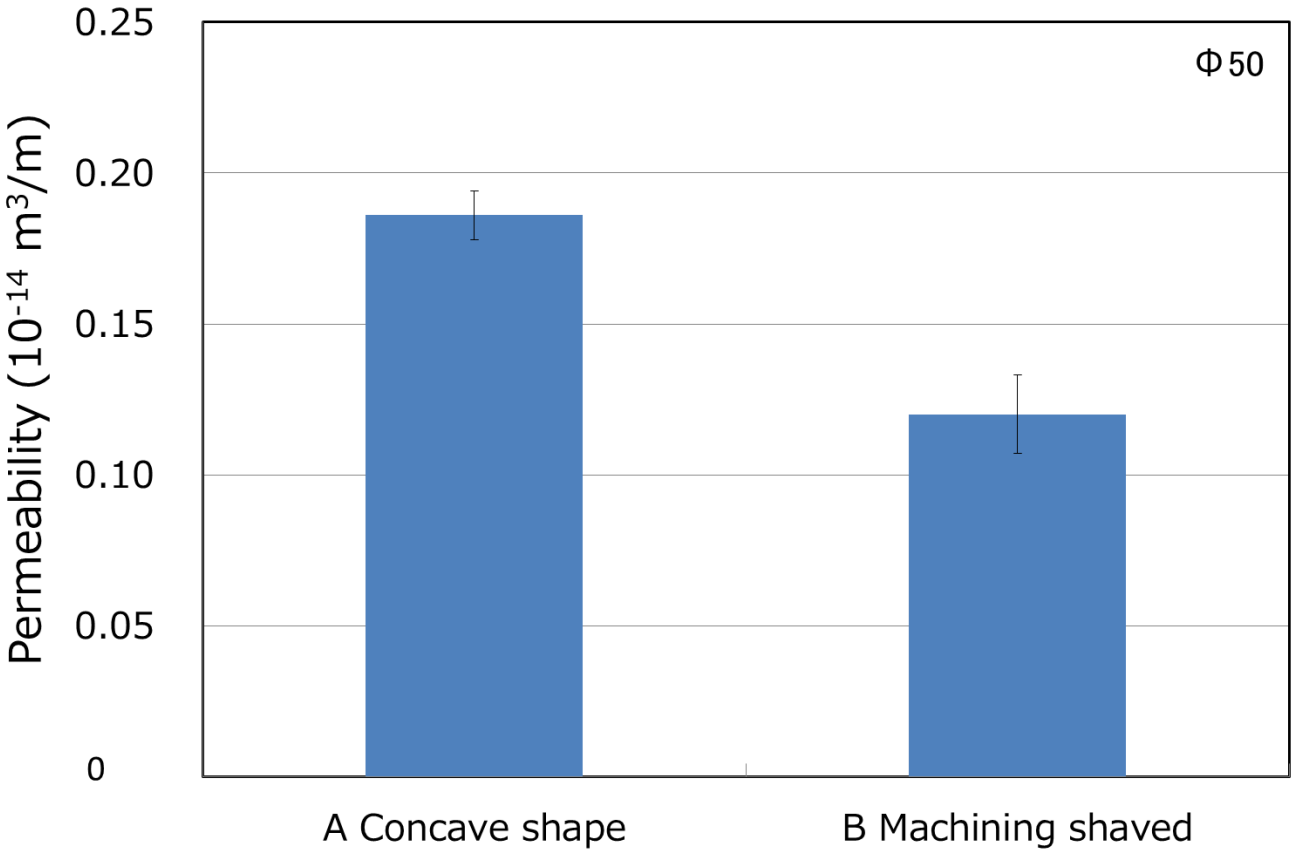
	A Concave  	B Supersonic Machining  
Outside diameter (sealability)	Primary coat (good sealability)	Machining cross section (depends on processing)
Coating direction	Differ from normal shell	Vertical to gas direction

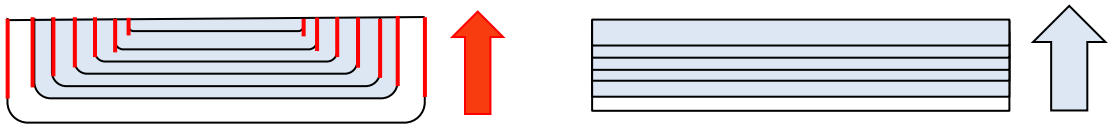
4. Sample preparing method

① Statement of outside diameter

Concave sample has stucco surface parallel to gas direction.
Stucco surface has many vacant pockets of air (not filled by slurry) and the gas permeation is easy

Supersonic Machining is more appropriate as the sampling method

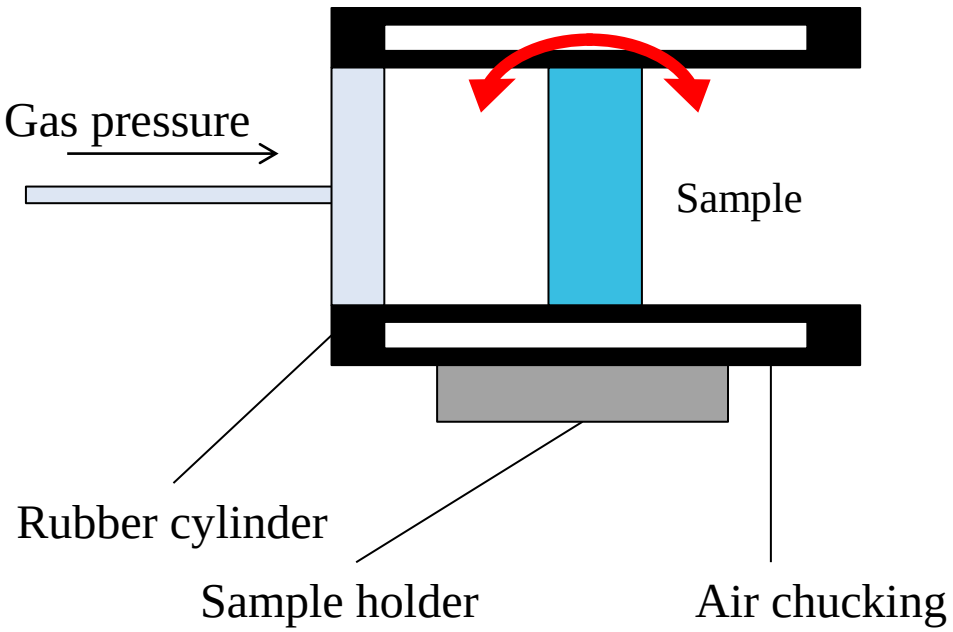


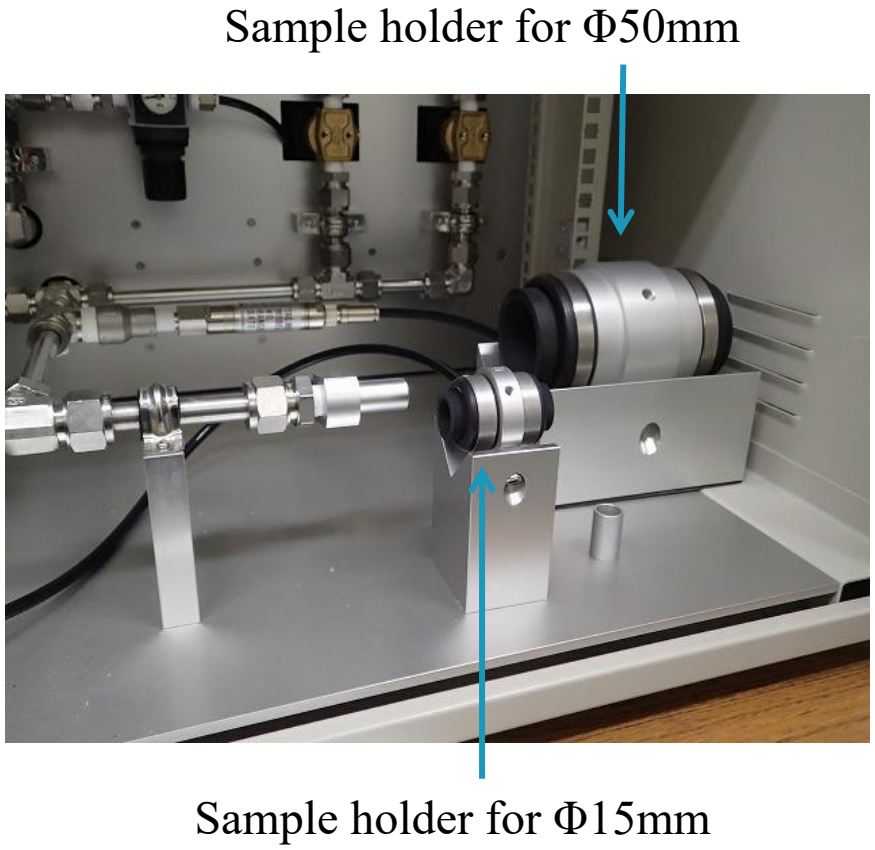


Escaping gas direction

Escaping gas direction

4. Sample preparing method





② Large diameter sample : Straight setting is more difficult

Small diameter sample : Small flow rate and measurement seems to be difficult.

⇒ The investigation of the differences in the sample diameter was carried out.

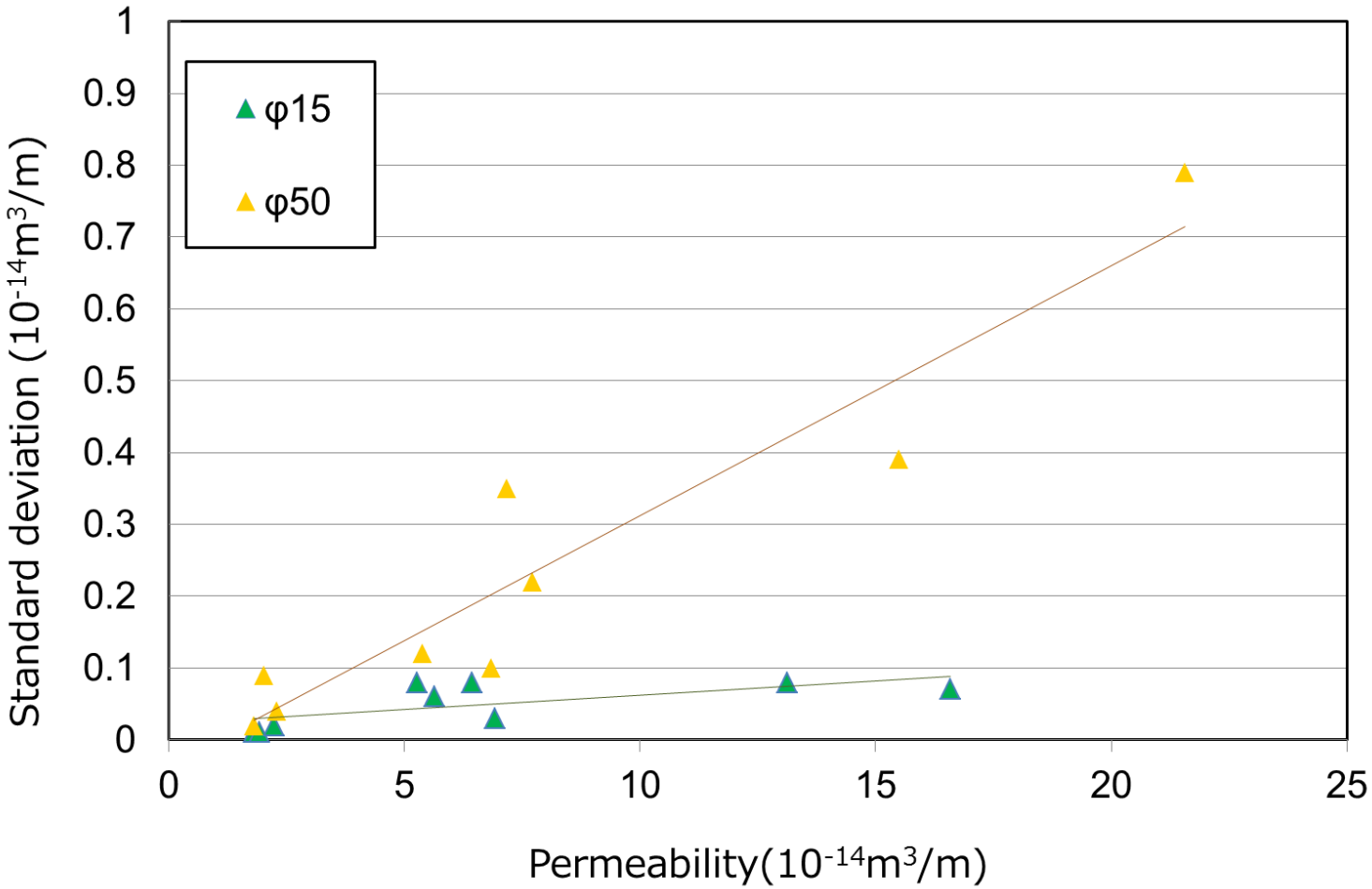
4. Sample preparing method

② Influence of sample diameter

- φ50 sample has higher dispersion in permeability than Φ15 sample.

⇒Influences of tilting of the sample.

Φ15mm is better than Φ50mm



4. Sample preparing method

Results for investigation of sample preparation

① Sample processing : Supersonic machining

② Diameter of the shell : Φ15mm

5. Relationship between the state of shell and permeability

To apply the permeability measurement for management, relationship between statement of shell and permeability should be known. As a first step, measurement for simple shell is carried out.

Stucco size and heating temperature are chosen as parameters and the same slurry is used through the primary layer to back up layer.

Primary slurry ～ back up slurry

Filler	Zircon, Cobalt aluminate	
Binder	Colloidal silica solution	
F/B ratio	3.7	
Stucco	Mullite #35-100	Mullite 0.5-1.0mm
Number of layers	9 layers	
Firing condition	900℃、1100℃、1300℃、1500℃ (2hr)	

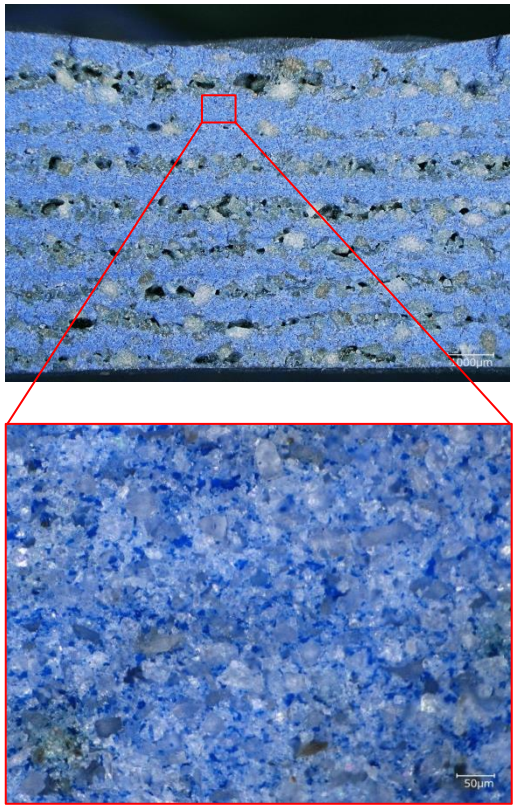
5. Relationship between the state of shell and permeability

① Decrease in permeability when fine stucco is used and fired at 1500℃.

Cross section of shell
Stucco: Mullite#35-100

Magnification image for slurry part.

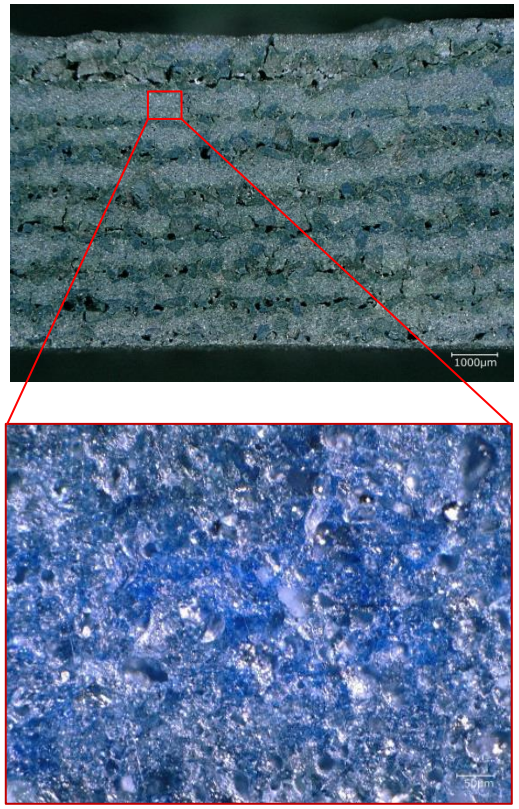
Firing at 1300℃



1mm

100μm

Firing at 1500℃



1mm

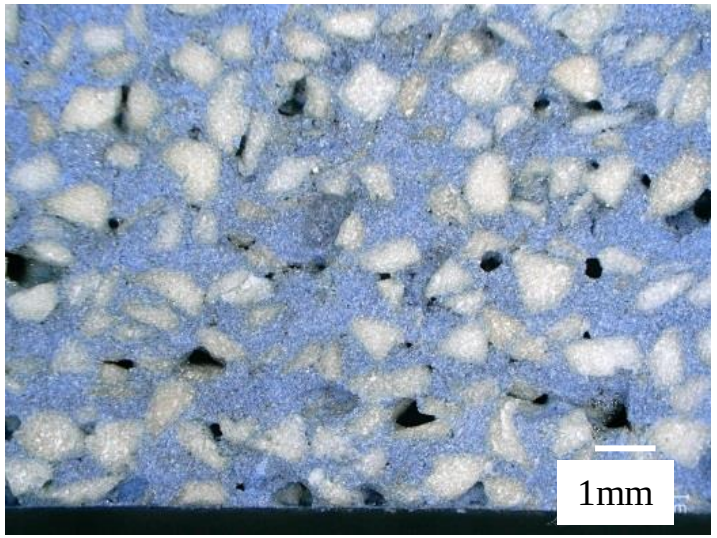
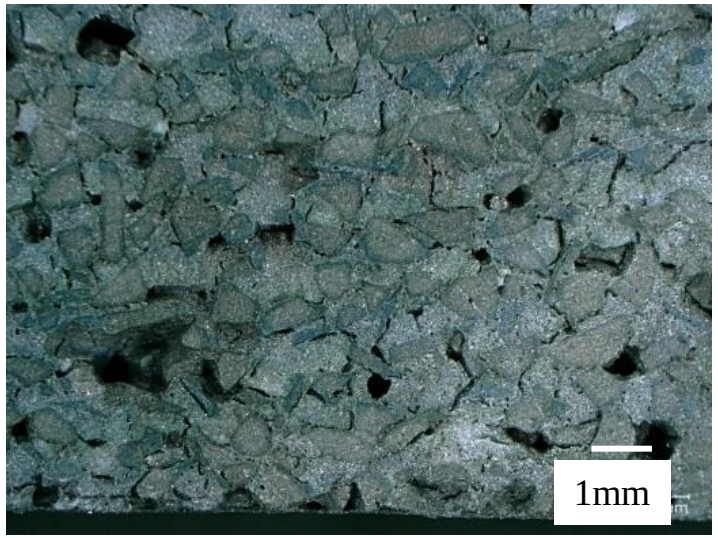
100μm

Escaping gas direction

	Firing at 1300℃	Firing at 1500℃
Density of slurry part	Low	High
Permeability	High	Low

5. Relationship between the state of shell and permeability

② Increase in permeability when the stucco is 0.5-1.0mm mullite and fired at 1500℃

	Firing at 1300℃	Firing at 1500℃
Mullite stucco 0.5-1.0mm		
Interface between slurry and stucco	No or few cracks	Many cracks
Permeability	Low	High

Escaping gas direction

Cracks at the interface between slurry and stucco make permeability value higher

5. Relationship between the state of shell and permeability

The amount of filler may affect to density of slurry part. And it seems to have relationship with permeability.

Slurry

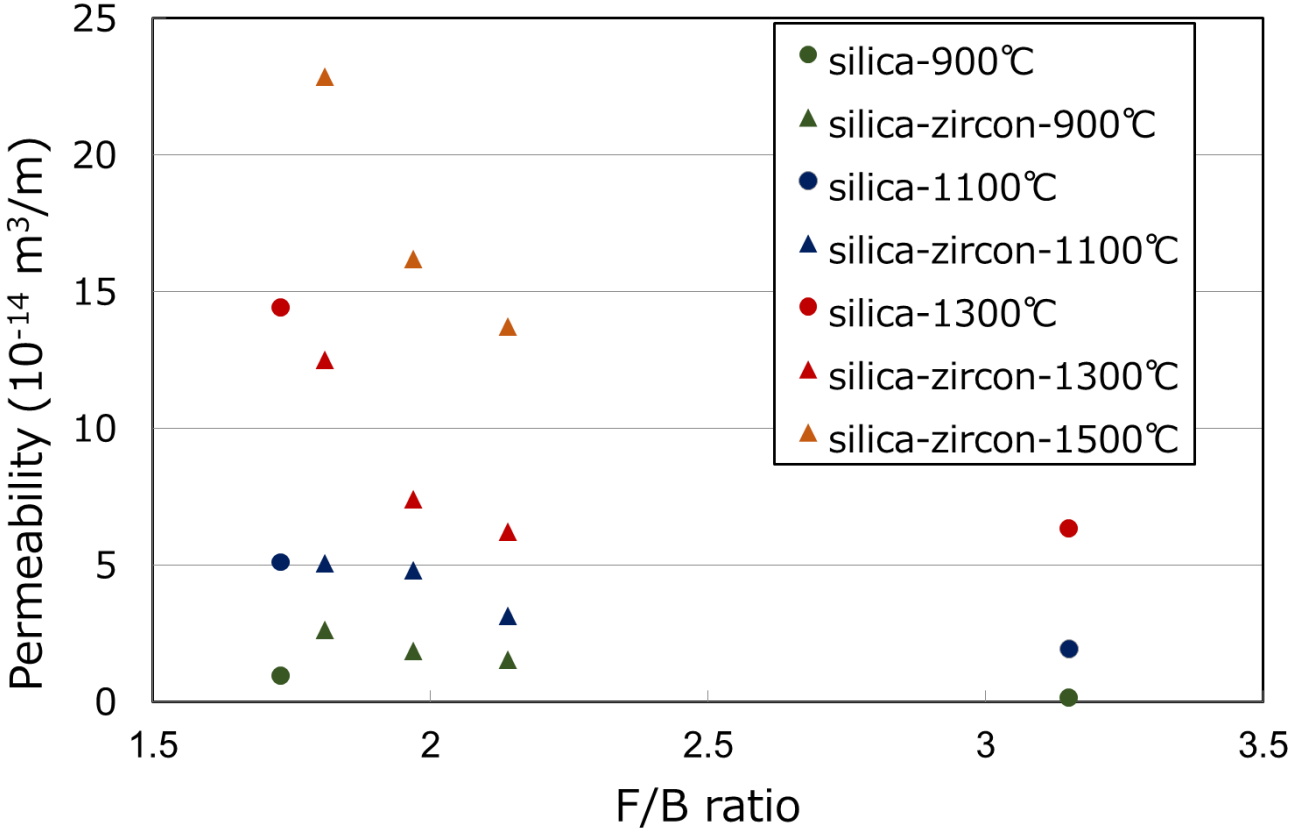
Filler	silica		Silica-Zircon		
Binder	Colloidal silica solution				
F/B ratio	1.73	3.15	1.81	1.97	2.14

Stucco

Primary coat	Fine alumina
Back up coat	Corse mullite

The relationship between F/B ratio and permeability was investigated.

5. Relationship between the state of shell and permeability



Permeability value decreases to F/B ratio for all firing temperature.
When the F/B ratio is large, the slurry part of the shell seems to be densified.
Then, the permeability value gets lower.

Conclusion

In this study, permeability measurement by JISR2115 method is applied for ceramic shell molds.

- Sample preparing method is investigated and supersonic machining process is applied.
  Sample size was optimized at Φ15mm.

- To investigate the relationship between shell condition and permeability, stucco size and firing temperature are selected as parameters in this study.
  As a result, density of the slurry part and cracks parallel to escaping gas direction affect permeability value.