Mix Optimization for Reducing Cement Content, Shrinkage and Thermal Cracking and Carbon Footprint of Concrete




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1. Packing of Solid Particles

- **From macro-scale perspective, a concrete comprises of aggregate particles and cement paste.**

- Size of aggregate ranges from 75 μm to 10, 20 or 40 mm.
- The packing of aggregate largely affects the volume of cement paste needed or the excess cement paste available for workability.

- **From micro-scale perspective, a cement paste comprises of grains of cementitious materials and water.**

- Size of cementitious materials ranges from < 1 μm to 75 μm.
- The packing of cementitious materials largely affects the volume of water needed or the excess water available for workability.

1. Packing of Solid Particles

Packing Theory by Powers (1968)

- Successive filling of the voids by smaller size particles can decrease the volume of voids and increase the packing density of the particle system.

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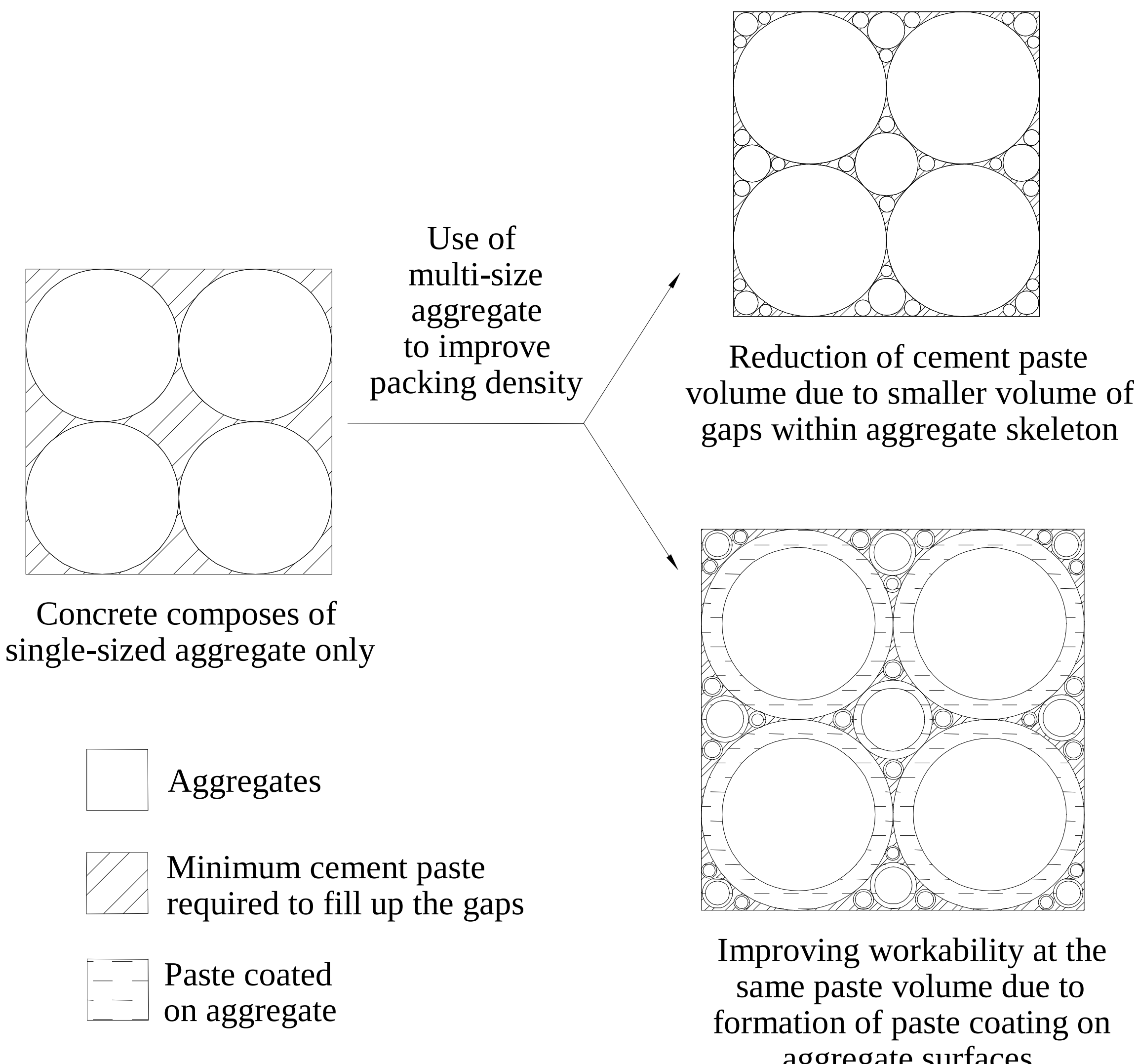


1. Packing of Solid Particles

- Packing density of aggregate can be measured under dry condition.

- However, the packing density of cementitious materials cannot be measured in the same way due to agglomeration.

- **The University of Hong Kong** has recently developed a ***wet packing test*** for cement paste.

1. Packing of Solid Particles

Wet Packing Test

- It mixes the cementitious materials with different amounts of water and determines the highest solid concentration achieved as the packing density.

- The effect of water, effect of SP and any air trapped inside the cement paste can be taken into account.

- Its accuracy has been verified against established packing models, being very small within 3%.

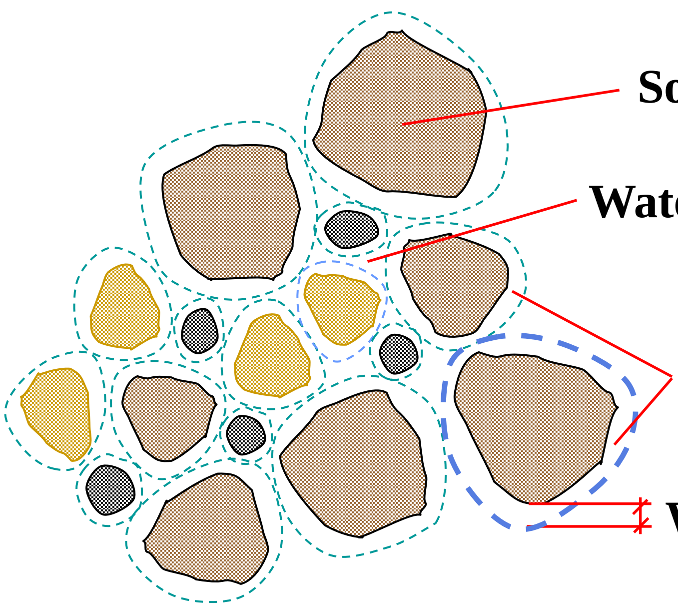
- Using the test, it had been proved that the addition of ultrafine particles such as CSF can increase the packing density of the cementitious materials.

- The University of Hong Kong has developed a computer program, which is capable of evaluating the packing density of the whole particle system in cement/mortar/concrete.

2. Water Film Thickness

- Apart from ***packing density***, ***surface area*** of the particle system also has great effects on the rheology of cement paste/mortar/concrete.

- This may be explained in terms of the **thickness of the water films** coating the solid particles.



2. Water Film Thickness

- The average ***water film thickness*** may be evaluated as the excess water to surface area ratio.

- The combined effects of ***water content***, ***packing density*** and ***surface area*** may be evaluated in terms of one single parameter – the ***water film thickness***.

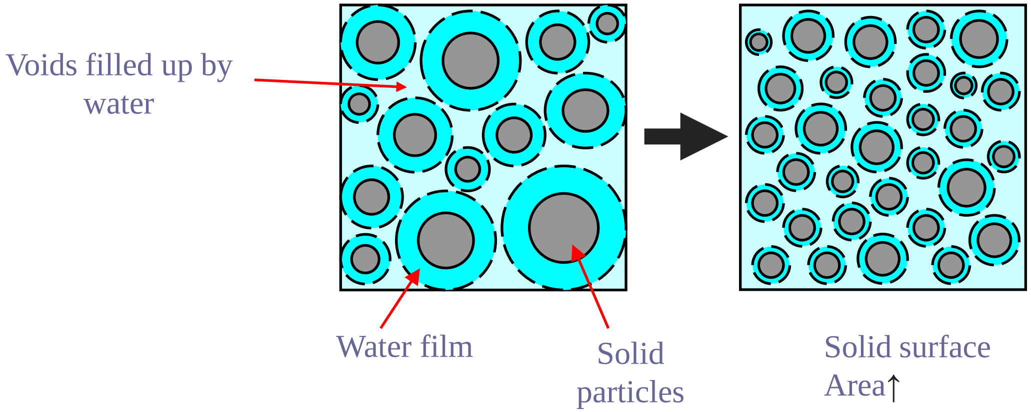
- It is found to be the major factor governing the rheology and cohesiveness of cement paste/mortar/concrete.

2. Water Film Thickness

- Traditionally, mix design optimization was done by maximizing the packing density.

- However, in fact, the addition of very fine particles, such as CSF, ultra PFA, superfine GGBS that can increase the packing density, would also increase the surface area.

- Therefore, the water film thickness may increase or decrease.

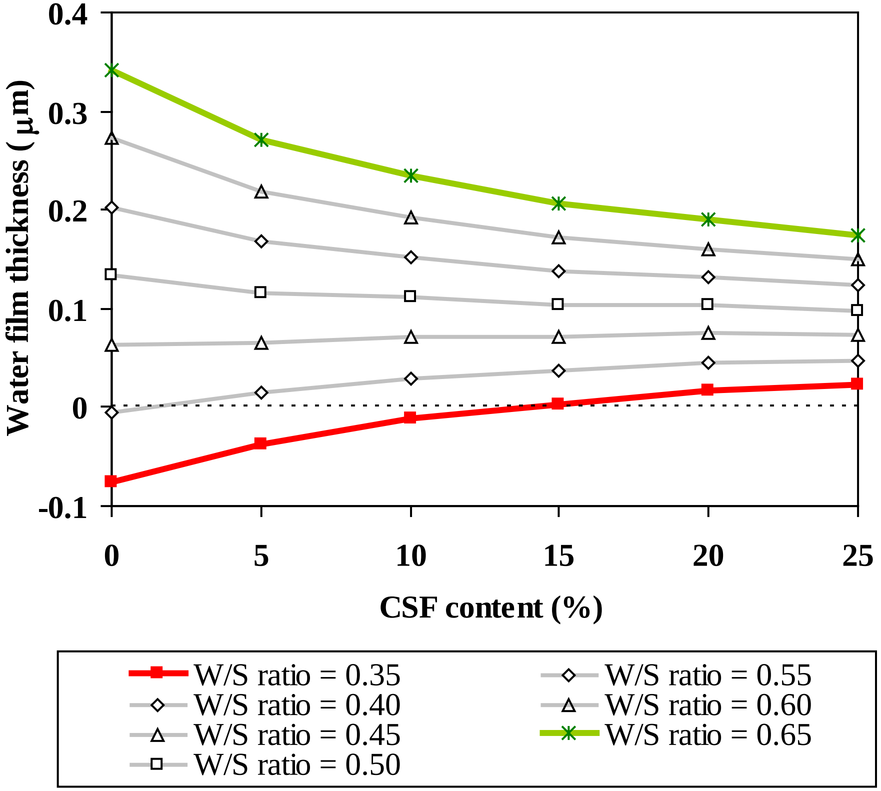


2. Water Film Thickness

- It had been found that as CSF is added, the water film thickness may increase or decrease, depending on the water content of the cement paste of mortar.

When the water content is **low**, ***water film thickness*** would **increase** as the **CSF content** increases.

When the water content is **high**, ***water film thickness*** would **decrease** as the **CSF content** increases



3 Fillers

<u>Different types of fillers</u>

- ❖ Ultra/ground **PFA**
- ❖ Superfine **GGBS**
- ❖ Superfine **Limestone Filler**
- ❖ Superfine **Cement**

- ➢ Due to their fineness, their addition can increase the packing density and at the same time increase the surface area of the powder content.

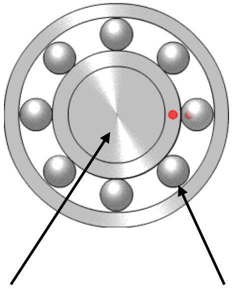
- ➢ Therefore, the rheology of the cement paste/mortar/concrete can be positive or negative, depending on the **particle size distribution** of the powder content and **dosage of fillers** added.

- ➢ Nevertheless, their addition will always increase the ***cohesiveness*** and thus help to ***reduce segregation***, ***bleeding*** and ***sedimentation***.

3 Fillers

- Some other fillers, such as ***ordinary limestone fillers*** and ***ground sand***, are coarser than cement but finer than fine aggregate. Their addition can increase the packing density of the aggregate but will also increase the surface area of the aggregate.

- The net effect of their addition on the rheology of mortar/concrete can also be positive or negative.



- Nevertheless, their addition will always increase the ***cohesiveness*** by increasing the surface area and increase the ***passing ability*** by increasing the amount of excess fine coating the coarse aggregate particles.

4 Green Concrete

- ☹The production of cement involves heating of limestone.
- ☹For each tone of cement produced, almost ***one ton of CO_2*** is generated.
- ☹Account for around ***7-8%*** of global ***greenhouse gas*** emission.

4 Green Concrete

It is our mission:

☺ to reduce the carbon footprint of our construction.

☺ to ensure sustainable development for our future generations.

☺ For this reason, concrete which can help to minimize cement consumption should be called **green concrete**.

4 Green Concrete

- ☺ A **green concrete** is not just a concrete with a low cement content per unit volume.

- ☺ It should be also able to ***reduce the volume of concrete*** needed and ***increase the service life*** for the structure built.

- ☺ The use of a ***higher strength concrete*** can serve the purposes.

4 Green Concrete

- ☺ **One Island East**, a newly completed 70-storey concrete building in Hong Kong, serves as a good example.
- ☺ The use of **Grade 100 concrete** instead of the originally planned **Grade 45 concrete** has reduced the volume of concrete needed for the vertical elements by **30%.**
- ☺ The **Grade 100 concrete** has the same cement content per unit volume of that of the **Grade 45 concrete** (Its ***high strength*** was achieved by adding ***PFA*** and ***CSF***).
- ☺ The ***higher durability*** of the Grade 100 concrete can also extend the design service life from 50 years to ***75 years*** or even ***100 years***.

5 Conclusions

- With the advent of **chemical** and **mineral admixtures**, concrete technology has advanced greatly and many different types of **HPC** have been developed.

- However, the conventional concrete technology has remained rather empirical.

- There are still many aspects of concrete behaviour that are beyond our comprehension.

5 Conclusions

- In the past 20 years, The University of Hong Kong has been working on the theories of ***packing of solid particles*** and ***water film thickness***.
- These theories are evolving into "**Modern Concrete Science**".
- Based on these theories, computer models and software can be developed for theoretical prediction of concrete performance.
- It is envisaged that such computer software can finally help to optimize our mix design for better HPC and allow quicker response during production to variations in quality of the ingredients.

5 Conclusions

- Furthermore, The University of Hong Kong is also developing new technologies such as ***green concrete***.

- It should be noted that a ***HPC*** is also a ***green concrete***.

- Finally, we can and should contribute to sustainability by optimizing the mix design to reduce cement consumption.

Thank you!