CONCRETE TECHNOLOGY MODULE SEMESTER 1 – LECTURE 5

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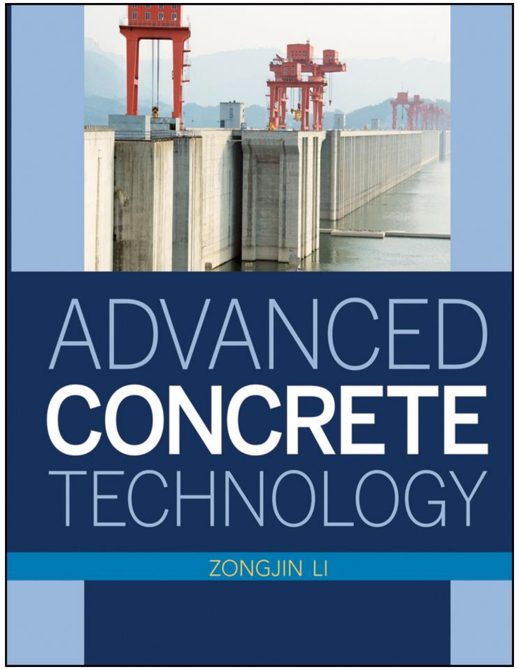
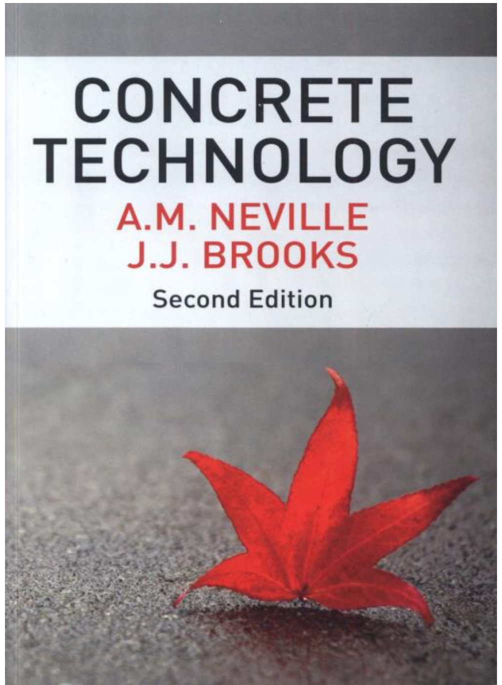
SEMESTER 1 OUTLINE

Item	Subject	Item	
1	**Introduction: Cement and Aggregate**		
2	**Manufacturing of concrete** - Mixing - Transportation - Placing and compaction - Curing - Finishing	**4**	**Strength of Concrete** - Compressive strength - Tensile strength - Modulus of rupture - Bond strength with steel reinforcement - Factors affecting concrete strength - Factor affecting concrete test
3	**Properties of Fresh Concrete** - Workability and Consistency - Segregation and Bleeding - Pressure on form work - Stripping of form	**5**	**Deformation of Concrete** - Creep - Shrinkage - Modulus of elasticity and Poisson's ratio

REFERENCES

- Concrete technology by Dr. Moaid Nory
- Advanced concrete technology by Zongjin Li
- Concrete Technology -2dn Ed by A.M. NEVILLE





LECTURE CONTENTS

1. **Cementitious Binders**
   i. 2.2.2.5 Types of Portland cements
   ii. 2.2.2.6 The role of water
   iii. 2.2.2.7 Basic tests of Portland cement

2.2.2.5 Types of Portland cements

According to the ASTM standard, there are five basic types of Portland cement:

- Type I regular cement, general use.
- Type II moderate sulfate resistance, moderate heat of hydration
- Type III increase C3S, high early strength
- Type IV low heat
- Type V high sulfate resistance

In BSI, four basic Portland cements are standardized:

- Ordinary Portland cement (OPC),
- Rapid hardening Portland cement (RHPC),
- Low-heat Portland cement (LHPC), and
- Sulfate-resistant Portland cement (SRPC).

OPC is equivalent to type I in ASTM, and RHPC, type III; LHPC, type IV; and SRPC, type V. There is no Portland cement similar to type II in BSI.

Table 2-8 Chemical compositions and physical properties of different Portland cements

Chemical Compositions and Physical Properties	Portland Cement Type				
	I	II	III	IV	V
C_3S	50	45	60	25	40
C_2S	25	30	15	50	40
C_3A	12	7	10	5	4
C_4AF	8	12	8	12	10
CSH_2	5	5	5	4	4
Fineness (Blaine, m^2/kg)	350	350	450	300	350
Compressive strength (1 day, MPa [psi])	7 [1000]	6 [900]	14 [2000]	3 [450]	6 [900]
Heat of hydration (7 days, J/g)	330	250	500	210	250

- The typical chemical compositions of five types of Portland cement in ASTM are given in Table 2-8.
- Type I is usually used as a reference, which contains 50% C3S, 25% C2S, 12% C3A, 8% C4AF, and 5% gypsum.
- Compared to type I, type III has more C3S (60%) and less C2S (15%). Moreover, type III has a larger fineness number than type I.
- As a result, the early strength of type III at 1 day is doubled as compared to that of type I.
- Meanwhile, the heat released by type III increases to 500 J/g (type I is 330 J/g).
- On the other hand, type IV has less C3S (25%) and more C2S (50%). Hence, the early strength of type IV at 1 day is only half of that of type I. However, the heat released by type IV greatly decreases to 210 J/g, and thus is called-low heat Portland cement.
- As for type V, its sum of C3A and C4AF is only 14% and much less than the 20% of type I. Since these two compounds readily react with sulfate, the lower content gives it less opportunity to be attacked by sulfate ions.

In addition, Figures 2-20 and 2-21 show the strength and temperature rise for the different types of cement, which are consistent with the information in Table 2-8.

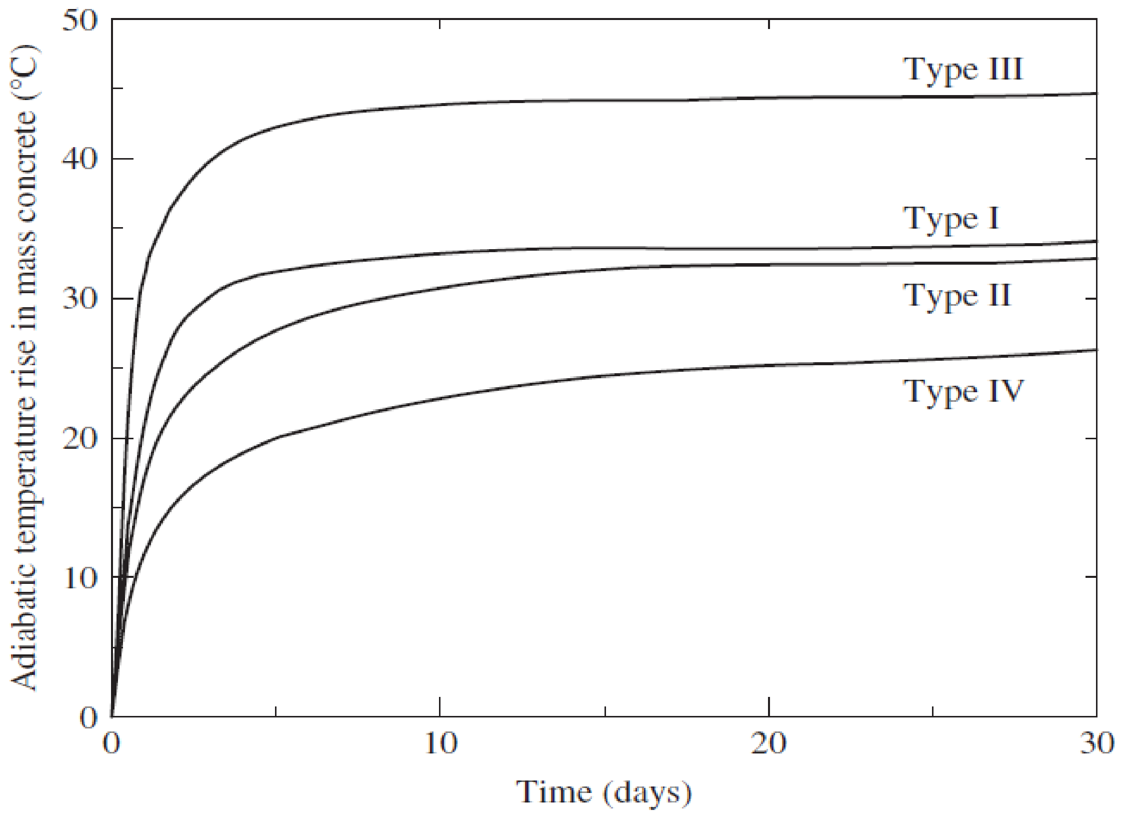


Figure 2-20 Adiabatic temperature rise in mass concretes with different types of cement

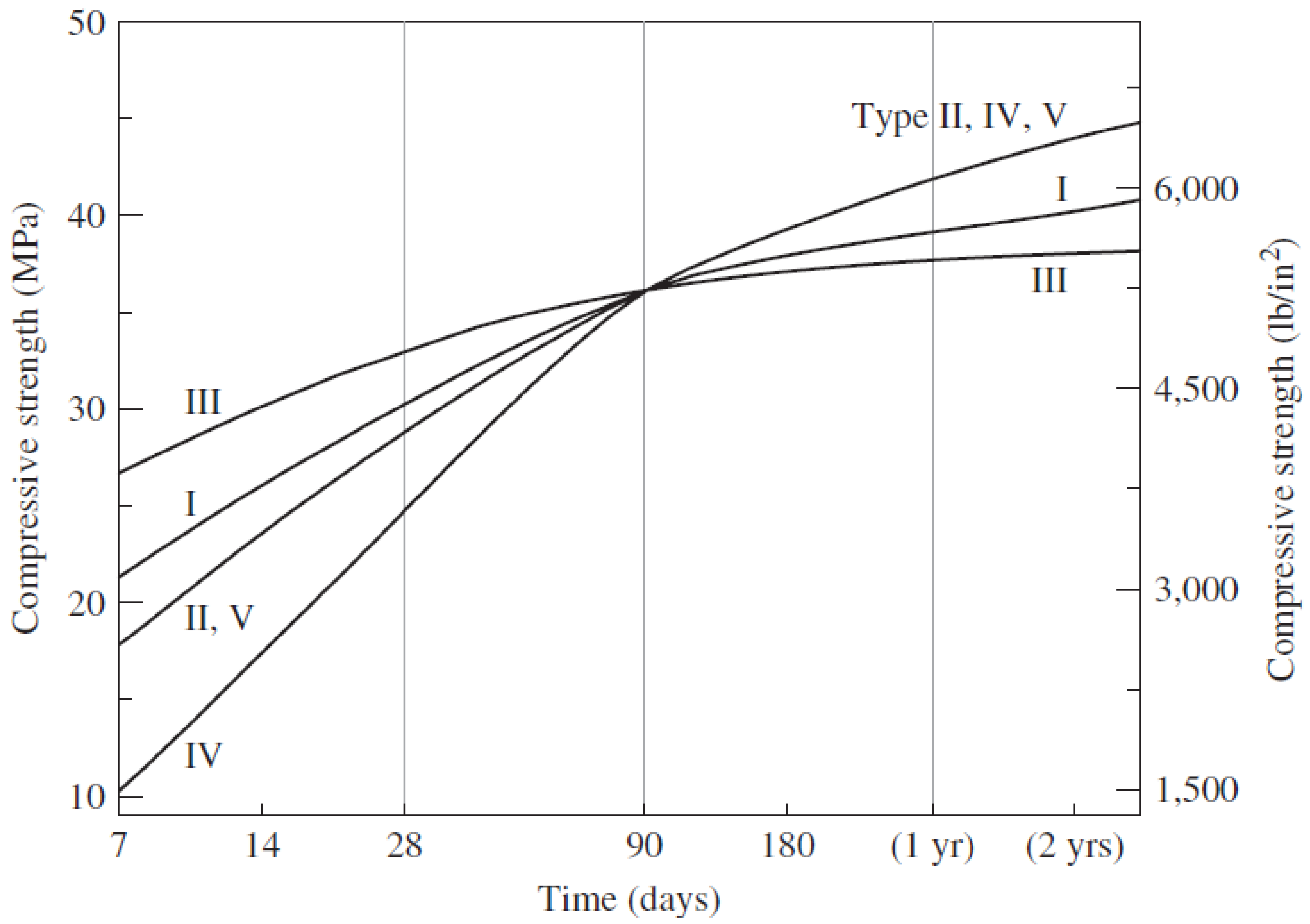


Figure 2-21 Strength development of cement pastes with different types of cement

- From the information provided in Table 2-8, we can evaluate the behaviour of each type of cement.
- The various behaviours provide the basic justification in selecting cement for engineering practice.
- For instance, for massive concrete structures, hydration heat is a big consideration because too much heat will cause a larger temperature gradient, thermal stress, and cracking. **Hence, type IV cement should be the first candidate** and type III should not be used.
- For a marine structure, high sulfate resistance and lower ettringite are needed; thus, **type V** should be selected.
- If high early strength is needed, **type III** will be the best choice.
- Generally, **type I** is the most popular cement used in civil engineering

2.2.2.6 The role of water

Of course, water is necessary for the hydration of cement. However, the water added in the mix is usually much higher than what the chemical reaction needs due to the fluidity requirement of concrete for placing.

Thus, we can distinguish the three kinds of water in cement paste according to their roles:

- **Chemically reacted water**

The chemically reacted water or chemically bonded water is the water that reacts with C, S, A, F, and S to form a hydration products such as C–S–H, CH, and AFt. This type of water is difficult to remove from cement paste and a complete decomposition happens at a temperature about 900◦C.

- **Absorbed water, and**

Absorbed water is the water molecules inside the layers of C–S–H gel. The loss of absorbed water causes shrinkage, and the movement or migration of absorbed water under a constant load affects the creep.

- **Free water.**

Free water is the water outside the C–S–H gel. It behaves as bulk water and creates capillary pores when evaporated, and can influence the strength and permeability of concrete.

Porosity is a major component of the microstructure that is mainly caused by loss of water.

The size of the capillary pores formed due to the loss of free water is in the range of 10 nm to 10 µm. The size of the gel pores involved in absorbed water is in the range of 0.5 to 10 nm.

A knowledge of porosity is very useful since porosity has such a strong influence on strength and durability. According to experiments, the gel porosity for all normally hydrated cements is a constant, with a value of 0.26. The total volume of the hydration products (cement gel) is given by

$V_g = 0.68\alpha$ **cm3/g** of original cement

where α represents the degree of hydration.

The capillary porosity can then be calculated by

$P_c = W/C - 0.36\alpha$ **cm3/g** of original cement

Where ***w*** is the original weight of water, **c** is the weight of cement, and ***w*/c** is the water to cement ratio. It can be seen that with an increase of ***w*/c**, the capillary pores increase.

Simplified scheme of hydrated cement paste microstructure

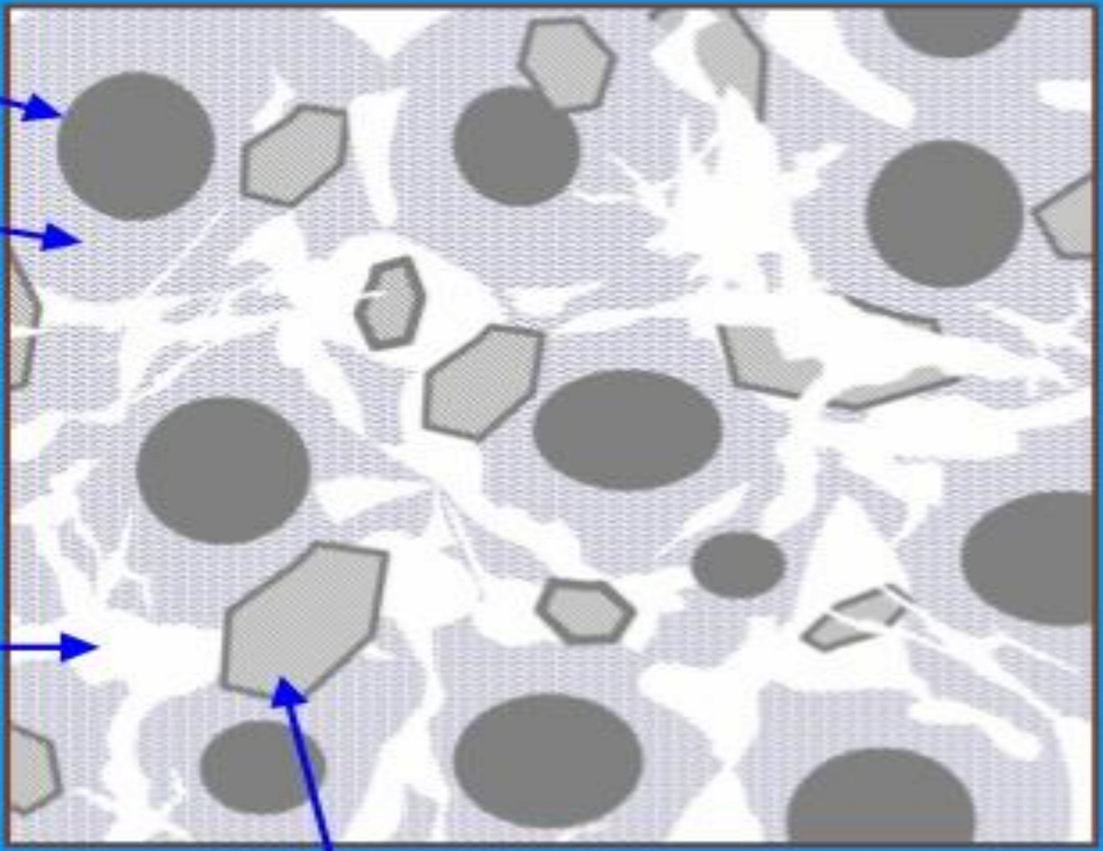
1. Unhydrated cement

2. C-S-H gel containing gel pores (interlayer water)

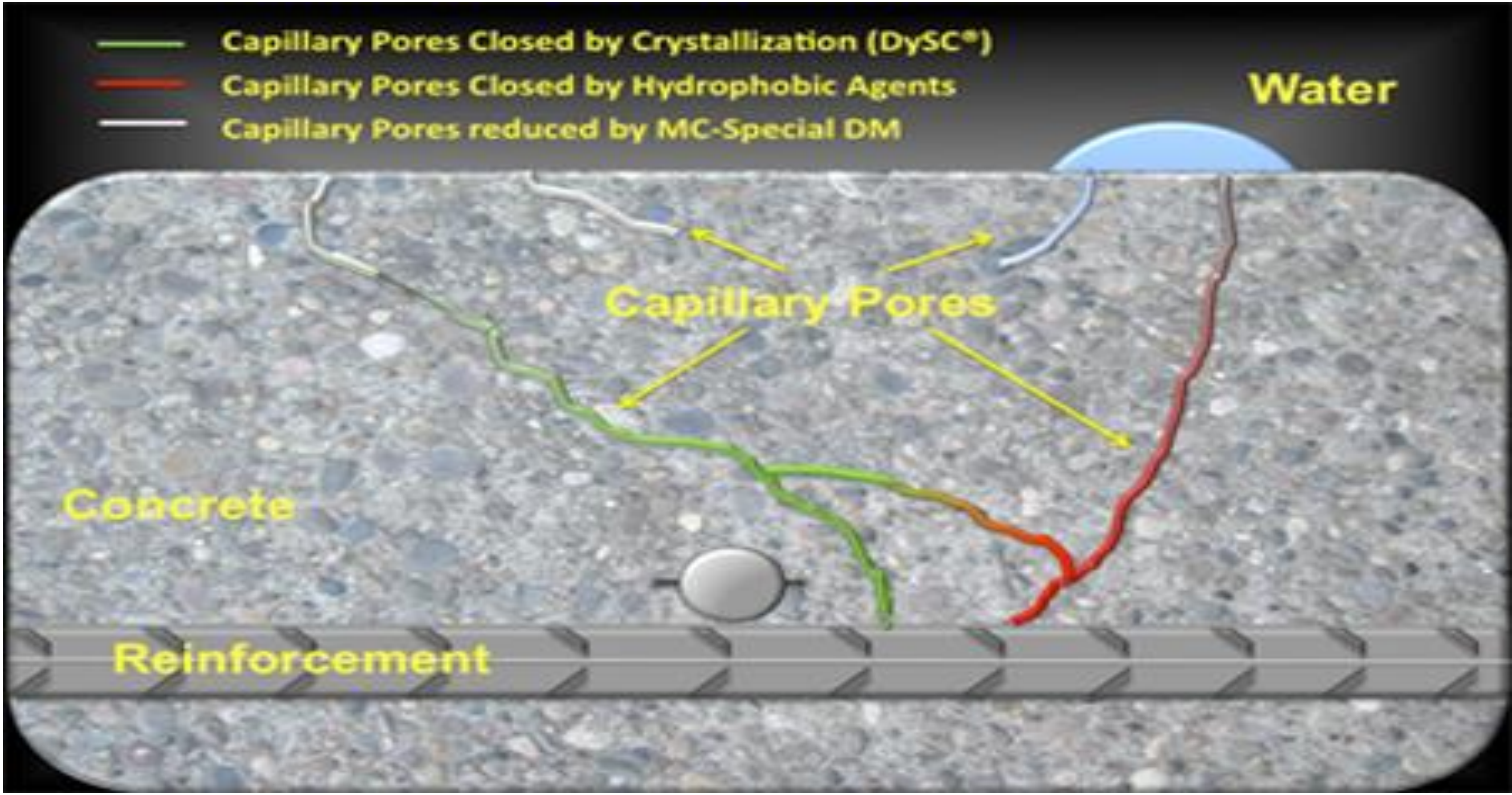
Gel (or interlayer) pores have size of 0.5-2.5 nm and occupy about 28 vol. % of C-S-H gel

3. Capillary pores (capillary water)

Capillary pores can have sizes from 10 to 1000 nm (1 μm) and even up to 5 μm. Volume and size depends on water/cement ratio and degree of hydration

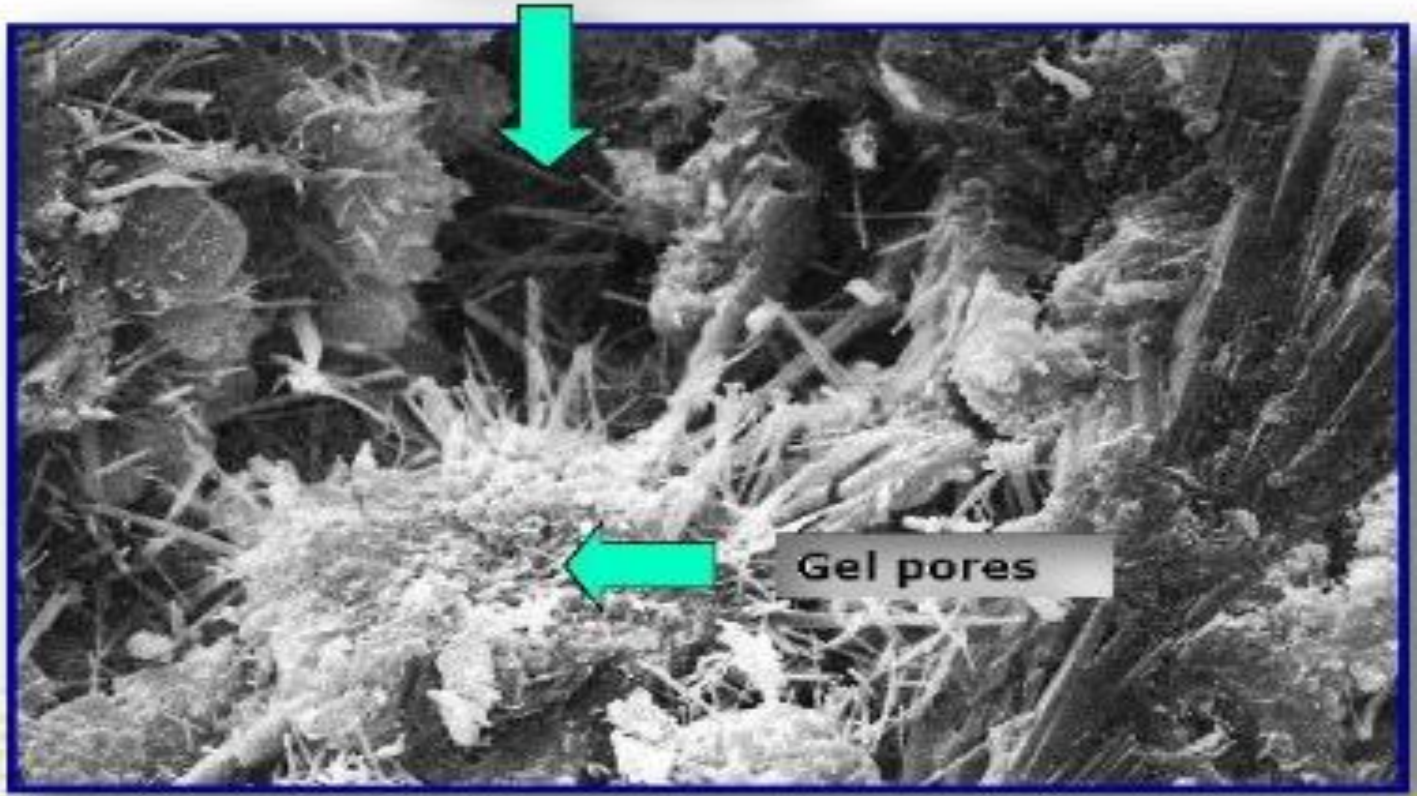


4. Hexagonal crystals of calcium hydroxide (portlandite)


Capillary Pores Closed by Crystallization (DySC®)
Capillary Pores Closed by Hydrophobic Agents
Capillary Pores reduced by MC-Special DM
Water
Capillary Pores
Concrete
Reinforcement

Concrete Porosity

- Capillary Pores 0.1µ
- Gel Pores <0.01µ



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Capillary Segmentation

- **Capillary porosity**

capillary pores larger in size compared to that of gel pores, will allow water and hence aggressive chemicals into the concrete, which adversely affects the durability of concrete in long term

- **C-S-H gel porosity**

Less impact on concrete strength and durability

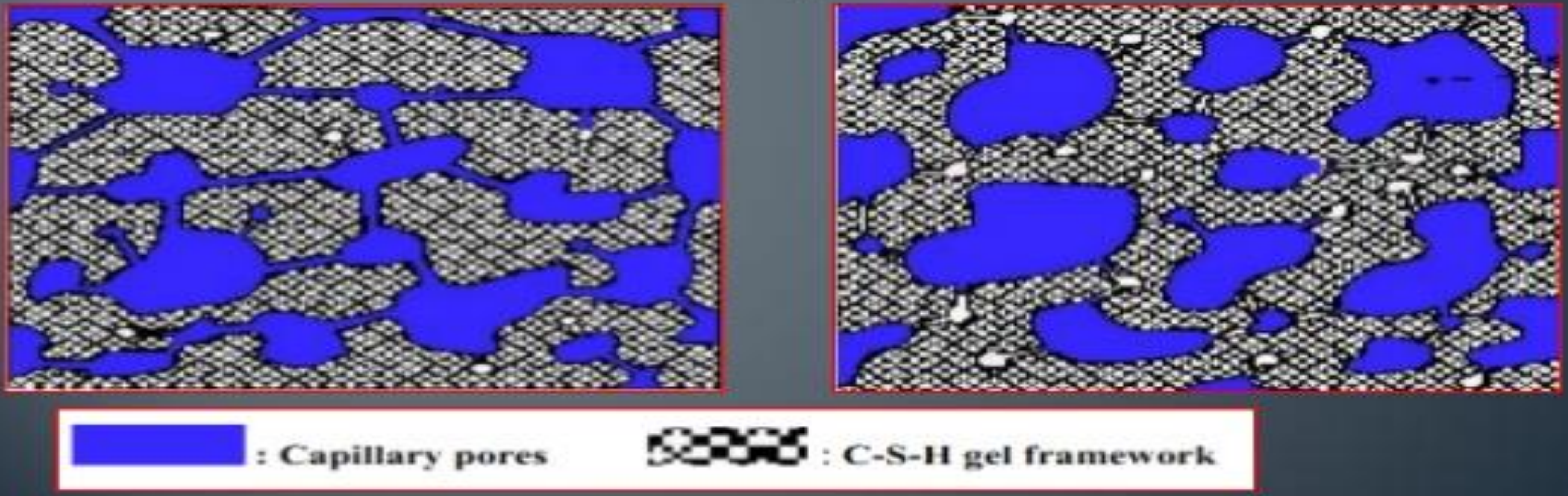

Fig: a)Capillary pores interconnected b) Partially connected capillary pores

The **gel/space** ratio (X) is defined as:

$$X = \frac{\text{volume of gel (including gel pores)}}{\text{volume of gel} + \text{volume of capillary pores}} = \frac{0.68\alpha}{0.32\alpha + w/c}$$

- The **gel/space** ratio reflects the percentage of solid materials in a cement paste. The higher the ratio, the more solid the materials and hence the higher the compressive strength.
- It can be seen from Equation that the **gel/space** ratio is inversely proportional to the ***w/c***.
- It can be deduced that a higher ***w/c*** leads to a low compressive strength of cement paste or concrete.
- The minimum ***w/c*** ratio for complete hydration is usually assumed to be **0.36 to 0.42.**
- It should be noted that complete hydration never happens and that residual anhydrate cement is beneficial for attaining a high ultimate strength.
- The space requirements for the cement gel are less than the requirements of water plus cement particles so that when the available water is used up, the cement paste will self-desiccate.

(d) *Soundness:* Unsoundness in cement paste results from excessive volume change after setting. Unsoundness in cement is caused by the slow hydration of MgO or free lime. The reactions are

$MgO + H_2O \rightarrow Mg(OH)_2$

and $CaO + H_2O \rightarrow Ca(OH)_2$

Another factor that can cause unsoundness is the later formation of ettringite.

Since these reactions are very slow processes, taking several months and even years to finish, and their hydration products are very aggressive, their crystal growth pressure will crack and damage the already hardened cement paste and concrete.

The soundness of the cement must be tested by an accelerated method due to the slow process.

One test is called the Le Chatelier test (BS 4550), and is used to measure the potential for the volumetric change of the cement paste.

The Le Chatelier test is used mainly for free lime detection.

The main procedures are as follows:

- Fill the cylinder-shaped container with cement paste of normal consistency as shown in the figure
- Cover the container with glass plates.
- Immerse in water (20◦C) and measure the distance of the indicator at the top of the apparatus.
- Boil the specimen for 1 h and measure the distance again after cooling.
- Expansion should be less than 10mm for acceptable cement quality.

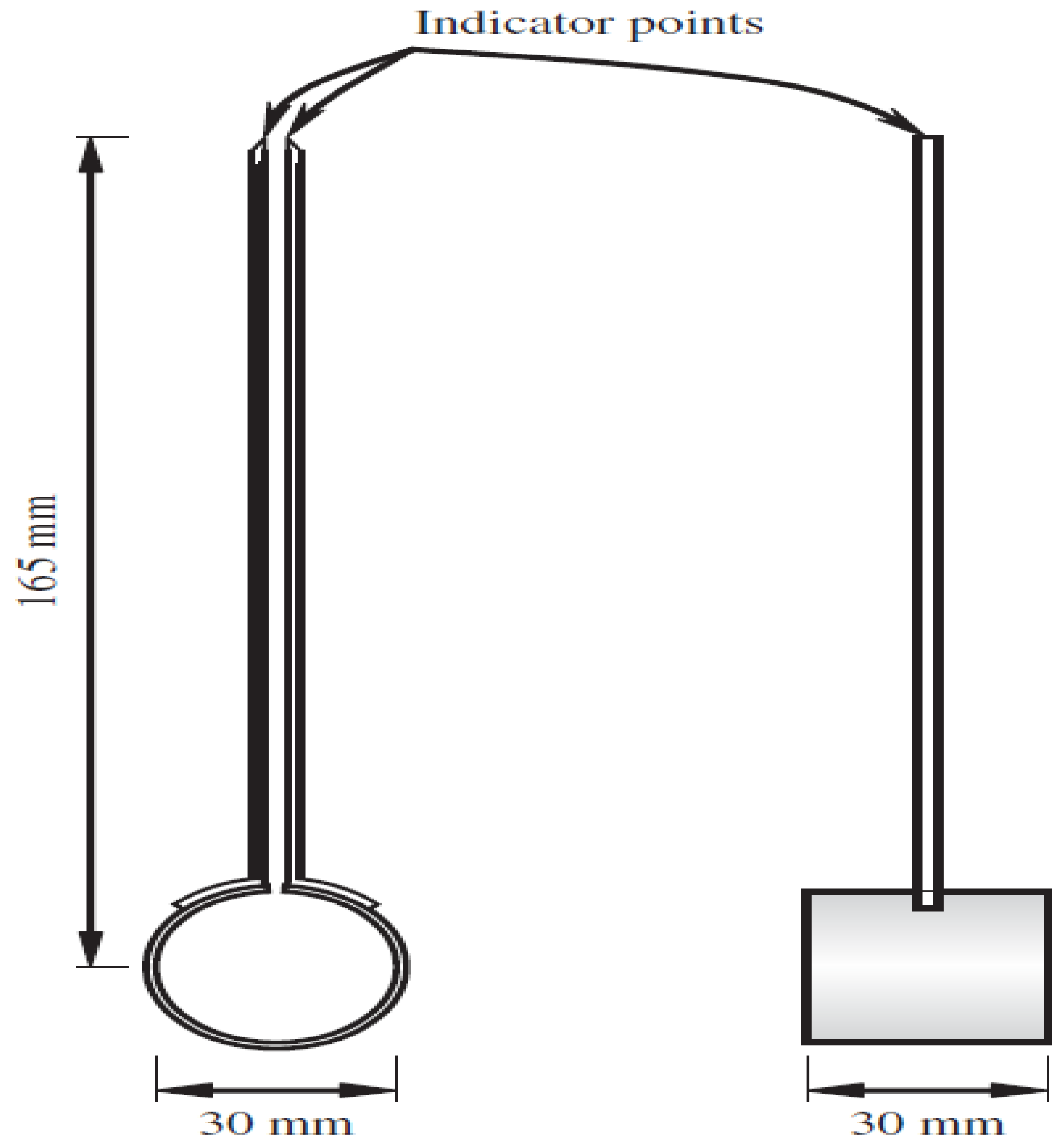

Figure 2-24 Le Chatelier test apparatus

- Another method is the autoclave expansion test (ASTM C151), which uses an autoclave to increase the temperature to accelerate the process. The procedures are as follows:
- Mold a cement paste with normal consistency into a container and cure normally for 14 h.
- Then remove from the mold, measure the size of the specimen, and place the specimen into autoclave.
- Raise the temperature in the autoclave so that the stem pressure inside can reach 2MPa in 45 to 75 min. And Maintain the pressure of 2MPa for 3 h.
- Cool the autoclave down so that the pressure is released in 1.5 h.
- Cool the specimen in water to 23◦C in 15 min. After another 15 min, measure the size of the specimen again;
- The expansion must be less than 0.80% to be acceptable.
- Autoclave testing can test both excess free lime and excess MgO.


Thank you for
your
attention!

Lecture Five Quiz

Q1 - True or False

1- Increase C3S ➔ Low early strength cement.
2- Higher heat of hydration ➔ high sulfate resistance cement.
3- Absorbed water is the water molecules inside the layers of C–S–H gel
4- For marine structure, a cement that is high sulfate resistance and lower ettringite are needed.
5- Low-heat Portland cement has less C2S and more C3S

Q2 – Calculate the gel/space ratio (X) and capillary porosity (Pc) of a cement paste if the water cement ratio (w/c) is 0.40 and α=0.7.

Q3. Briefly Answer the Following:

1. Draw a figure showing the temperature rise for the different types of cement
2. How capillary pores are created in the concrete structure?

Q4. Use the information in column B to fill in the missing parts of the sentences in column A:

A	B
Rapid hardening Portland cement has more -------- and less ----------	C3S, C2S, C3A and/or C4AF
Low-heat Portland cement has less --------- and more --------	C3S, C2S, C3A and/or C4AF
Sulfate-resistant Portland cement has low total amount of -------- and ----------	C3S, C2S, C3A and/or C4AF