High Performance Concrete Engineering

Homework #1 (Deadline by 6pm on Sep 27th)

Submission of hand-written homework will be accepted.

Total 100 marks

(a) What is the environmental benefit of Roman concrete? [10 marks]

(b) Explain the CO2 emission process in cement manufacture and its environmental impact [10 marks]

(c) Explain the difference among cement paste, mortar, and concrete. Also explain the difference between cement and clinker [10 marks]

(d) Explain why we sometimes use Bogue equation to estimate the cement phase composition. [10 marks]

(e) Explain why calcium sulfate is intentionally added in clinker to produce cement. [20 marks]

(f) Explain why type V cement contains lowest amount of C3A. [20 marks]

(g) What are the definitions of initial and final set times? Correlate those two set times with certain periods in the graph of rate of heat liberation from cement hydration. [20 marks]

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(Q) What is the environmental benefit of Roman concrete?

- Roman concrete was made with hydraulic Roman cement with red volcanic tuff as aggregate and volanic ash.
- When making the Roman concrete, the Pozzolanic reaction is occur.

$$\text{Pozzolan} + Ca(OH)_2 + H_2O \rightarrow C-S-H$$

- This reaction goes slowly at ambient temperature. Therefore, this process needed much less fuel than modern Portland cement.
- The final product of making Roman concrete is Calcium-Silica-Hydrates (C-S-H). That is, the Roman concrete has hydraulic property, which is able to resist to water.
- Therefore, the Roman concrete was useful for various constructions
- Moreover, the Roman concrete is durable due to volcanic ash which prevents cracks spreading

(b) Explain the CO_2 emission process in cement manufacture and its environmental impact.

- In modern society, ordinary Portland cement is the representative cement for various construction.
- However, in the process of manufacturing the ordinary Portland cement, the CO_2 is released as below reaction.

$$\text{Limestone} \xrightarrow{\text{heating}} CaO + CO_2$$

$$\text{Clay} \xrightarrow{\text{heating}} SiO_2 + Al_2O_3 + Fe_2O_3$$

$$\text{Limestone} + \text{Clay} \xrightarrow{\text{heating at } 1850^\circ C} \begin{cases} 3CaO \cdot SiO_2 \\ 2CaO \cdot SiO_2 \\ 3CaO \cdot Al_2O_3 \\ 4CaO \cdot Al_2O_3 \cdot Fe_2O_3 \end{cases} + CO_2$$

- As shown in the above process, one ton of ordinary Portland cement clinker releases one ton of CO_2
- Averagely, every person consumes 0.7 ton of cement annually
- Currently, cement production is responsible for 5-8% of global CO_2 emission
- In case of Korea, the annual cement production is 50 million tons.
- That means, 1.2 ton of CO_2 release occur by a Korea person annually
- Also, during the process of making cement, huge energy input is necessary up to 1850°C. In this procedure additional amount of CO_2 is released
- Moreover, to transport the cement to construction site or other places, CO_2 emission is occur.
- These make human to have responsibility to the environment in terms of CO_2 emission.

(c) Explain the difference among cement paste, mortar, and concrete. Also explain the difference between cement and clinker.

- The cement paste is consisted of cement and water.
- The mortar is consisted of cement, water, and fine aggregate under 4mm. In other words, the mortar is consisted of cement paste and the fine aggregate.
- The concrete is composed of cement, water, fine aggregate and coarse aggregate. ✓

- Clinker is the material used for making Portland cement. This is composed of C_3S, C_2S, C_3A and C_4AF.
- And the cement is made with clinker and gypsum.
- Gypsum is added to clinker to prevent flash set. Gypsum only reacts with C_3A, and it makes Ettringite. ✓

(d) Explain why we sometimes use Bogue equation to estimate the cement phase composition.

- The Bogue equation is used to calculate the approximate proportions of the four main minerals in Portland cement clinker.
- The four main minerals are tricalcium silicate (C_3S), dicalcium silicate (C_2S), tricalcium aluminate (C_3A) and tetracalcium aluminoferrite (C_4AF).
- The Bogue equation is presented as below.

$C_3S = 3CaO \cdot SiO_2 = 4.07CaO - (7.60SiO_2 + 6.72Al_2O_3 + 1.43Fe_2O_3 + 2.85SO_3)$
$C_2S = 2CaO \cdot SiO_2 = 2.87SiO_2 - 0.754(3CaO \cdot SiO_2)$
$C_3A = 3CaO \cdot Al_2O_3 = 2.65Al_2O_3 - 1.69Fe_2O_3$
$C_4AF = 4CaO \cdot Al_2O_3 \cdot Fe_2O_3 = 3.04Fe_2O_3$

- Through the calculation of approximate proportions of main minerals, it can be found the proper usage of the cement.
- Also, the proportions of the minerals of cement determines the quality of the cement.
- The hydration reaction differs along with the mineral proportions.
- By dealing with the mineral contents obtained through the Bogue equation, desirable cement can be prepared for certain construction or usage

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(e) Explain why calcium sulfate is intentionally added in clinker to produce cement.

- The clinker is consisted of tricalcium silicate (C_3S), decalcium silicate (C_2S) and tricalcium aluminate (C_3A).
- During the reaction, C_3A reacts with water, and then, it makes calcium hydrates as below which lead to flash set.

$$2C_3A + 21H \longrightarrow C_4AH_{13} + C_2AH_8$$

- Flash set causes rapid hardening and it decomposed later
- Therefore, to avoid flash set, calcium sulfate should be added. For this purpose, the calcium sulfate, gypsum, is used.
- Gypsum only reacts with tricalcium aluminate (C_3A) and makes ettringite.

$$C_3A + 3C\bar{S}H_2 + 26H \longrightarrow C_6A\bar{S}_3H_{32}$$

- However, when gypsum is not enough to completely react with C_3A, the ettringite decomposed to monosulfate. Then it affected by sulfate from ground water and so on. This is very critical to concrete because it occurs the volume expansion which cause cracks to the concrete.
- Therefore, it is important to balancing the quantity of gypsum to meet the demand of sulfate.

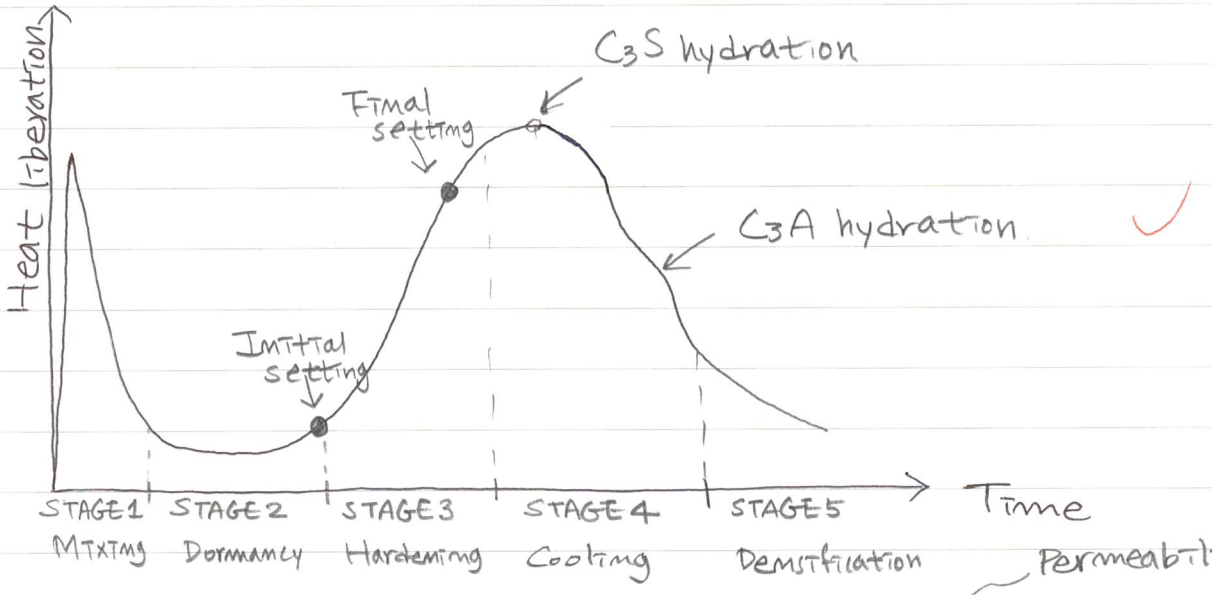
(f) Explain why type V cement contains lowest amount of C_3A.

- Type V cement is sulphate resisting Portland cement. Therefore, it is appropriate to use in situation subjected to high sulphate contents such as ground water or soil with high contents.
- Thus, to balancing the sulphate, the lowest amount of C_3A should be used, and also lower amount of gypsum should be used for type V cement than other type of cements
- If the cement affected by ground water or soil with high percentages of sulphate and react with the rest of C_3A, more ettringites are formed later. And ~~the~~ it causes volume expansion and cracks.
- Therefore, lowest content of C_3A should be contained for the type V cement.

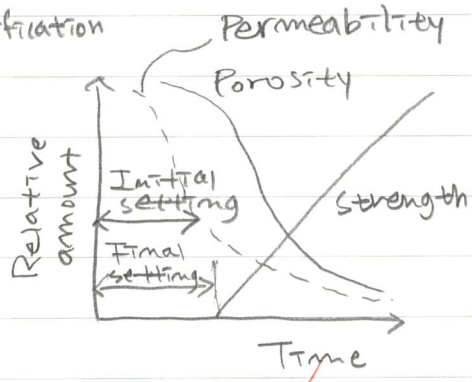
✓

(?) What are the definitions of initial and final set times? Correlate those two set times with certain periods in the graph of rate of heat liberation from cement hydration.

- The initial set time is the time period from the moment that water is added to the cement to stiffen considerably and can no longer be molded
- The final set time is the time period from the moment that water is added to the cement to be hardened to the point when it can resist some load.



- Stage 1 (Mixing): dissolution
- Stage 2 (Dormancy): induction
- Stage 3 (Hardening): acceleration
- Stage 4 (Cooling): deceleration
- Stage 5 (Densification): Steady



- Since the hydration process releases heat, before rising heat liberation is the initial setting time.
- And during hardening process the heat keeps releasing. When the time reach final setting, the strengths increases.