HKSAR Standing Committee on Concrete Technology
Annual Concrete Seminar 2010

New Research and Application Progress of High Performance Concrete in China

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Outline

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1. Essence and connotation of development of high and ultra high performance modern concrete
2. Major infrostructure engineering constructions prom te development of modern syructure UPC and UHPC materials
3. Promoting of anti-damage ability, durability and service life is the most important thing for construction of civil engineering
4. Research and state analysis about structure service characteristics of concrete & concrete structure at home and abroad
5. Green and ecological technology of modern HPC and UHPC
6. How to prolong and scientifically evaluate the service life of concrete and concrete structure are the common concerned problems all over the world
7. How to improve the scientificity and reliability of concrete durability evaluation and service life prediction?
8. Research Progress of HPFRC and UHPFRC
9. Conclusions and outlook

1. Essence and Connotation of development of high and ultra high performance modern concrete

Essence of development of high and ultra-high performance modern concrete

- New material technology, information technology and biology engineering are the three big underpinnings of the high new technology. Among them, the new material technology is the basis, premise and core.
- The development, reform, new ideas and creation of the new type modern high performance structure concrete materials are the key and support for great infrastructure development strongly.
- Development of modern high and ultra high performance concrete should have three abilities: anti damage, anti invasion and improvement of durability and service life of concrete, it is vital importance to engineering construction.

Connotation of development of high and ultra-high performance modern concrete

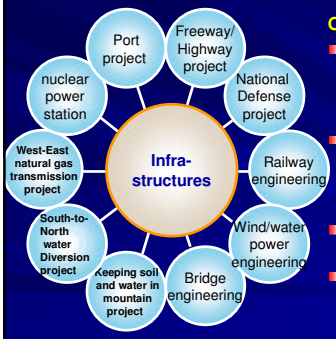
- In order to accordance with the high speed economic growth, great bridges, highway, pavement, high speed railways, nuclear power plants, water/wind power projects, dams are under construction on a large scale in China
- The construction of stride across the big river, clough, channel with big span and ultra big span bridge are increased day by day. China is from construction bridge big country to construction bridge strong country. Su-Tong highway bridge, Hang-Zhou Bay bridge and Da-Sheng-Guan railway bridge are the important symbols

Connotation of development of high and ultra-high performance modern concrete

- With the high speed construction of high speed railway, bridge, tunnel, highway, these projects differ in thus and of ways with different forms. All of these projects formed a big dragon construction. So that ,the construction level of infrastructure in China were promoted to strong country level soon
- Due to different and harsh service conditions, requirements for high and ultra high performance modern concrete become higher and higher

2- Ma[illegible]frostructure engineer[illegible]
[illegible]truction[illegible]romote development of
moder[illegible]ure [illegible]and UHPC mate[illegible]als

Typical examples of infrastructure construction in China

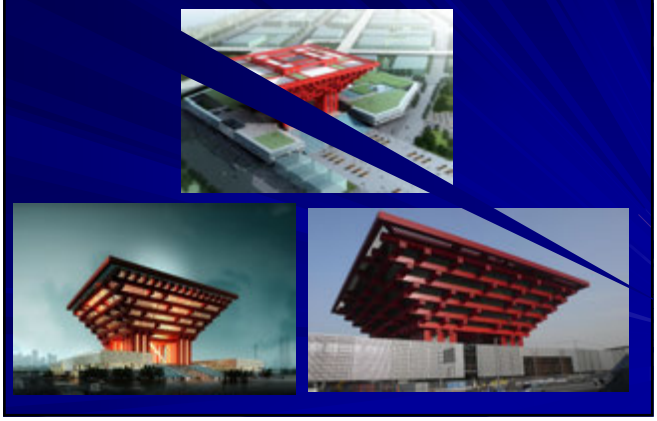


Of particular interests :

- In China, an astounding **RMB 4 trillion** will be invested in infrastructure. And railway construction (300 350 km/h) is the major component.
- Installed capacity of nuclear power has been increased from 2% to 4%. Total investment in 15 years will reach **450 billion RMB**
- Accelerate the construction of **wind power station**
- Current construction of dams and bridges in China account for around 50 per cent of the global total

- Scientific design and maintenance of concrete structures' performance during their service life are crucial for the constructions satisfying their 100 years of designed life.

China Pavilion, Shanghai Expo, 2010



- **Take bridge construction for example:**
  - Over **0.594 million bridges** are standing on 1.8 million kilometers roads in the mainland of China(2008). Among them, more than **717** bridges with length more than1000 meters
  - The designed service life of important bridges is 100 years or more. For example, **Hong Kong-Zhuhai-Macau Bridge-Tunnel project is designed for 120 years.** The different service conditions of every bridge require the properties of materials more and more seriously.
  - 120 bridges will be built at intervals of 30 km along Yangtze River .
  - Our country spent 142 billions RMB to Qiongzhou Channel Chunnel. It s the first and biggest project in China. It will use the newest technology for the construction and makes it s durability can be reached the designing service life.

Statistics o[illegible] the appli[illegible]on of [illegible]C [illegible]hina

Name of prijects	Dosage of UPC(ten thousand m³)	Name of prijects	Dosage of UPC(ten thousand m³)	Name of prijects	Dosage of HPC(ten thousand m³)
Traffic project		Water conservancy		High[illegible]way	
Hang-Zhou bay bridge	245	Three gorges dam	2800	Hu high-[illegible]way	3000
Su-Tong highway bridge	110	Xiang-Jia –Ba water and electricity station(On the stocks)	1600	Wu-Guan[illegible]h speed railw[illegible]	[illegible]0
[illegible]ng	106			Shi[illegible]Wu high speed railway	2[illegible]00
	[illegible]2[illegible]	[illegible]Du water and [illegible]n(On the	1300	Hu-Ning high speed railway	[illegible]00
				Ning-Hang high speed railway	1300
Total dosage of HPC	581	Total dosage of HPC	5700	[illegible]HPC	13400

There are two kinds of HPC: One is high strength with high durability, other is low strength with high durability(the strength grade is from C30 to C60.Table show only a small part information. But the number is large about 2 hundred million m³)

There exist great gap between China and developed countries in basic engineering

Compared with developed countries, the gap of basic project construction in China is still large (take comparing with America for example, according to statistics in 2008)

Highway traffic mileage in American	643 ($\times 10^4$)	Highway traffic mileage in China	187 ($\times 10^4$)	The data of America is 3.4 times
Railway traffic mileage in American	22.7 ($\times$	Railway traffic mileage in China	7.5 ($\times 10^4$)	The data of America is 3 times of China
The number of airport in American	14947	The number of airport in China	467	The data of America is 32 times of China

China's GDP is keeping a high speed growth. According to global investment banker Goldman Sachs, China's GDP will increase from 2,998$\times 10^9$USD in 2010 to 44,453$\times 10^9$USD in 2050. Thus, China's GDP might exceed that of the U.S and would be the largest in the world.

Infrastructure construction on a large scale in China will last for 30～50 years.

Construction of important project and architectural engineering on a large scale has powerfully driven the promoting of cement, concrete and steel output

In 2008, production of cement in China more than 1.4 billion tons(48% of world output), concrete more than 3 billion cubic meters (50% of world output), steel was 0.5 billion tons(38% of world output); Most of these materials were used in infrastructure

Infrastructure construction account for nearly 40 percent of world energy use

Energy saving and emission reduction of engineering construction is an important strategic measure of China

Large amount of CO_2 released during the production of cement, which will increase atmospheric CO_2 concentration and may worsen the environmental conditions

Prolong the service life of structures and replacement of clinker in concrete are efficient measurements to save energy and resources, which help protecting the ecological environment

3、Promoting of anti-damage ability, durability and service life is the most important thing for construction of civil engineering

Typical examples of the degradation of reinforced concrete ahead of time

The dock of Qing-Dao
(service life is only 30 years)

Bridge approach of rainbow bridge in Tian-Jing

The fifth bridge in Tian-Jing

Lao-Gao-Zhai bridge in Tian-Jing

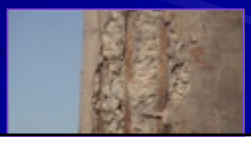
San Mateo-Hayward b… erica…

Typical examples of damaged concrete structures in China

Damaged dock above the ocean

Chloride damaged bridges

Chloride damaged pole in West saline zone



Collapse of FengHuang bridge(凤凰桥) in HuNan Province (2007)

Collapse suddenly during the period of construction

64 people died

Collapse of Jiu-Jiang bridge in GuangDong Province(2007)

Length: 1675.2 meters， width: 16meters， height of the tower: 80 meters。

Start working on September,1985;

Opened to traffic on June,1988。

Won second-class National Scientific and Technological Progress Award in1990;

National Bronze Prize for Excellent Engineering Design in 1991

- The collapse of Mississippi Bridge in August, 1 ,2007, 17 people died
- 79 people injured, 30 people lost, rebuilding cost will be 250 million USD
- It was used for 40 years ,destroyed by fatigue（Actually caused by the couple factors of fatigue loading and environment factors）

Profound Revelation from Concrete Failure Ahead of Designed Service Life

The load capacity and durability are two characteristics of modern concrete and structures with complex components. The value and interaction of them are critical for the service life of concrete structure.

The concrete failure ahead of designed service life are caused by the instability of material property, structure design and construction quality. It is a system engineering to be investigated.

The toughness and crack-resistance are key for the durability, anti accident ability and service life of concrete.

The coupled effects of loads and environment must be considered for improving the scientificity, reliability and accuracy of the predicted service life of concrete materials and structures.

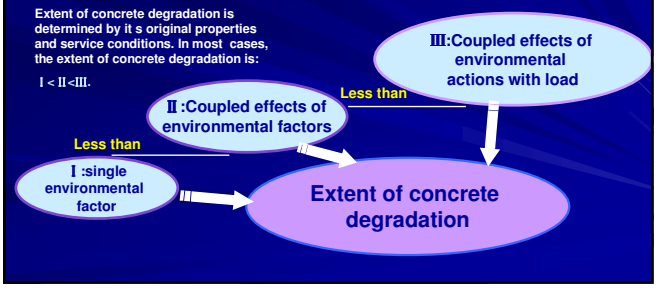
Damaged buildings in Wen Chuan earthquake

Service Life of Structural Concrete & Concrete Structures

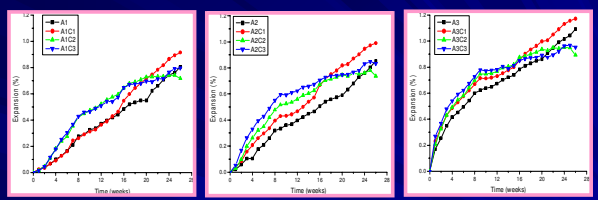
- Service life of modern concrete and structures is determined by two aspects:
  - load capacity (statistic and dynamic loads)
  - Durability (interaction of coupled environmental factors)
- Material properties (especially the toughness) are vital for durability, service life and resistant capability of modern concrete structures.

Extent of concrete degradation is determined by it s original properties and service conditions. In most cases, the extent of concrete degradation is:

Ⅰ＜Ⅱ＜Ⅲ.



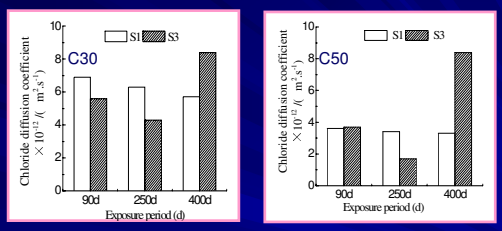
Coupled effects of environmental actions



Damage law of concrete under coupled effects of chloride and alkali-silica reaction

High concentration of chloride substantially speeds up the ASR degradation at early period. However, at a longer time, a moderate concentration of chloride may accelerate ASR expansion to a larger extent.

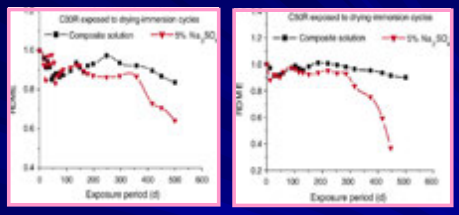
Coupled effects of environmental actions



Chloride diffusion coefficient of concrete in S1 (3.5% NaCl) and S3 (3.5%NaCl-5%Na_2SO_4) solutions

The composition of sulfate into the chloride solution inhabits the ingress of chloride into concrete at early exposure period, but obviously accelerates the chloride diffusion at later period.

Coupled effects of environmental actions

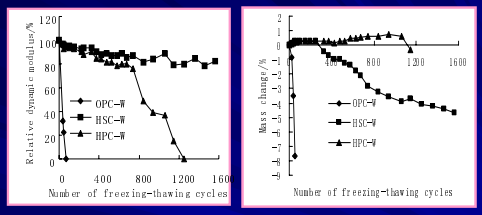


Damage law of concrete under coupled effects of sulfate and drying-wetting cycles

Under the drying wetting cyclic condition:

- Before 100 days, RDME (in sulfate solution) ≈ RDME (in composite solution)
- After 100 days, RDME (in sulfate solution) > RDME (in composite solution)

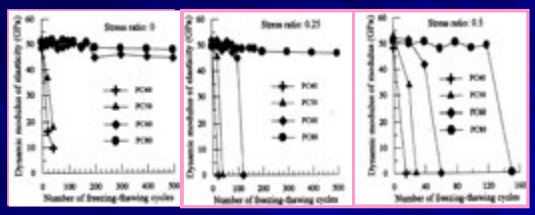
Coupled effects of environmental actions



Damage law of concrete under coupled effects of different material properties and freeze-thaw cycles

Higher quality concrete shows greater resistance to degradation of concrete under the same severe conditions.

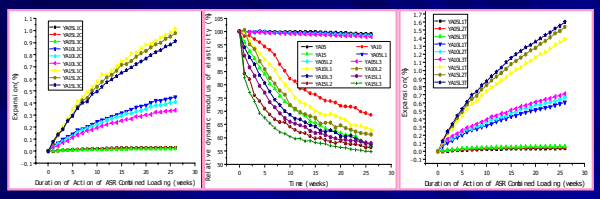
Coupled effects of load and environmental factors



Loss of dynamic modulus of elasticity of concrete under the coupled actions of load and freezing-thawing cycles

- The freeze thaw damage process accelerates with the increase of stress ratio.
- At high stress level (0.5) the HPC fails under freeze thaw cycles.

Coupled effects of load and environmental factors



Damage law of concrete under coupled actions of bending load and ASR

The bending load accelerates the damage degradation of concrete with ASR.

Durability and service life of concrete and concrete structure are the common concerned problems all over the world

Experience and lessons at home and abroad：

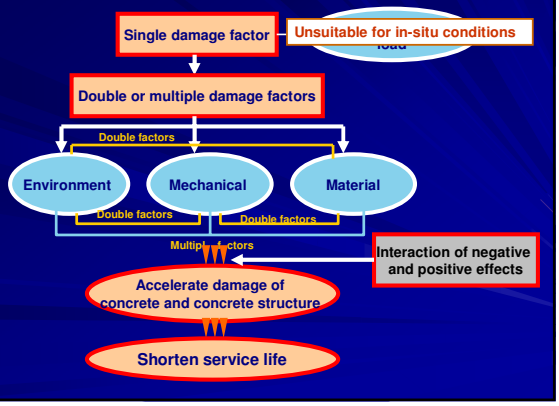
- **The causes of the failure of concrete：** Freeze thaw cycles、wet-dry cycles, carbonation, steel corrosion, alkali - aggregate reaction, chemical corrosion, Seawater Erosion, fresh water corrosion, spalling at high temperature, abrasion, stress corrosion et al.
- **Experience and lessons：**
  In 2008,we got the information there are 600905 bridges in America. Among them, 72868 bridges(12.1%) were deteriorated with different extent, 89024 bridges(14.8%) were lost efficacy.

  There are 11 viaducts(whole long is 21 km), the sum of the cost is 28 million pounds. However, the repair cost is 1.2×10^9 pounds. It is 6 times of the sum cost.

  The direct loss caused by the damage of reinforced structures was more than RMB100 billion per year in China.

4、Research and state analysis about durability and structure service characteristics of concrete & concrete structure at home and abroad

Research and state analysis about durability and structure service characteristics of concrete & concrete structure at home and abroad （1）



Research and state analysis about durability and structure service characteristics of concrete & concrete structure at home and abroad （2）

Our government pay a great attention on the research of the service life of concrete

- 863 projects
  - Basic Research in Low Energy Production and High Efficient Application of Cement
  - Basic Research on Environmental Friendly Modern Concrete
- 973 projects

Abroad research has been carried out about the evolution laws of micro structure coupled load and environment factors and multi-scale modeling, initial research of service properties and service life of concrete material and concrete structure has been carried out. The research of full service life design became a hot topic.

5、Green and ecological technology of modern HPC and UHPC

(1) Significance of green and ecological technology of structural concrete

- The output of the cement and concrete has been risen fiercely, which leads to more energy consumption and environment pollution ,and is harmful to the sustainable development of society.
- Large amount of industrial waste (such as silicon fume, fly ash, blast furnace slag , coal gangue) can replace cement to different extend(15% 85%). Concrete with different performance level and strength grade (C25 C200) has been widely used in the protection projects and infrastructures.
- Due to its outstanding instinct nature and no grinding process, fly ash has been the first choice of the mineral admixture in all kinds of major civil engineering projects. The application of fly ash for big city in China has reached 100%, more than 45% for the whole country. There is urgent need to exploit new residue resources.
- In average, 30%～50% of cement can be replaced by industrial waste. It means that 100 million tons cement clinker can make 140 200 million tons cement, which has outstanding economic and environmental benefit.
- Due to the incorporation of fly ash, some key technical properties (shrinkage resistance, crack resistance, creep resistance, fatigue resistance and durability) are improved.

- In China, there are huge storage of coal gangue, red mud, silica fume (nano-scale) and several industrial waste, especially fly ash, slag, steel slag and so on, because of the industrial development, the number of its production increasing, and now there are more than 7 billion tons and their variety physical structure, chemical composition, hydration mechanism and dosage also affects the performance of different concrete (which has a positive effect, negative effect and the interaction of positive and negative effects).

To maximize the efficient use of industrial wastes to replace the more cement clinker, is an important measure to save resources and energy, protect ecological environment and improve the material properties, also is the only way for sustainable development of society.

(二) Mechanism of the special effect of fly ash on cement & concrete

Effect of fly ash on the macro-properties of modern concrete compared with reference concrete

The substitution of cement by 30% fly ash (by mass) may reduce 30% of dry shrinkage of concrete

The creep value can drop by more than 50%

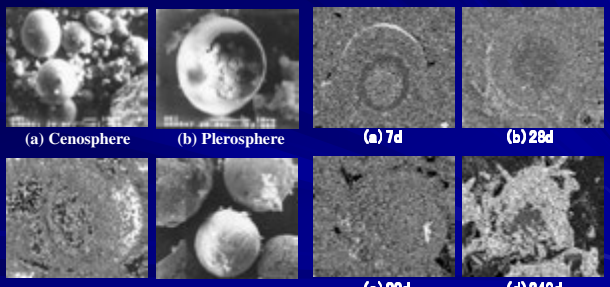
Improve the anti cracking ability (defer the time of cracking, reduce the dimension and quantity of cracks)

The fatigue life of concrete is improved more than 3 times at the same stress ratio

Improve the durability of concrete (except for the freeze thaw ability and carbonization ability)

Mechanism of the special effect of fly ash on cement & concrete

Three special effects of FA (**morphological effect,** pozzolanic effect, micro-aggregate effect)



(a) Cenosphere (b) Plerosphere (a) 7d (b) 28d

(c) Sinksphere (d)Magnetic sphere (c) 90d (d) 240d

Morphology of fly ash particles

Strong chemical bond between fly ash sphere and cement particles

Characteristics of microsphere in fly ash

Cenosphere： lighter than water，more than 65% are hollow，much smaller glass microballoons are compassed in them. They are called mother spheres or multispheres, whose dosage is small in the fly ash, about 0.07% 0.50% of original grays. However its activity has great influence on the performance of the concrete. Their mean diameter is 2.2 22um, and the wall thickness is 0.2 20um.

sinksphere： heavier than water, they occupy more than 90% of the fly ash. Their compressive strength can reach 500 700MPa，which make them important to develop the micro aggregate effect. They have irregular protruding points on their surface. There are pores on the wall. Most of them are hollow, with smaller glass microballoons in them too.

Magnetic sphere： iron rich sphere， 1.5% of them are iron rich , 55% is Fe_2O_3. They are magnetic, so they are called magnetic sphere. Their shape is nearly spherical and they are bonding with each other for their magnetism. They are also hollow inside, just like cenosphere.

Predominant contribution to macro properties of sink sphere

Its content in fly ash is over 90%

It has high strength （500～700MPa） and high elastic modulus

It can form strong chemical and physical binding with cement matrix and hydration products

It can strengthen the ITZs (microsphere～C S H gel, fine aggregate～matrix, coarse aggregate～motar)

6、How to prolong and scientifically evaluate the service life of concrete and concrete structure are the common concerned problems all over the world

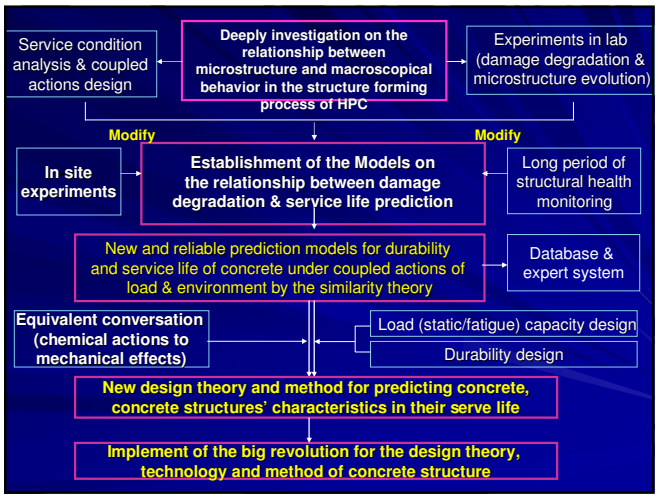
How to prolong and scientifically evaluate the service life of concrete and concrete structure are the common concerned problems all over the world

- **Service life of concrete**：from use to failure；
- **Designed service life (British standard)**， civilian construction ,60 years; Airport Pavement, 15～20 years; industrial building, 30 years; Ocean Engineering, 40 years; the Hall of Justice and prison, 100 years; bridge, 120 years; monumentality architecture , 200 years;
- **long-life projects**，North Sea oil platform (United Kingdom) English, Akashi Kaikyo bridge (Japan), Union bridge (Canada), 100 years；Shield tidal barriers (the Netherlands), 250 years；Macau Tower (Macau), 150 years; Tsing Ma Bridge (Hong Kong) , 120 years；King Fahd Causeway (the Kingdom of Saudi Arabia and the Kingdom of Bahrain), greater than 120 years. Service lives of subways and bridges in china are designed in 100 years or more.
- **Two problems:** How to guarantee the service life of concrete and concrete structure? How to predicting the remaining service life of concrete structure?
- **In the final analysis:** Lack of new theory and method for scientifically evaluating the durability and service life; Lack of maturity whole service life theory and technology for reinforced concrete structures.

Questions that we should answer

- How to guarantee the service life of concrete and concrete structure （Take material, structure, construction and repairing as an integral science and systems engineering to implement . Design theory and method based on the life cycle ）
- How to predict the service life of concrete and concrete structure （fully consideration the deteriorations process and the mechanism of micro structure evolution of concrete and concrete structure deterioration coupled load and environment factors. ）fully consideration to concrete and concrete structure
- How to evaluate the durability of structural concrete and concrete structure （Establish the new theories, new methods and new systems of concrete durability evaluation coupled mechanics (dynamic load and static load) and environment factors. ）
- How to improve the capacity of anti-disaster of engineering, anti-invasion of modern weapons and anti-coupling factors from the view of concrete material. In situ toughened improvement is the critical issue.
- Strengthen the quantitative description of the relationship between micro-structural evolution and macro-behavior of the entire process of structure formation and degradation of cement-based materials.(Constitutive between micro structure and mechanics, constitutive of micro structure and transport, research of multi scale modeling of micro structure and service life prediction)

7、How to improve the scientificity and reliability of concrete durability evaluation and service life prediction?



Healthy development of HPC and sustained innovation must seize the fundamental research

- Strengthen the environment-friendly, ecological of concrete material in basic construction of modern structure， Strengthen the basic theory and research of In-situ toughening technology is essential.

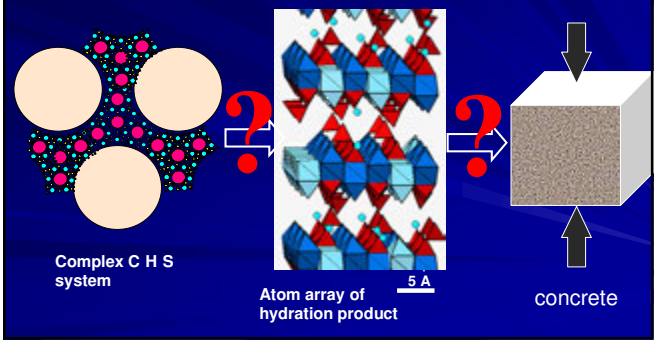
Fully utilize industrial waste ; **Minimize** the assumption of cement ⇒ energy saving and emission reduction

- Improvement of durability; Prolong the service life of concrete; combination of structure, material and construction ⇒ effective ways for energy saving and emission reduction
- Improvement of anti-damage ability and anti-invasion ability of modern weapons ⇒ the safety of the people's lives and property

Strengthening the basic study of modern concrete brooks no delay !

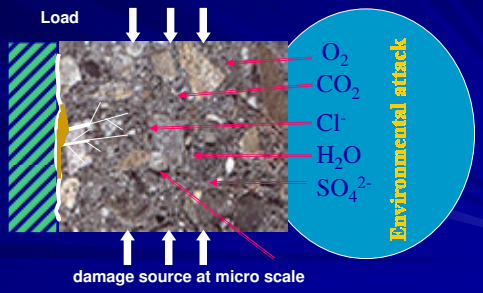
Issues for Immediate Attention Ⅰ:

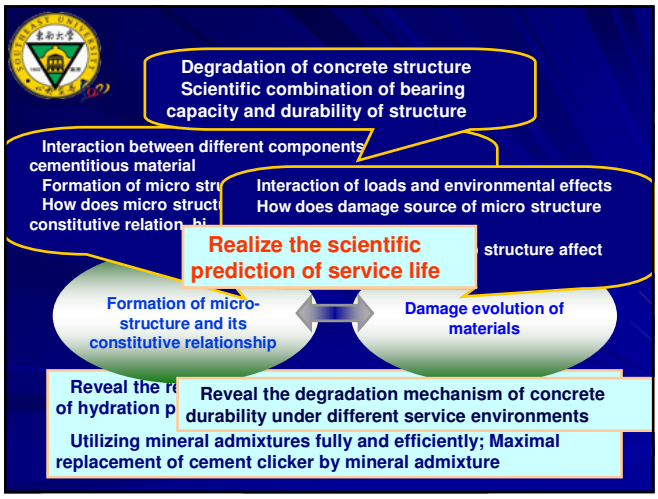
formation mechanism of microstructure of calcium silicate hydrate (C S H)

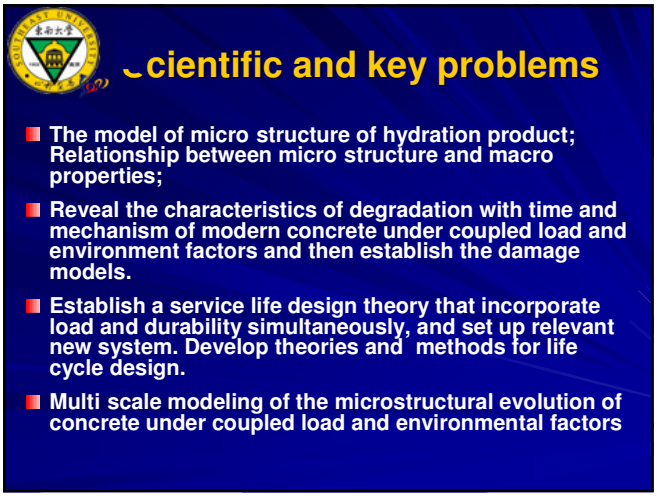


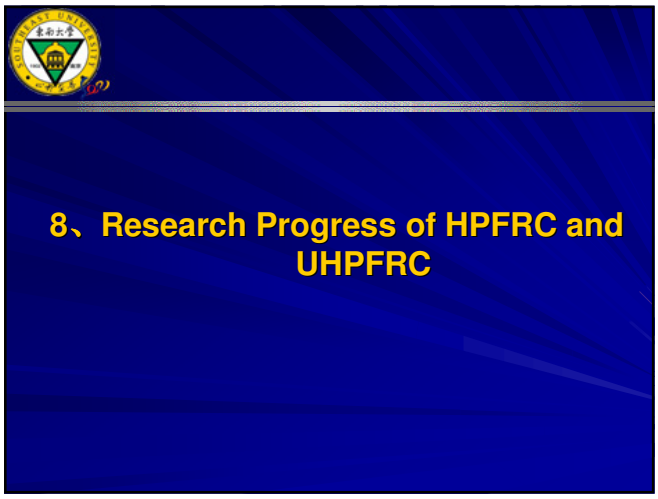
Issues for Immediate Attention Ⅱ:

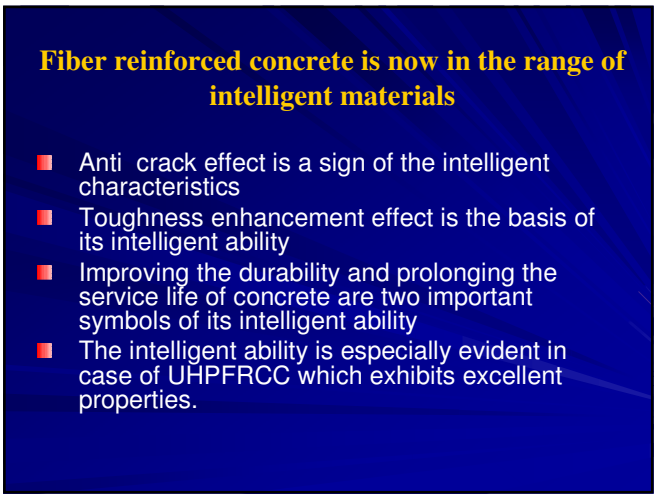
Damage evolution of modern concrete











（1）Past, present and future of UHPFRC

1. **Past of UHPFRC（Science 1980's）**

- MDF（Macro Defect Free cement）
  It is composed by cement, polymer and water, and its compressive strength and flexural strength can run up to 300MPa and 100～150MPa respectively, fracture energy 3KJ/m^2. The ratio of flexural strength to compressive strength can reach 1：3 and1：2. However , due to its intrinsic limitations, such as complicated preparation and curing process, gradual deterioration of long term performance ,low moisture resistance, low performance cost ratio, and indistinct structure and property formation mechanism, it has been out of date.
- DSP（Densified System Containing Homogenously Arranged Ultrafine Particles）
  It is composed by cement, ultrafine particles (silica fume or fly ash), water and fiber, with compressive strength 350MPa. But similar to MDF, it has complicated preparation process, poor workability and durability, especially low moisture resistance. All these limitations narrowed its application prospect.

(2) Development of UHPFRC

- **SIFCON and SIMCON（Slurry-infiltrated-fibered concrete and slurry infiltrated mat concrete）**
  They are effectively enhanced by fibers, but they are still difficult to be applied on a commercial scale for its complicated preparation process and low performance cost ratio.
- **RPC（Reactive Powder Concrete）**
  RPC , a type of new material occurred in the 1990s, is composed by cement, ultra fine grinding quartz powder, large volume of silica fume and super plasticizer. It has no coarse aggregates, with ultra fine grinding quartz powder （ particle size less than0.6mm） as fine aggregates. It has three grades: RPC800、RPC400 and RPC200. Owe to its excellent workability , mechanical properties, dynamic behaviours and super high durability, it has been a type of ultra high performance cement based composite, which can act as a counterweight to the widely used metallic materials and polymer materials. However , fibers must be added to its matrix so as to make the most of its advantages.

Comparison of RPC and OPC

Conventional Concrete plate
(Length:60cm;Thickness:3cm)

Reactive Powder Concrete plate
(With the same size)

Provided by Prof. Chen Zhen Chuan, Taiwan University

Application in the world

Seonyugyo Bridge, Korea

Sherbrooke Footbridge , Canada

The Shawnessy Light Rail Train Station in Calgary

unique, innovative creations

Undergroud railway station in Monaco

- Easy to install
- Lightweight
- Beautiful
- Durable

Acoustic panels

Panels ——an average of 2.30 m by 1.80 m, with 20-mm thickness in the solid areas and 15-mm thickness in the perforated areas.

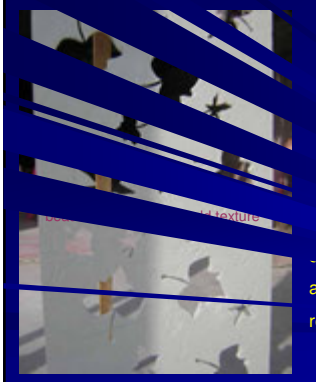
The new bell tower in Lavai, Canada

Reinforcement of ... clinker silo at the Lafarge plant in ... Couronne

...degree temperature difference between the interior and exterior surface

Wind power

wind turbine foundations



and reduce the risk of ... filling,

resulting in exceptionally uniform surfaces

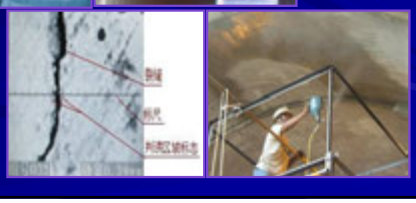
Application of HPFRC、UHPFRC in china

Pavement cover plate in high speed railway

Compressive strength≥130MPa、Flexural strength≥18MPa、 Modulus of elasticity ≥48GPa、 Penetration quantity of chloride ions＜40Coul、 Frost resistance grade >500

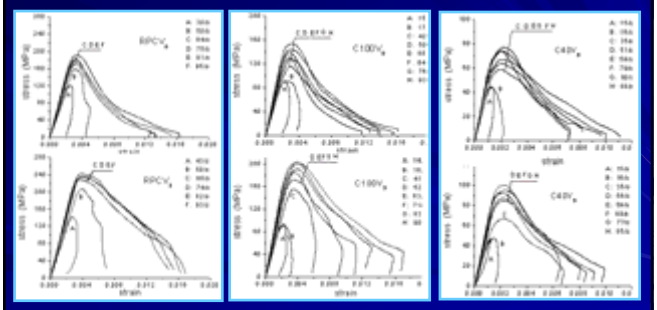
Application of HPFRC、UHPFRC in china

Fiber reinforced concrete used in Gui-Guang railway tunnel



Application of HPFRC、UHPFRC in china

Eco-UHPFRC used in defense works



ECO-UHPFRC　　HPSFRC100　　SFRC40

Damage pattern of samples subjected to compressive impact

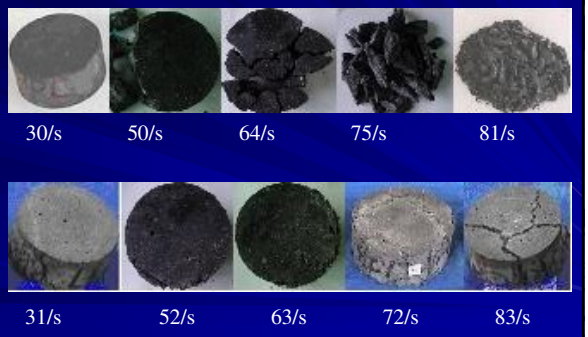
Specimen before impact

$C40V_0$　$C40V_2$　$C40V_3$

$C100V_0$　$C100V_2$　$C100V_3$

$UHPFRCV_0$　$UHPFRCV_3$　$UHPFRCV_4$

Damage pattern of ECO-UHPFRC at different stain rate



Anti-penetration of ECO-UHPFRC

CF40 C100 ECO-UHPFRC

Velocity of the projectile is 850m/s

Anti-explosion performance of ECO-UHPFRC (Back face of the targets)

CF40 C100 ECO-UHPFRC

Dosage of TNT is 2.0kg

- **Deficiencies of RPC**

  Ultra fine powders are expensive and energy consuming during grinding; super fine metal fibers are also costly, so its performance cost ratio is very low. Not only RPC800、RPC400 are hard to be widely used in the actual projects, but also RPC200 is difficult to be applied.

- **Tendency of RPC**

  In order to improve its performance cost ratio, broaden its application, the superior properties of RPC can be fullly performed by exploiting the physical and chemical nature of the ultra fine industrial waste, replacing more cement , ameliorating the material composition and microstructure , optimizing the fiber dimension and shape and optimizing the curing process.

(4) The future of ECO-RPC and ECO-UHPFRC

- Exploit the combined effect of the industrial waste fully and efficiently, so as to make the material more ecological and environment friendly.
- Optimize and enhance the three level interface structure to make full use of the intelligent ability.
- Utilize the Superplasticizer whose water reducing rate can be more than 40% to enhance the self leveling behavior of ECO UHPFRC.
- Incorporate high strength coarse aggregates to improve the performance cost ratio of UHPFRCC.
- Reveal the mechanism that contribute to its excellent durability, which can shed light on its extensive application in infrastructures, protection projects and special products.

9、Conclusions and Outlook

Conclusions

- Based on the present and future research achievements, it is necessary to establish new theory and methods to scientifically design the concrete structures which are exposed to coupled environment and mechanical actions.
- Based on the porous medium theory and thermodynamics, the chemical actions can be equivalently transferred to the corresponding mechanical effects, which can serve as a basis for innovative unification of durability design and bearing capacity design.
- Strengthen fundamental research in the field of HPC, and establish relationships between micro structural evolution and macro behavior of the entire process of structure formation and degradation of cement based materials.
- In order to ensure the realization of designed service life in HPC engineering, material, structure and construction should be considered simultaneously as an indivisible system project

Outlook

- Introduction of nano science and multi scale simulation technology into the field of concrete science is an important measure for adequately explaining the mechanisms of microstructure evolution/degradation and for discovering the quantitative relationship of microstructure degradation and concrete behavior.
- The experiment and modeling on the relations of microstructure degradation and macro durability, are primary for improving the service life of concrete and reinforced concrete structures.

ks for Your Kind Att ntion!

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