Low Carbon Technologies of Chinese Concrete Industry

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Responsibility for Low-Carbon Concrete Development

China’s economy is booming. Huge amount of cement and concrete are produced as utilized. The energy conservation and emission reduction in cement and concrete industry has an significant influence on Chinese low-carbon economy.

Contemporary Status of Cement and Concrete Industry in China

Since 1985, China’s cement production always ranks No. 1 in the world. In 2009, China’s cement production is about 1.6 billion tons, or 55 percent of the total world’s output. The energy consumption for cement production is equivalent to 180 million tons of standard coal, approximately 5 percent of domestic total energy consumption.

Great Demand on Cement and Concrete for Rapidly Economic Development

By 2049, the total capacities will be 24 times as large as Three Gorges Project capacity.

17,000 kilometers of high-speed railway will be built in five years

100,000 kilometers of expressway will be achieved in five years.

The large-scale bridges in China amount to 50% of worldwide amount

Outline of the presentation

- Government policy on low carbon development
- Examples of low carbon cement practiced in China
- Examples of low carbon concrete practiced in China
- China Project 973 on *Environmentally Friendly Concretes*:
  - Started year 2009
  - Funded by government at $ 5 million/5 years
  - Supports basic research of concrete to link structural performance to nano-scale and microstructure

Policy

Government Policy on Low-Carbon Development

- **Energy-Saving & Emission-Reduction** : Optimization of conventional cement manufacture process with high-tech for the purposes of energy-saving, emission-reduction and environmental protection
- **Utilization of Industrial Solid Wastes** : Use of industrial solid wastes as substitutes for silicates or alumino-silicates, either partially or completely, for cement clinker to produce eco-cement and for concrete to gain high performance
- **Prefabricated Concrete Components:** To achieve industrialization of construction, prefabricated concrete structures are highly recommended by government to develop innovative structural components, multi-functional building envelope, prefabricated building products

High Belite Cement

Energy could be saved and emission reduced by developing new cement with low-calcium, and calcinated with low temperature.

Charachteristic of High Belite Cement

Types	C_3S (%)	C_2S (%)	Lime (T/T clinkers)	Calcination Temperature (℃)	Coals consumption (Kg/T Clinkers)
High belite cement	21±3	50±5	1.16	1330~1350	160
Portland cement	50±5	21±3	1.23	> 1450	198

Calcination temperature: decrease of 100℃, saving the coal of 20%-30%

Limestone consumption: reduction of 5%-10%

CO_2 emission: approximately 10% reduction

SO_2 and NOx emission: corresponding decrease

Clinker unit cost: reduction of 27.75 y/t

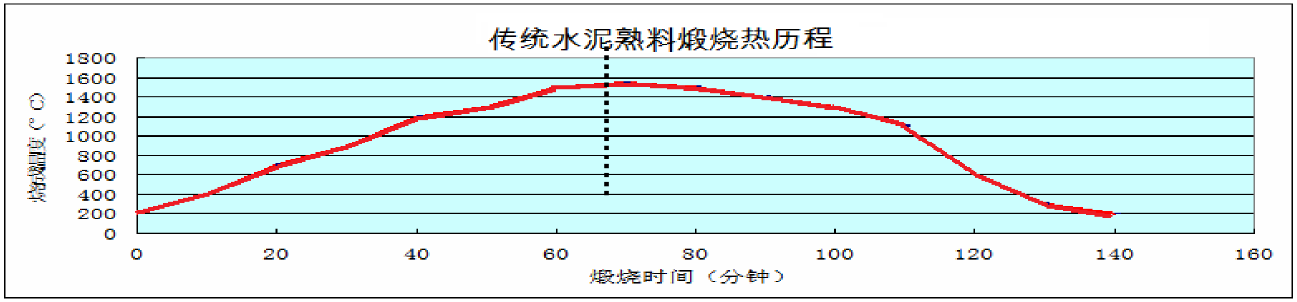
Cement unit cost: reduction of 7~15 y/t

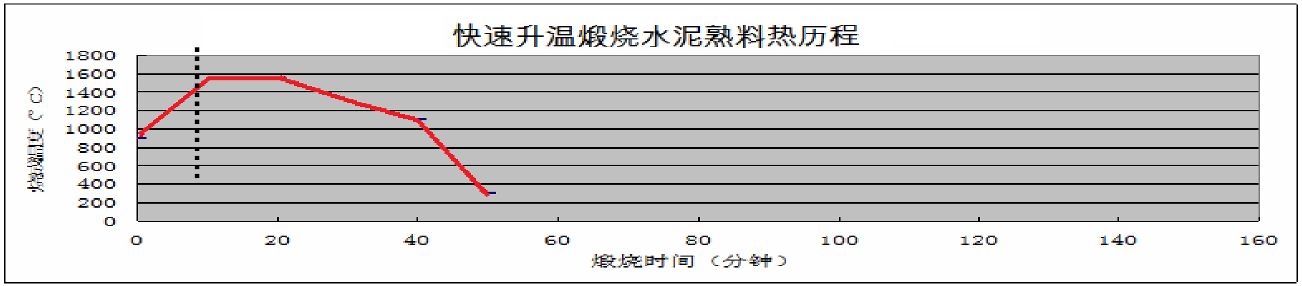
It is available to reduce the emission of 7.86kg CO_2 per ton clinker production because the decrease of CaO in clinker.

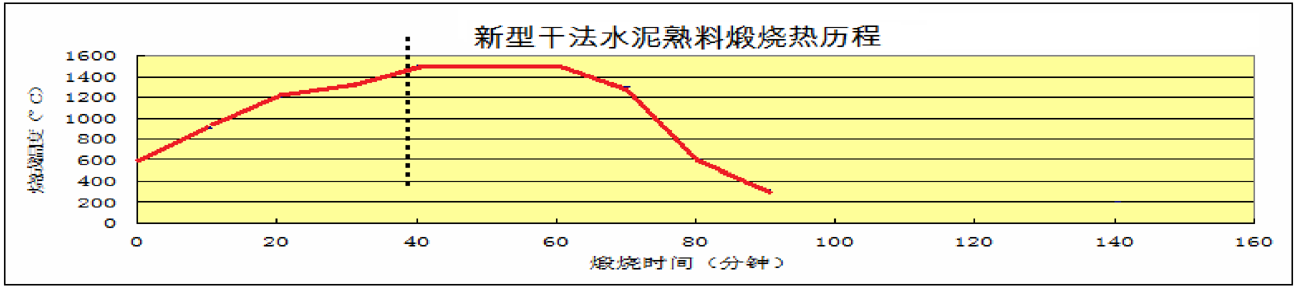
Low Carbon Cement

Fast Calcination Technology of Cement

New dry technology such as suspension, boiling and pre-decomposition calcination.


传统水泥熟料煅烧热历程


快速升温煅烧水泥熟料热历程


新型干法水泥熟料煅烧热历程

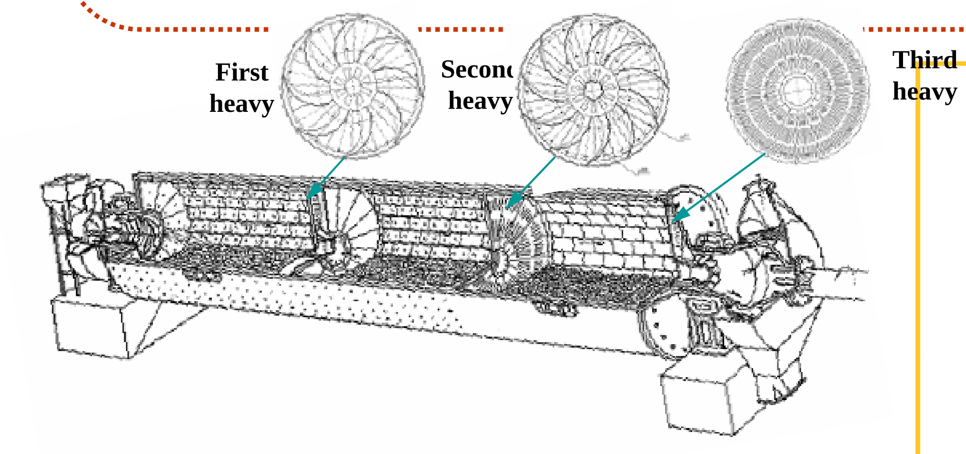
Fast calcination of clinkers has obvious effect on energy-saving.

Energy Conservation from cement grinding

—— Tube mill technology

Grinding energy in cement production accounts for 30% of total energy consumption. In 2009, for cement manufacture, total energy power consumption is more than 110 billion kW-h.

Tube mill is mostly used in cement grinding in China, therefore, improving grinding efficiency can lead to significant energy saving.



Principle of powder selection with open flow

Technical Innovation:

- principle of powder selection with open flow
- multiple air classier
- distributing wind technology
- flow control technology
- raising material technology
- anti-pellet technology

Utilization of Industrial Wastes in Concrete

There are more than 1 billion tons solid calcareous derivatives production each year in China's industry(blast furnace slag, fly ash, steel slag, gangue, carbide slag, construction waste such as powder, etc.). Their compositions are listed as follows:

Types	CaO	SiO_2	Al_2O_3	Fe_2O_3	FeO	MgO	MnO	P_2O_5
Clinker	63~67	21~24	4~7	2~4	-	1 ~ 2	-	-
Blast furnace slag	35~45	30~35	8~12	1~2.5	-	6~8	-	-
Steel slag	30~60	8~30	1~7	~9	10~15	5~15	-	~4
Fly ash	4~8	30~45	35~50	4~10	-	1~2.5	-	-
Manganese slag	32~40	22~30	9~20	0.5~3	-	2.0 ~9	4~18	-
Phosphorous slag	40~50	30~43	1~4	0.5~2	-	2~6		2~5

Technological core：

chemical and mechanical activation

Developed technical projects

Steel slag: Wuhan, Shanghai iron and steel corporation
Phosphorous slag: Yunnan Kunming
Manganese slag: Guangxi Yufeng
Furnace slag: Cement plant in Hunan homeland
Fly ash: Power plants around the country

With industrial waste as admixture in cement and concrete, it could decrease the cement clinker consumption with the result of energy and resource conservation.

Utilization of Recycled Concrete

discarded concrete blocks → heat → crack formation and extension on the components interfaces → rub → aggregates separate with set cement → sieve → coarse aggregate / mortar

mortar → grind → fine aggregate separate with set cement further, set cement ground → select powder by wind → fine aggregate / set cement powder

Separation technology for waste concrete components

Technology for preparing renewable cementing materials using waste concrete

discarded concrete ↓ primary crushing ↓ secondary crushing ↓ 300^{o}C heat-treatment → machine vibrating ↑ sieve

sieve → renewable coarse aggregate → new concrete

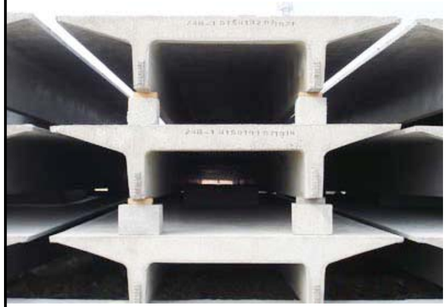
sieve ↑ mortar ↑ grind → select powder by wind

select powder by wind ↓ high quality renewable fine aggregate → new concrete

select powder by wind ↑ set cement powder → 650^{o}C low-temperature calcination → renewable cementing materials

Prefabricated Concrete Components

In order to reduce material waste caused by the construction site, to control the quality, to guarantee the durability and service life and other issues, should be researched and development the preparation techniques and construction technology for prefabricated concrete components.



Pre-stressed concrete double T board

Track board

Hollow slab

Project 973

China Project 973

- Project: Fundamental study on environmentally friendly contemporary concrete
- Objectives:
  - Establish microstructure models of contemporary concrete,
  - Understand the degradation mechanism,
  - Formulate service life design theory,
  - Improve efficiency,
  - Develop low energy consumption and long life concrete

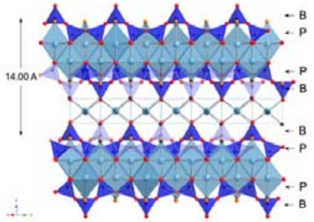
China Project 973: Tasks

- **Theme1: Mechanism of microstructure formation in contemporary concrete**
- **Theme 2: Constitutive relations of modern concrete subject to complex loading**
- **Theme3: Damage mechanism of contemporary concrete subject to chemico-mechanical coupling action**
- **Theme4: Service life design theory of contemporary concrete**
- **Theme5: Optimization of microstructure in concrete structure**

Mechanism of Microstructure Formation in contemporary Concrete

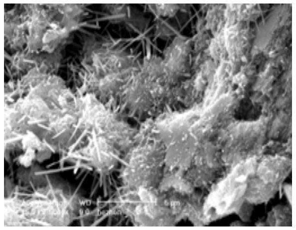
- To understand the mechanism of microstructure formation in complex components system
- To propose microstructure model of C-S-H
- To provide theoretical guideline to justify the microstructure through optimization of mixture proportion of clinkers and different additions

WHUT & WHU



C-S-H solid

C-S-H solid + pole

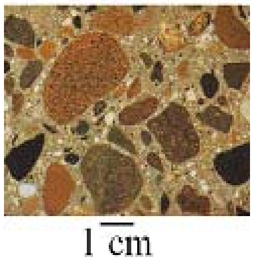


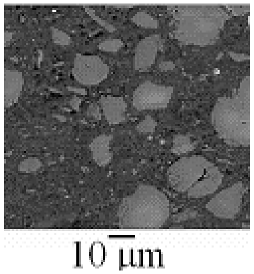
C-S-H matrix + other hydration products + clinker

Constitutive Relations of Concrete Subject to Complex Loading

- To formulate a mechanical and transport constitutive equations of concrete based on multi-scale theory
- To establish the relationships between nano-scale charateristic and macro-behavior

Concrete



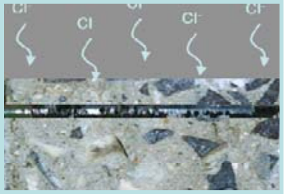


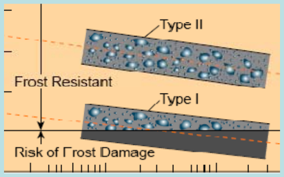
Paste

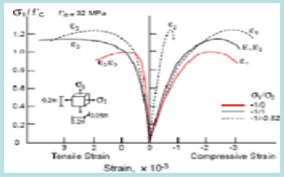
- **HKUST**

Damage Mechanism Subject to Chemico-Mechanical Coupling Action

- To establish progressive damage model for contemporary concrete subjected to environmental and mechanical loads
- To study the chemical – mechanical conversion in concrete subject to environmental exposure using porous medium theory and thermodynamics





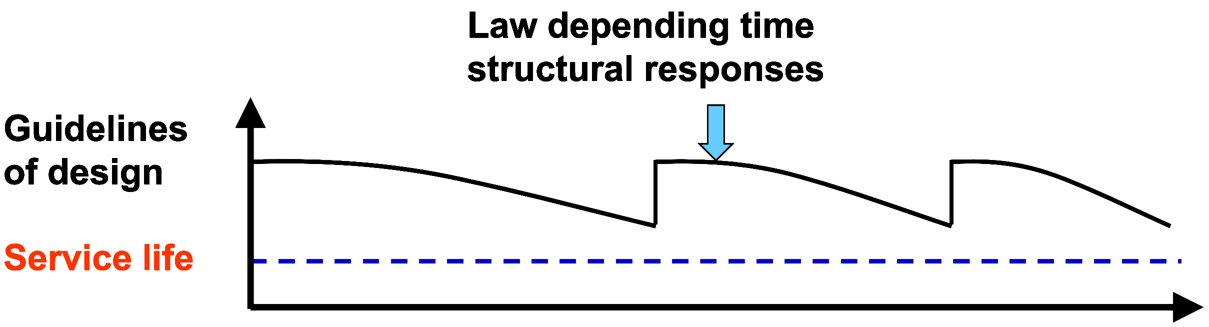


Southeast U & TsinghuaU

Service Life Design Theory of Concrete

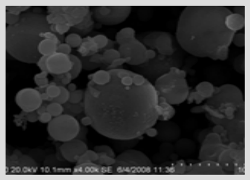
- **To develop service life design theory of environmentally friendly contemporary concrete based on constitutive equations under multi-directional stresses**

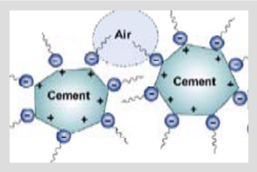
ZJU & TongjiU



Optimization of Structural Behavior of Modern Concrete

- **To optimize microstructure and develop micro-engineering of concrete for contemporary concrete structural design**
- **To promote high toughness and long life concrete for sustainable development**





Structure behavior

Jiangsu Research Institute of Building Science Co., LTD.

Theme 1: Understanding of Microstructure and its Engineering Target

Calcium Silicate Hydrates (C-S-H)

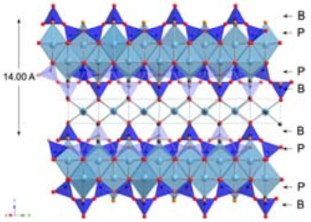
"the most important hydration product of cement based materials

- 50~60% of cement paste
- responsible for most of the cement propertie

  stiffness / strength / brittle
- major source of cohesion in materials

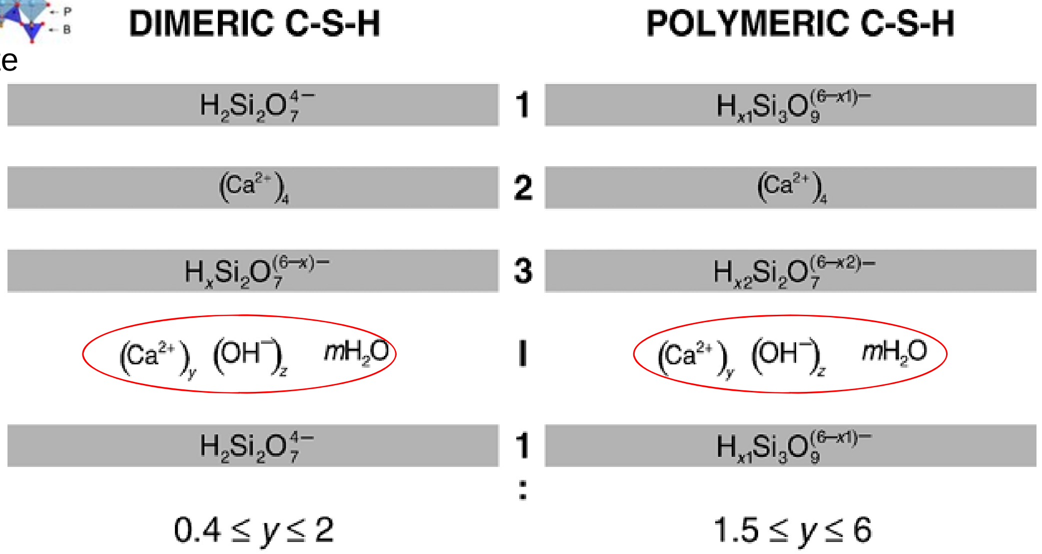
Objective: to develop engineered C-S-H for environmentally friendly concrete

C-S-H: Ca/Si Ratio Dependence



Tobermorite

Ca/Si: 0.7 ~2.3

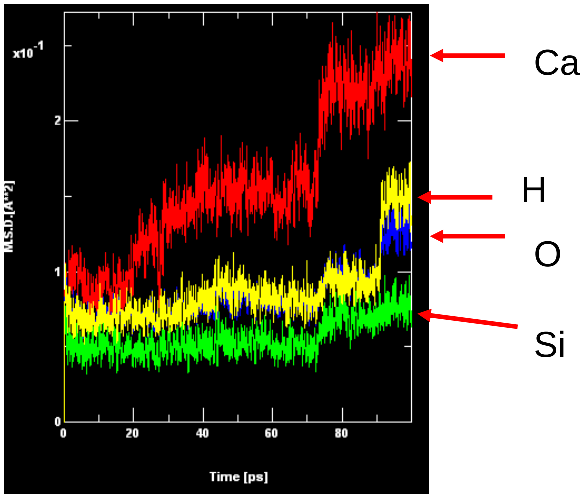


DIMERIC C-S-H		POLYMERIC C-S-H
$H_2Si_2O_7^{4-}$	1	$H_{x1}Si_3O_9^{(6-x1)-}$
$(Ca^{2+})_4$	2	$(Ca^{2+})_4$
$H_xSi_2O_7^{(6-x)-}$	3	$H_{x2}Si_2O_7^{(6-x2)-}$
$(Ca^{2+})_y \ (OH^-)_z \ mH_2O$	I	$(Ca^{2+})_y \ (OH^-)_z \ mH_2O$
$H_2Si_2O_7^{4-}$	1	$H_{x1}Si_3O_9^{(6-x1)-}$
	:	
$0.4 \le y \le 2$		$1.5 \le y \le 6$

How to do for C-S-H? Reducing Ca^{2+} effect, H_2O effect? Stability?......

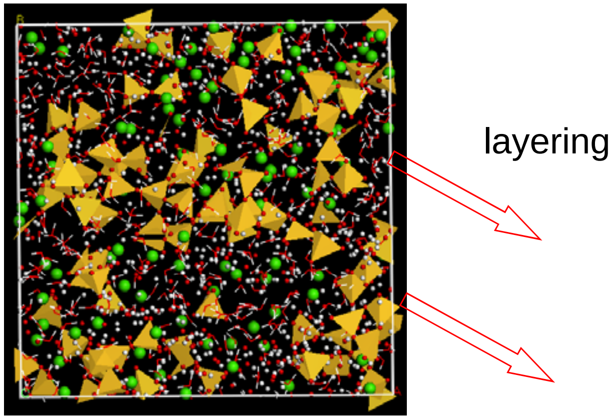
The Hint of Simulation about C-S-H Structure

Q0 - - - -> polymerization vs. Qn - - - - -> structures - - - - - -> properties



Mean Square Deviation

- To form the stability crystal structure
  l = 3 nm, d = 1.66 g/cc
- To form Si-O framework
- Ca moved: $D=3 \times 10^{-8}$ cm^2/s
- H_2O: $D=6 \times 10^{-7}$ cm^2/s



1. C-S-H shows layering and unordered structure, SiO^{-4} framework, Ca and H_2O is distributed in layer.
2. Si-O-Si forms low-polymer, e.g. dimer and pentamer.
3. Initial hydration, Polimerization degree P = 78%, Q0 ~ 22%, Q1 ~ 42%, Q2 ~ 25%, Q-factor ~ 0.6

C-S-H: Qn and Distribution

"lamella nanostructures"

Q^n: chemical shift of a Si bound to *n* bridging O

Q^n distribution:

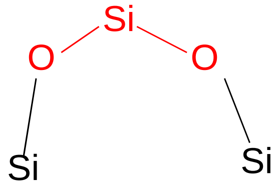
- polymerization degree: P% = 100 - Q^0
- Q-factor: $Q = Q^1 / (Q^1 + Q^2 + Q^3)$

$Si - (OH)_4$ Q^0

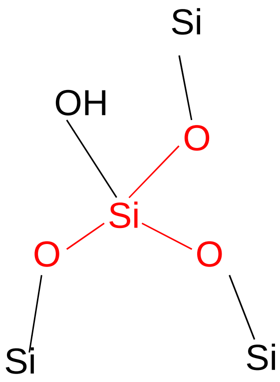
Si - O - Si Q^1

"chain"

"bridging"

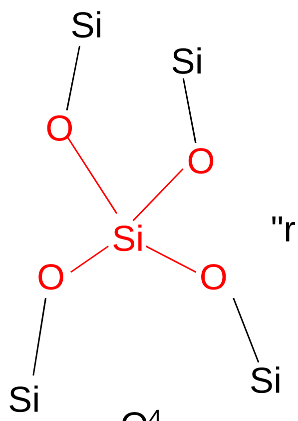


Q^2



"branched"

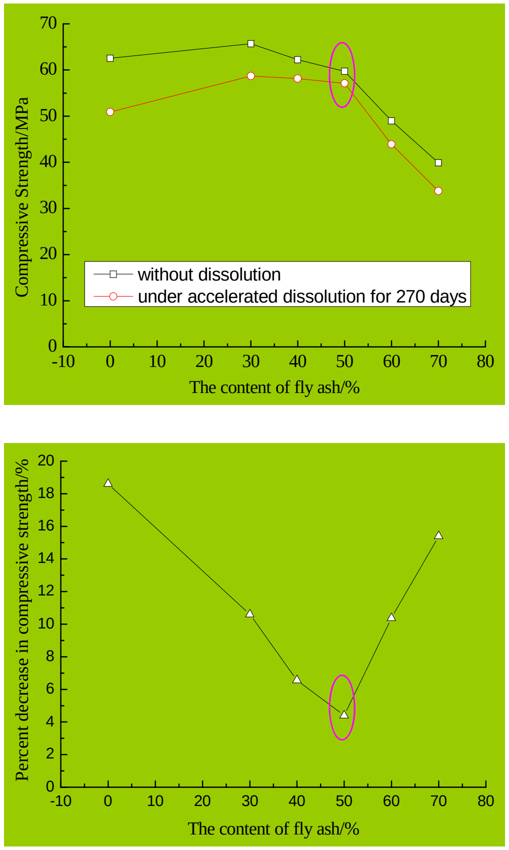
Q^3



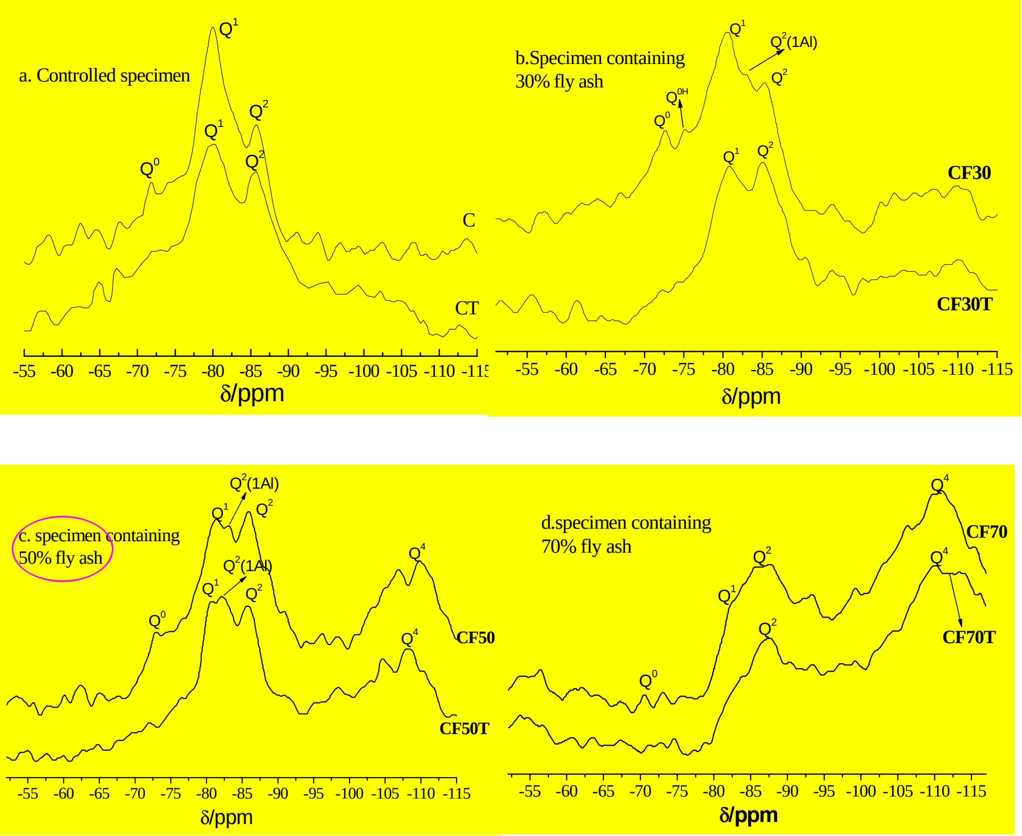
"ring"

Q^4

Proper dosage of FA and engineered C-S-H

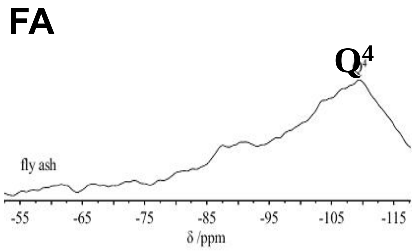


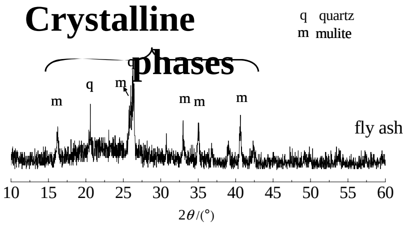
Strength of samples with different contents of FA and the change after accelerated dissolution

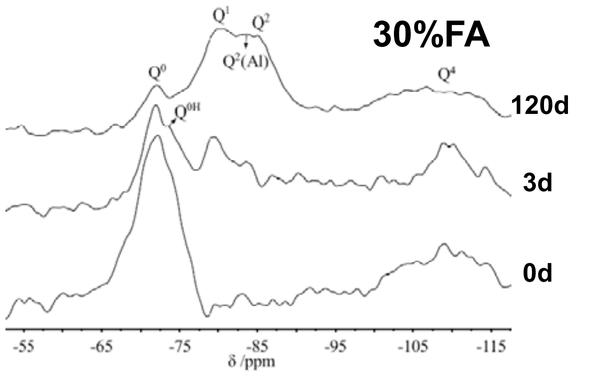


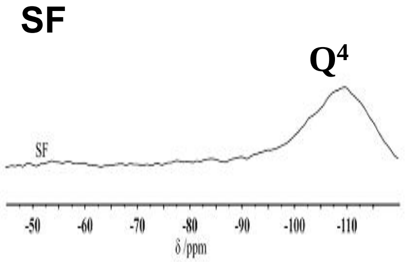
NMR spectrum of samples with different contents of FA

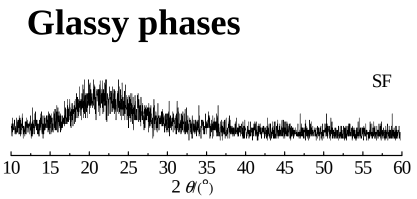
Microstructure regulate

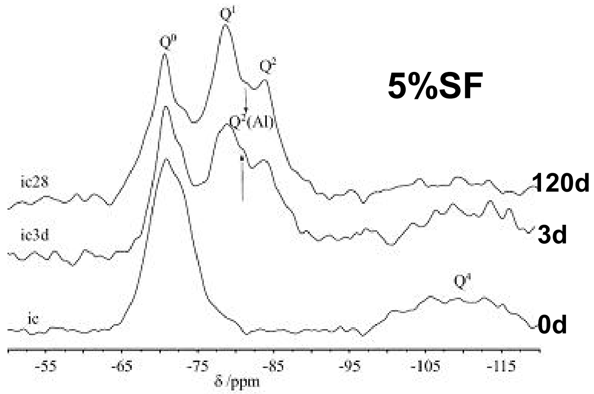












NMR spectrum of samples with FA and SF at different age

3d / 120 d	OPC	OPC With FA	OPC With SF
Q1	31.3% / 55.2%	17.7% /31.4%	24.1 % / 45.0%
Q2	1.9% / 6.8%	2.5% / 12.2%	3.8% / 25.0%
Strength	31MPa / 58MPa	22MPa / 53MPa	42MPa / 61MPa

To close engineering target

No.	W/B	FA,%	SF,%	I (α),%	f, h/cm
H-1	0.32	0	5	0.347	4.85
H-2	0.32	15	0	0.725	2.41
H-3	0.32	30	10	0.557	3.23
H-4	0.30	0	8	0.263	6.74
H-5	0.30	15	10	0.365	4.61
H-6	0.30	30	0	0.701	2.49
H-7	0.28	0	0	0.383	4.45
H-8	0.28	15	5	0.263	6.74
H-9	0.28	30	8	0.443	3.80

- Under the action of high velocity flow carrying sand and gravel on the surface of hydrostructure concrete, a certain strength and corresponding toughness are required.
- With identical aggregate, anti-abrasion strength is very low in the only FA system, such as H-2 and H-8. Thus in order to meet the requirement of anti-abrasion, FA would be denied to use in engineering.
- According to the research of microstructure, the wear resistance and cohesion can be improved after an adjustment of microstructure with SF. Therefore, concrete anti-abrasion strength was improved such as H-3 and H-9.
- In contrast with H-8 and H-4 , their anti-abrasion is quite close, yet due to the utilization of FA in the former system, it is more corresponding with the demand of law-carbon design.

Conclusions

- **To maximize the utilization of industrial wastes and improve strength and durability of concrete, it is necessary to have a C-S-H structure with more Q1 and Q2 content. In this case, the proper dosage of fly ash in concrete is 50% of binder.**
- **In special applications, fly ash should be mixed with other compounds such as silica fume, to increase Q1 and Q2 and extend application area of fly ash to improve abrasion and erosion resistance.**
- **The macrostructure properties of concrete can be enhanced by regulating C-S-H at nano-scale and micro-scale. It is hoped more environmental friendly, high reliable and low-carbon concrete can be produced.**

Thanks for your Attention!

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