# Strategies for Shrinkage Cracking Mitigation of Concrete

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# Outlines

- Background
- Multi-field coupling prediction model
- New technologies for shrinkage crack mitigation
- Typical applications
- Conclusions

# 1 Background

- Modern concrete, benefited from the wide use of chemical admixtures and industrial waste residues, can reduce the consumption of resources, and meanwhile meet **the performance requirements of modern civil engineering with** improved durability and other properties

**Conventional concrete**

- Cement
- Sand
- Coarse aggregate
- Water

Chemical admixtures

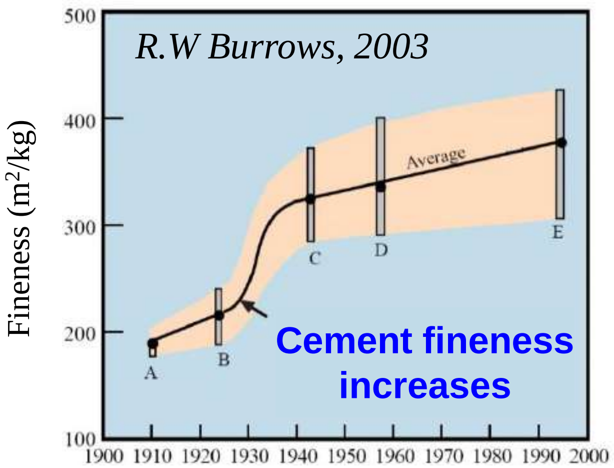
Optimization of concrete mix proportion, preparation, and construction technologies

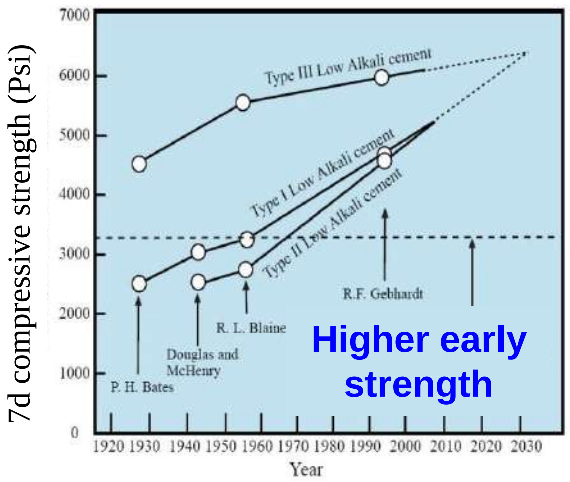
Mineral admixtures

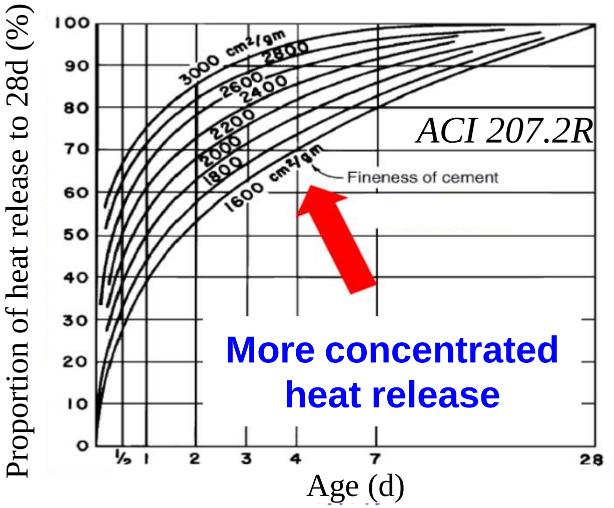
**Modern concrete**

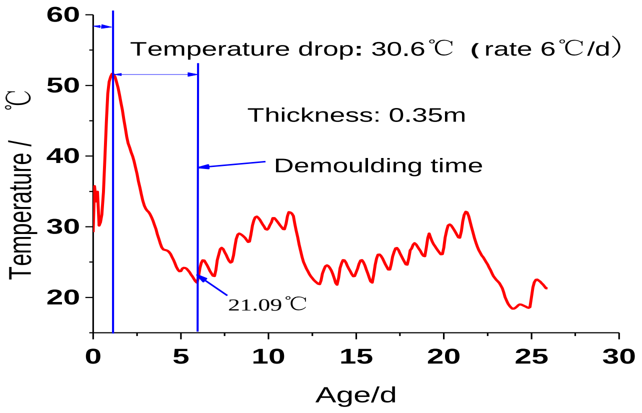
| Compositions characteristics | Performance characteristics |
| --- | --- |
| • Complex composition<br>• Lower w/b<br>• Higher paste volumes | • Large flowability<br>• Enhanced strength<br>• Improved durability |

- The fineness increase and significant mineral composition changes of cement result in a rapid and concentrated heat release at early-age hydration



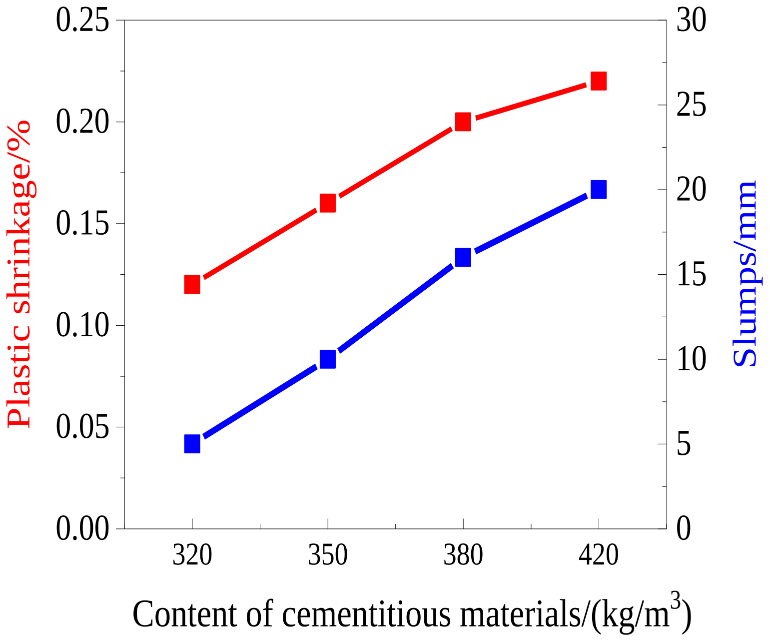

| Cement fineness and composition | Cracking temperature |
|---|---|
| Fineness increases from 280m²/kg to 380m²/kg | Increased by 9.5 ºC |
| $C_3A$ content increased by 4% | Increased by 6 ºC |

**Concrete temperature reaches the peak at about 1d, and internal temperature is over 70℃**

# Background

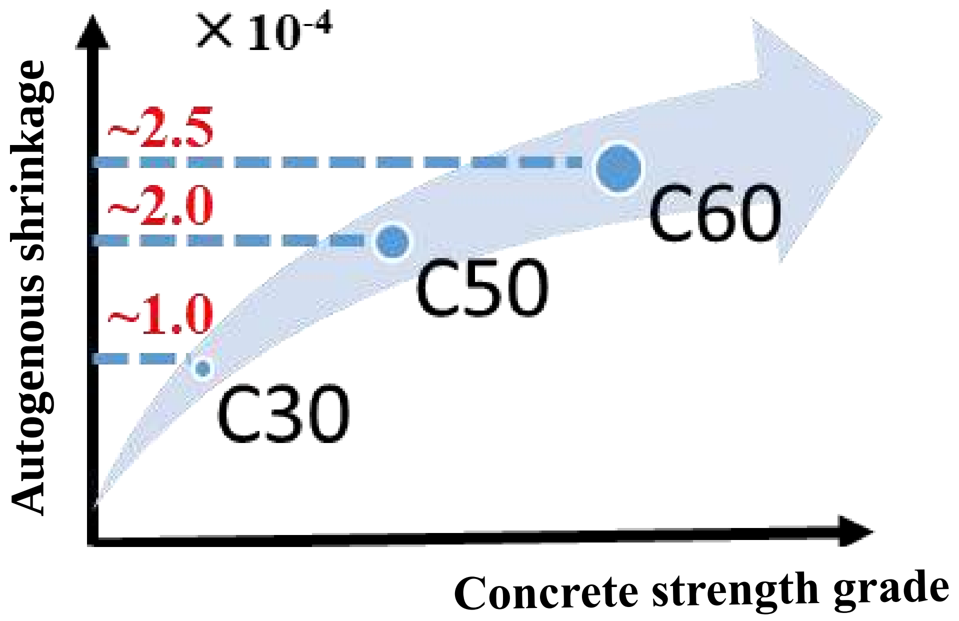
## Engineering status

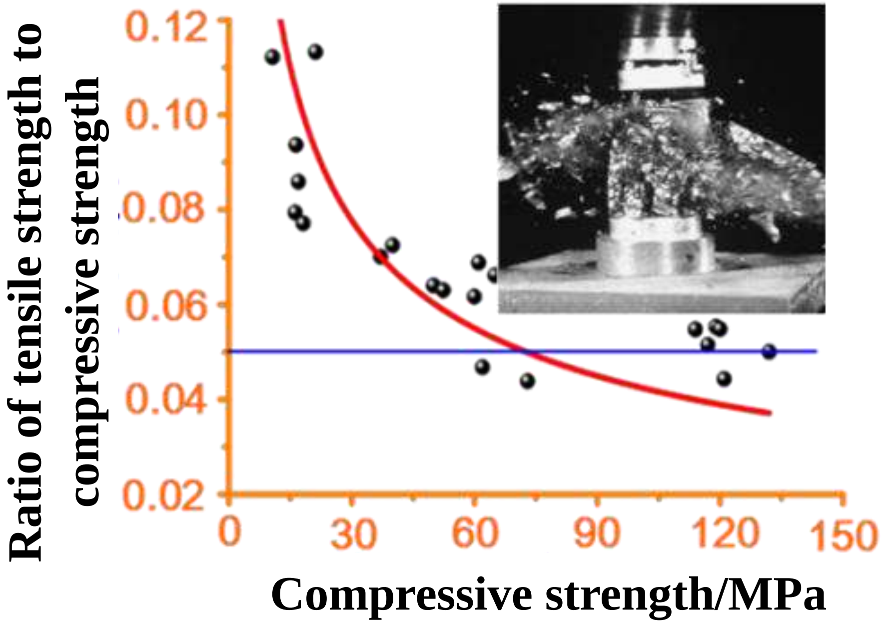
- The flowability of concrete increases, resulting from a decrease in coarse aggregate content and an increase in binders and fine aggregate content, leading to typical increase in shrinkage




**Value of plastic shrinkage doubles**

- The increment of concrete strength also leads to the increase of autogenous shrinkage at the early ages, and also decrement of the toughness

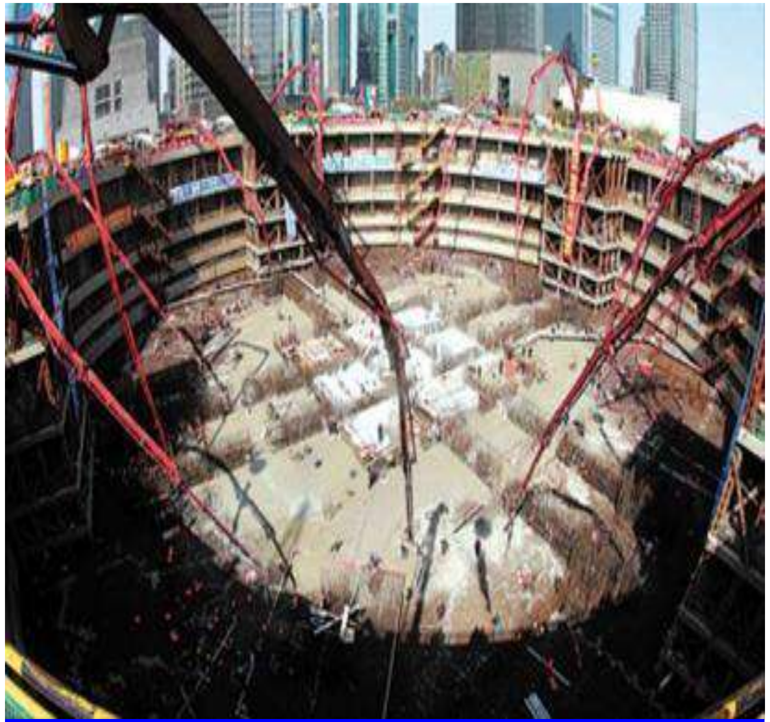


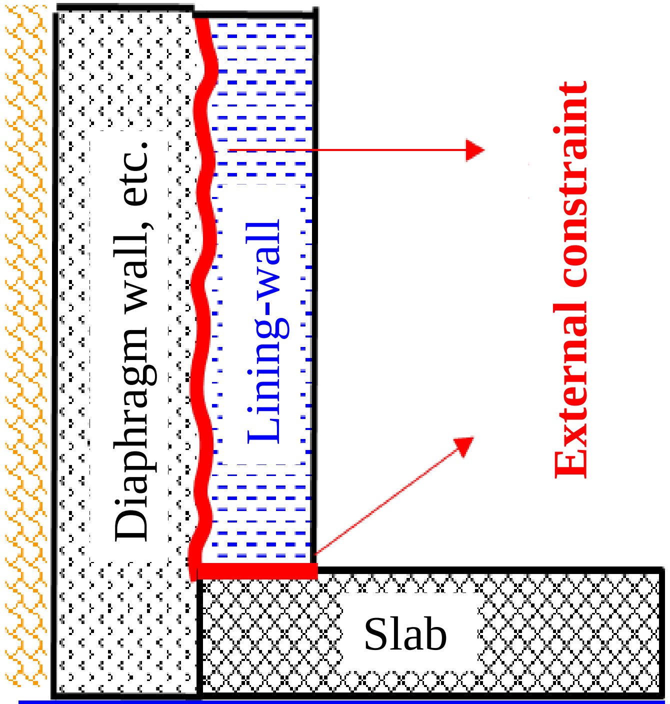




- The value of autogenous shrinkage doubles, and shrinkage at early ages (28d for ordinary concrete, 60d for mass concrete) accounts for more than 90% of the total shrinkage
- The tensile-compressive strength ratio of C30 is about 1/10-1/12, and that of C60 is about 1/16

- **Shrinkage stress is much higher in modern structures with long spans, large volumes and strong constraints**


Long spans


Large volumes



Strong constraints

# Large shrinkage and strong constrains lead to prominent shrinkage cracking problems in modern concrete structures

- **Bridge deck: Over 50% are cracking quickly after construction** (data from P. K. Mehta and R. W. Burrows)
- **Cast-in-place sideway wall: over 90% are cracking** (data from an investigation report by Special Committee of Jiangsu Urban Rail Transit Construction)

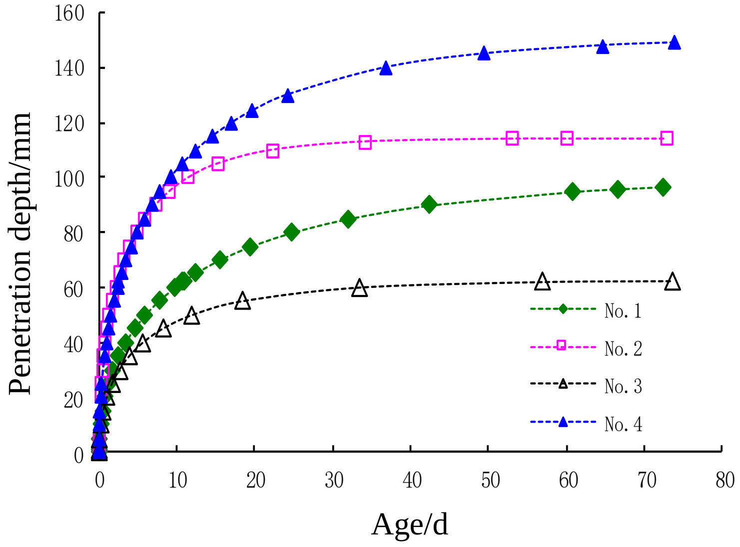
**Shrinkage-induced cracks account for more than 80% of cracking in concrete**

# Background

## Impact of cracks on service performance

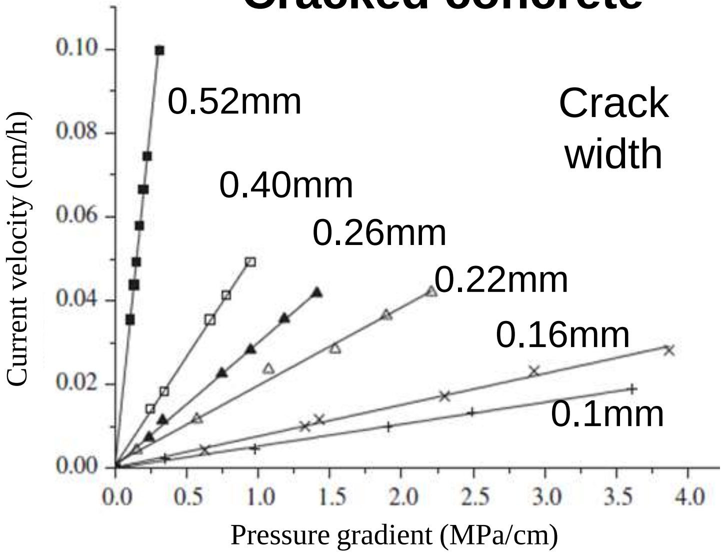
- Through cracks of concrete will lead to a sharp increase of permeability, causing leakage and other problems, which seriously affect the service performance  of the structure

**Uncracked concrete**




Modern concrete with strength grade ≥ C30 fully meets the requirements of self waterproofing

**Cracked concrete**




The permeability coefficient of the 0.1mm-width through crack is $10^8$ times of that in the matrix

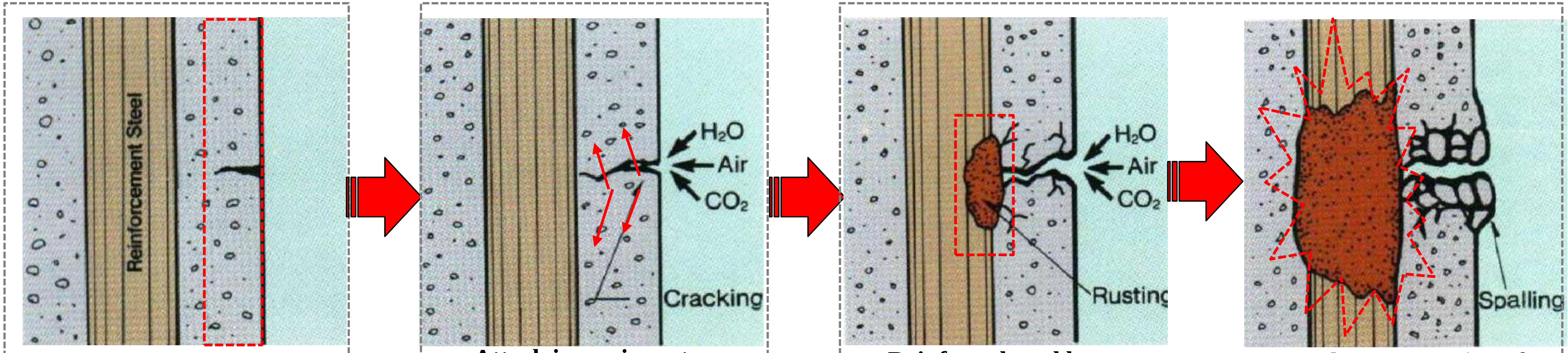
**Cracking is the dominant factor for leakage in modern concrete structures**

# Background

## Impact of cracks on concrete durability

- **Cracks accelerate the transmission of aggressive medium and will shorten service life of structures**
  - Stage Ⅰ—Reducing the effective thickness of cover depth
  - Stage Ⅱ—Accelerating the transmission of attack ions, air and water within the concrete structure
  - Stage Ⅲ—Shortening depassivation and corrosion time of reinforcement, reducing the service life of structures

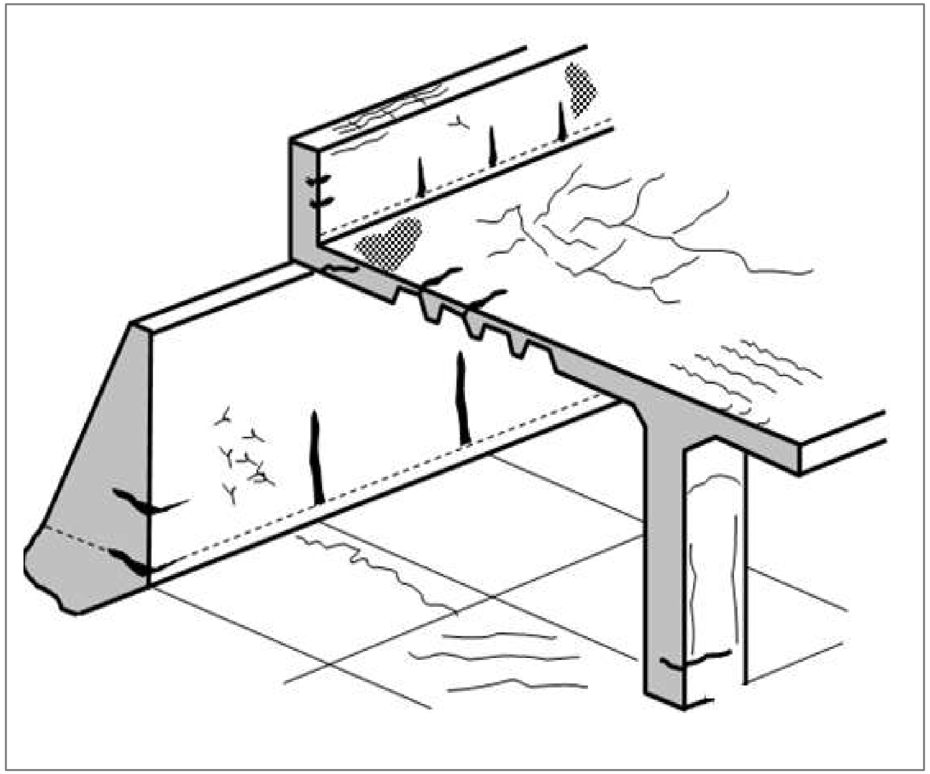
**Stage I** | **Stage II** | **Stage III**




Concrete cracking | Attack ions, air, water ingress into concrete | Reinforced steel bar starts to rust | Volume expansion of reinforced steel bar

**Seriously affecting the safety of structures**

- Due to the characteristics of multiple influencing factors, complex structural constraints, and long duration



| Multiple types of shrinkage | Greatly affected by environment | Complex structures |
|---|---|---|
| ■Plastic shrinkage<br>■Auto. shrinkage<br>■Drying shrinkage<br>■Thermal shrinkage | ■Ambient temp.<br>■Ambient humidity<br>■Curing technology | ■Long spans<br>■Large volumes<br>■Strong constraints |

Plastic stage — Hardening stage — Performance stable stage

Lasting for days or even months

**Shrinkage cracking remains a challenging task that has long plagued in engineering without any effective solution**

# Research ideas

## Three major bottleneck issues of shrinkage cracking

Materials-Structure-Environment

| | | |
|---|---|---|
| Theoretical methods | Quantitative estimation of cracking risk | "Diagnosis" |
| Functional materials | Reduction of shrinkage in whole process | "Pharmacy" |
| Applied technology | Full-stage cracking risk control (FCRC) | "Treatment" |

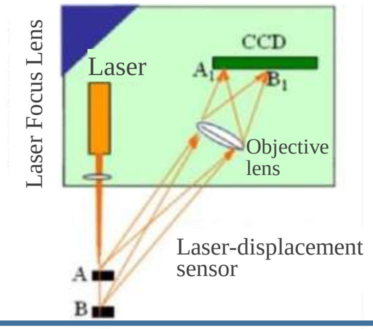
## Fundamentally mitigating the shrinkage cracking of concrete

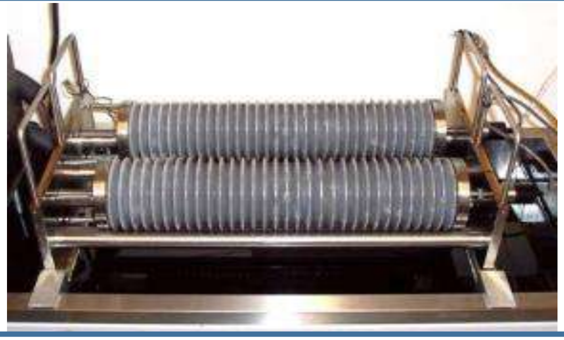
# 2 Multi-field coupling prediction model

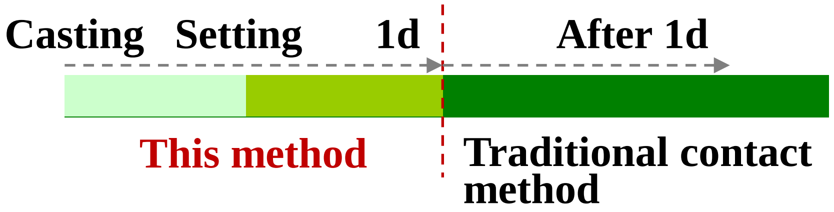
# Plastic stage

- A non-contact laser displacement testing system was invented to achieve phased and whole process shrinkage measurement starting from concrete casting

## Test device






## Test results

**Autogenous shrinkage prediction model:**

$$\varepsilon_r(t) = \int_{t_0}^{t} (1-2\nu)\left( \frac{1}{E(t')} + \varepsilon_\infty^0(t') \frac{(t-t')^{\alpha(t')}}{(t-t')^{\alpha(t')} + b(t')} \right) \cdot d\sum{}^{s}(t')$$

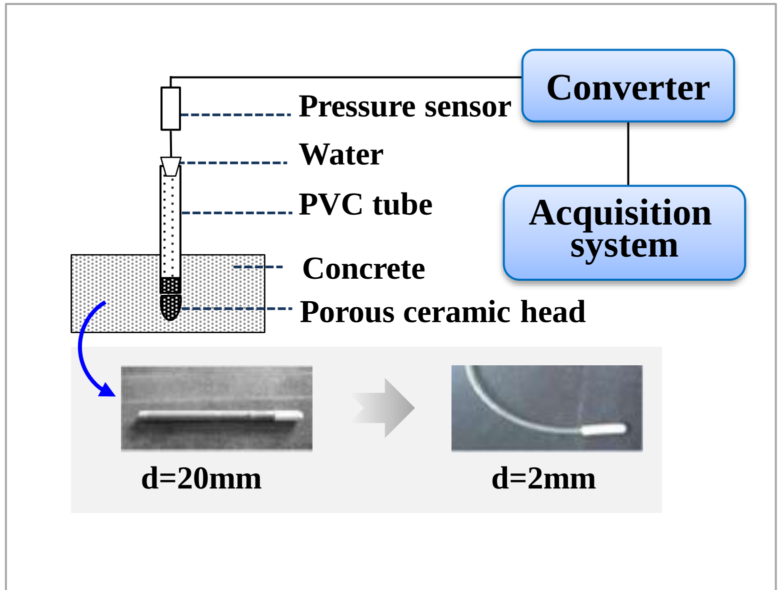
| Strength grade | C30 | C50 | C80 |
|---|---|---|---|
| Proportion | >30% | >50% | >60% |

The proportion of 1 d autogenous shrinkage to that of 28 d

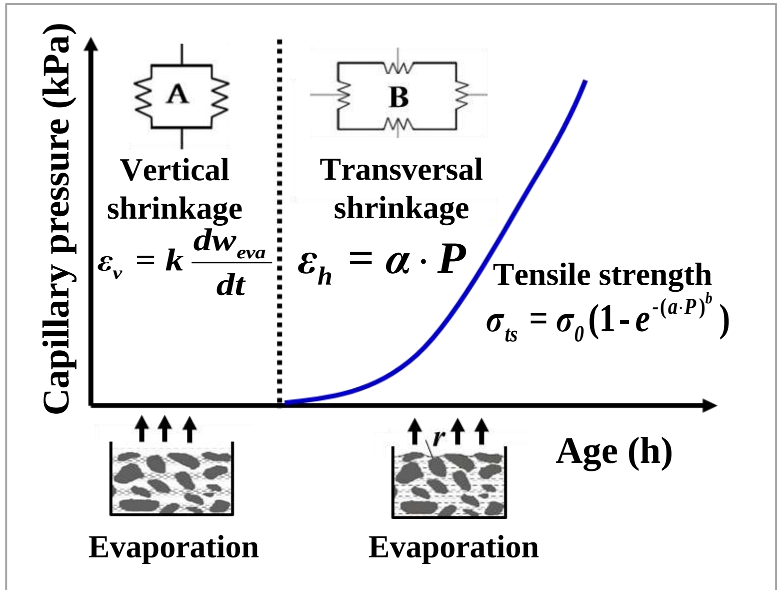
**Significantly reduces the error of shrinkage prediction model**

# Plastic stage

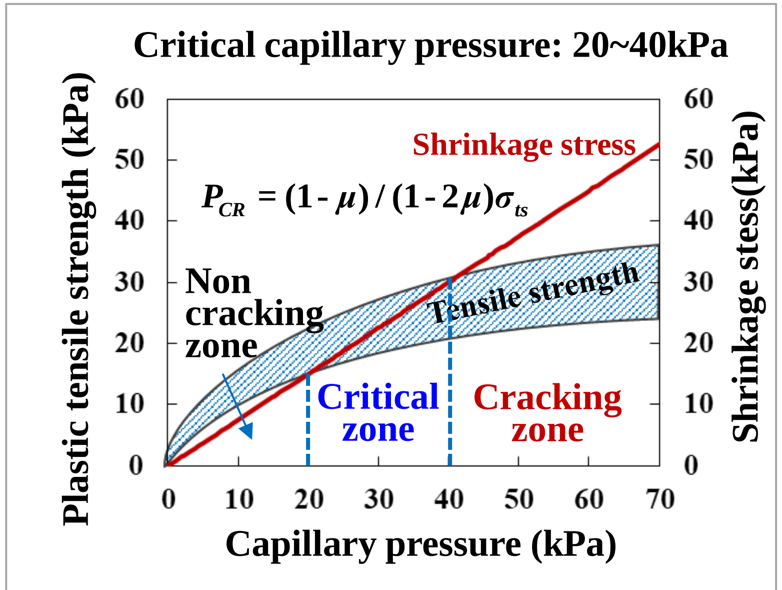
- A capillary pressure testing system was invented to quantify the relationship between capillary pressure and shrinkage / tensile strength. Cracking risk prediction model before hardening was then proposed




Capillary pressure testing system




Shrinkage & tensile strength before hardening



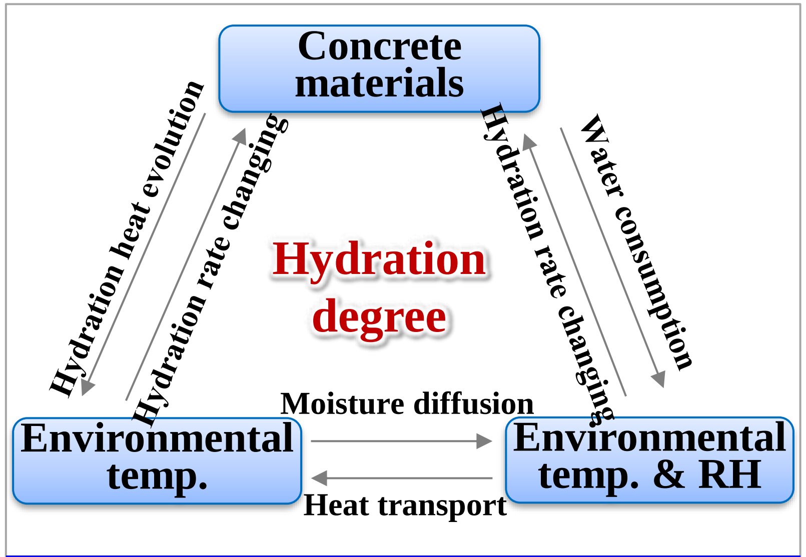

Cracking risk prediction model before hardening

**First realize the characterization of shrinkage driving force during the stage with high humidity**

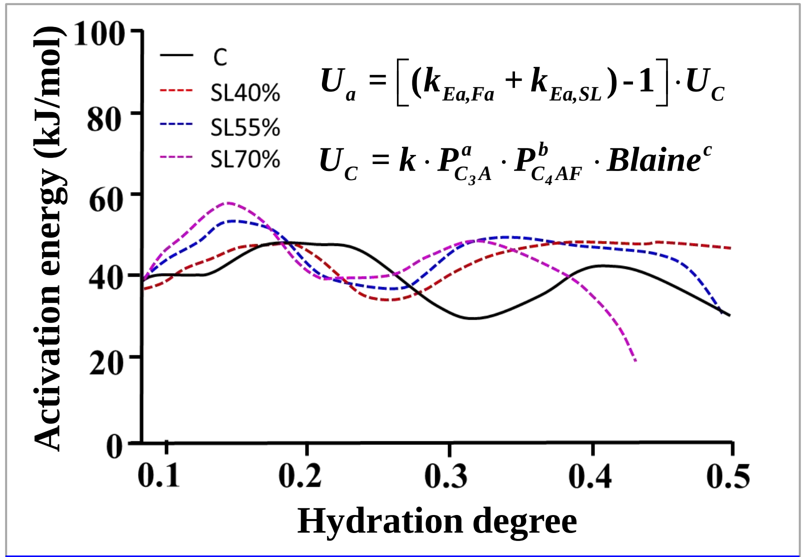
# Multi-field coupling model

## Hardening stage

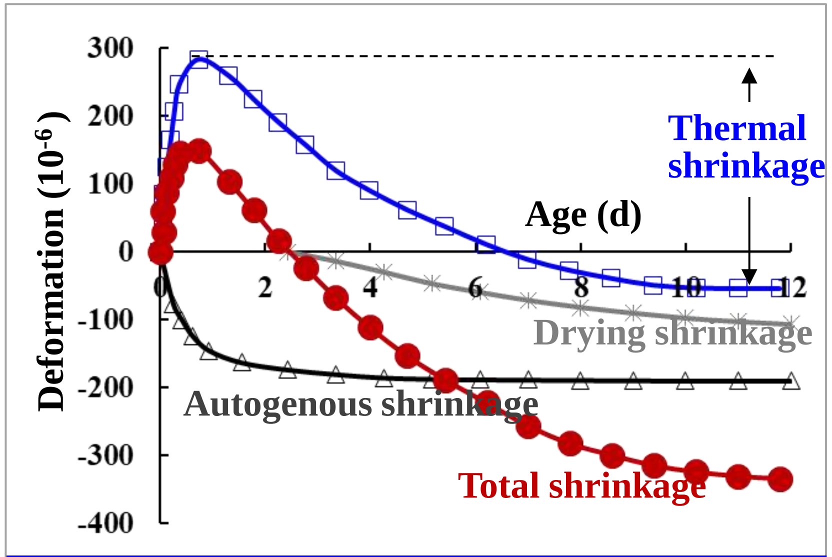
- A formula was derived for calculation the activation energy of the hydration reaction of cementitious system containing SCM, in which **hydration degree** was adopted as the **key parameter** to describe the evolution of concrete properties, and the complex interaction between materials and temperature & RH.




Complex interaction between materials and environment




Hydration activation energy of complex cementitious system



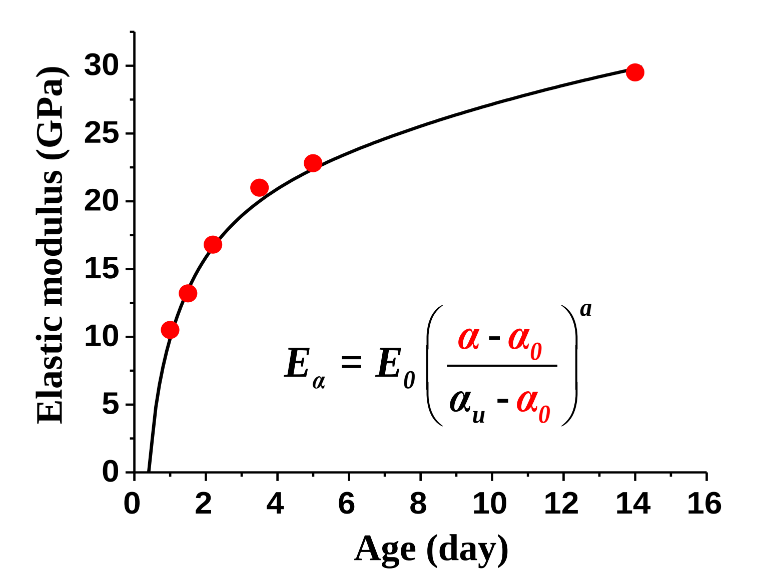

Coupled calculation of shrinkage

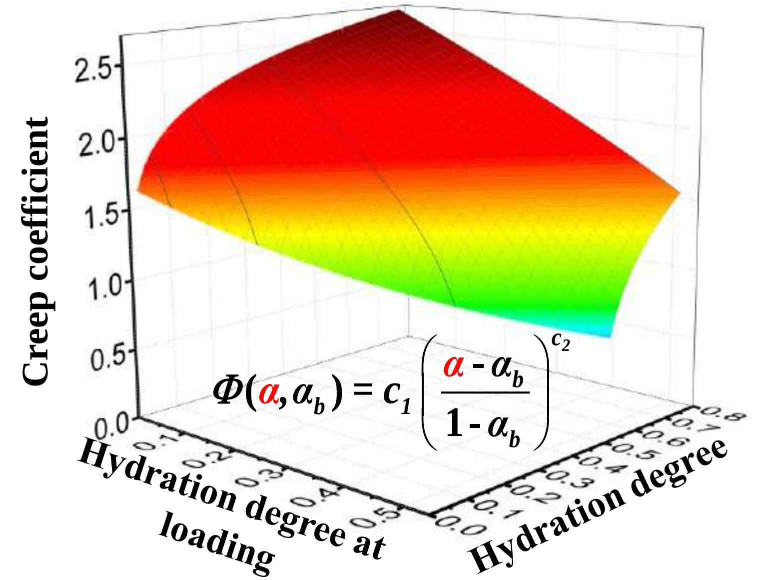
**Shrinkage under actual varied temperature and humidity can be calculated**

# Hardening stage

- A quantitative determination method for "time-zero" of shrinkage was proposed based on capillary pressure, and early-age elastic modulus and creep were modeled based on hydration degree

| | |
|---|---|
| China (GB) | Constant value |
| ACI | Not considered during construction period |
| JCI | Effective elastic modulus: $E_e(t) = \frac{1}{1+\varphi(t)} E(t)$ <br> $\varphi(t)$: 1.25 and 0.5 at temperature rise and fall stage |




Shrinkage stress: $\sigma(t) = \sum_{i=1}^{n} \left(\triangle \varepsilon_{T_i}(t) + \triangle \varepsilon_{s_i}(t)\right) \times E_i(t) \times H_i(t, \Phi, \tau) \times R_i(t)$

**The early-age shrinkage stress can be accurately calculated**

# Multi-field coupling model

# Hardening stage

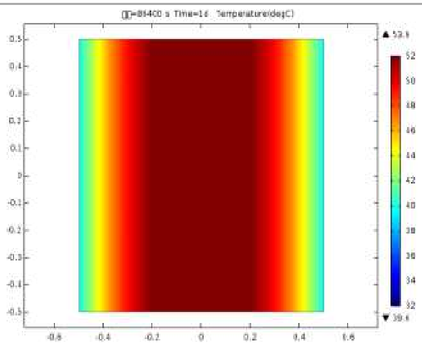
- A multi-field (hydro–thermo–hygro–constraint, HTHC) coupling model was introduced for shrinkage cracking of concrete during hardening stage

| | | |
|---|---|---|
| Coupling model | Hydration | $\dot{\alpha}_c = A_c(\alpha_c)\beta_h(h)\exp(-E_a / RT)$ |
| | Heat transfer | $\rho c_t \frac{\partial T}{\partial t} + \nabla\cdot(-\lambda\nabla T) = \dot{\alpha}_c c\tilde{Q}_c^{\infty}$ |
| | Moisture transfer | $\frac{\partial w(\alpha_c, h)}{\partial t} + \nabla\cdot(-D_h\nabla h) = 0$ |
| Shrinkage | Hygral deformation | $\varepsilon_{sh} = \Delta p\cdot\frac{S_w}{3}\left(\frac{1}{K_S}-\frac{1}{K_T}\right)$ $K_T = \frac{E(\alpha_c)}{3(1-2\mu)}$ |
| | Thermal deformation | $\varepsilon_T = \alpha(\alpha_c, h)\Delta T$ |
| Stress | Constraint | $u(x,y,z); f(x,y,z)$ |
| | Creep | $\Phi(\alpha,\alpha_b) = c_1[(\alpha-\alpha_b)/(1-\alpha_b)]^{c_2}$ |
| | Mechanical properties | $X(\alpha) = X(\alpha^{\infty})[(\alpha-\alpha_0)/(\alpha-\alpha_0)]^{\beta}$ |

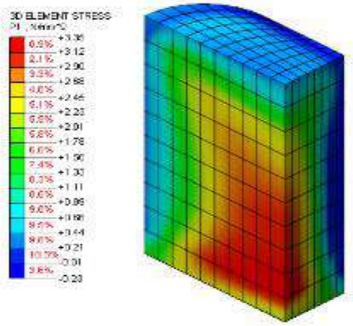
$\eta = \sigma_t / f_t$

Shrinkage cracking risk

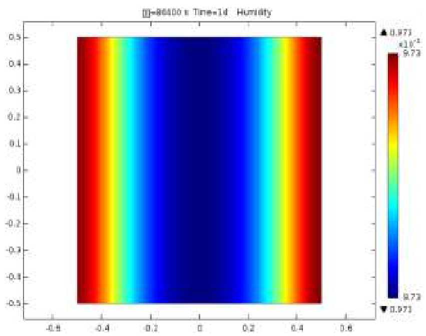
Shrinkage cracking risk evaluation model



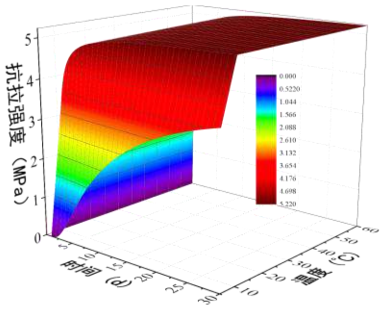
Temperature field



Shrinkage stress



Humidity field




Tensile strength

$$\eta = \frac{\sigma_t}{f_t}$$

$\sigma_t$ ------Tensile stress

$f_t$ ------Tensile strength

| | |
|---|---|
| $\eta > 1.0$ | Certainly cracking |
| $0.7 < \eta \le 1.0$ | Possible cracking |
| $\eta \le 0.7$ | Basically no cracking (reliability probability > 95%) |

Cracking risk index

**The shrinkage cracking risk of structural concrete can be calculated**

# 3 New technologies for shrinkage crack mitigation

# General ideas

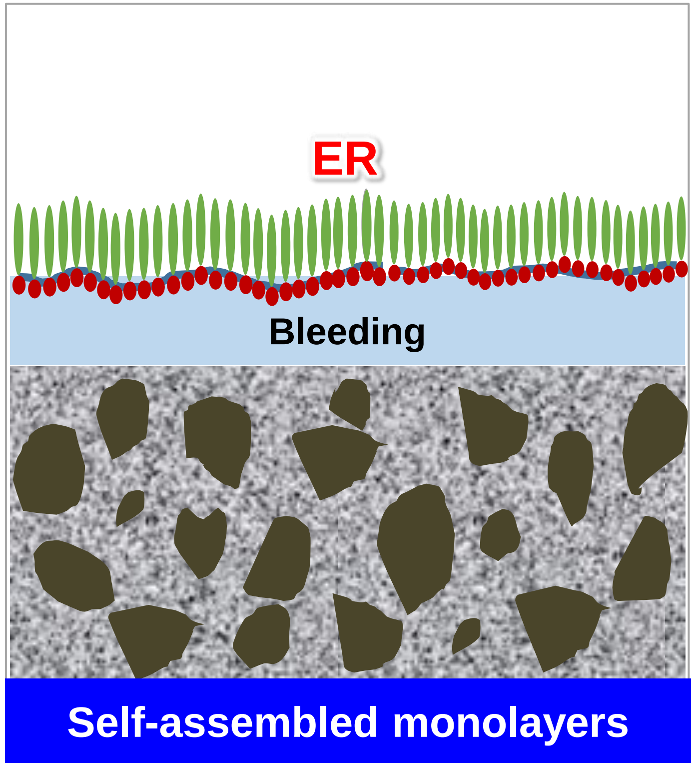
## Functional materials for shrinkage control in whole process

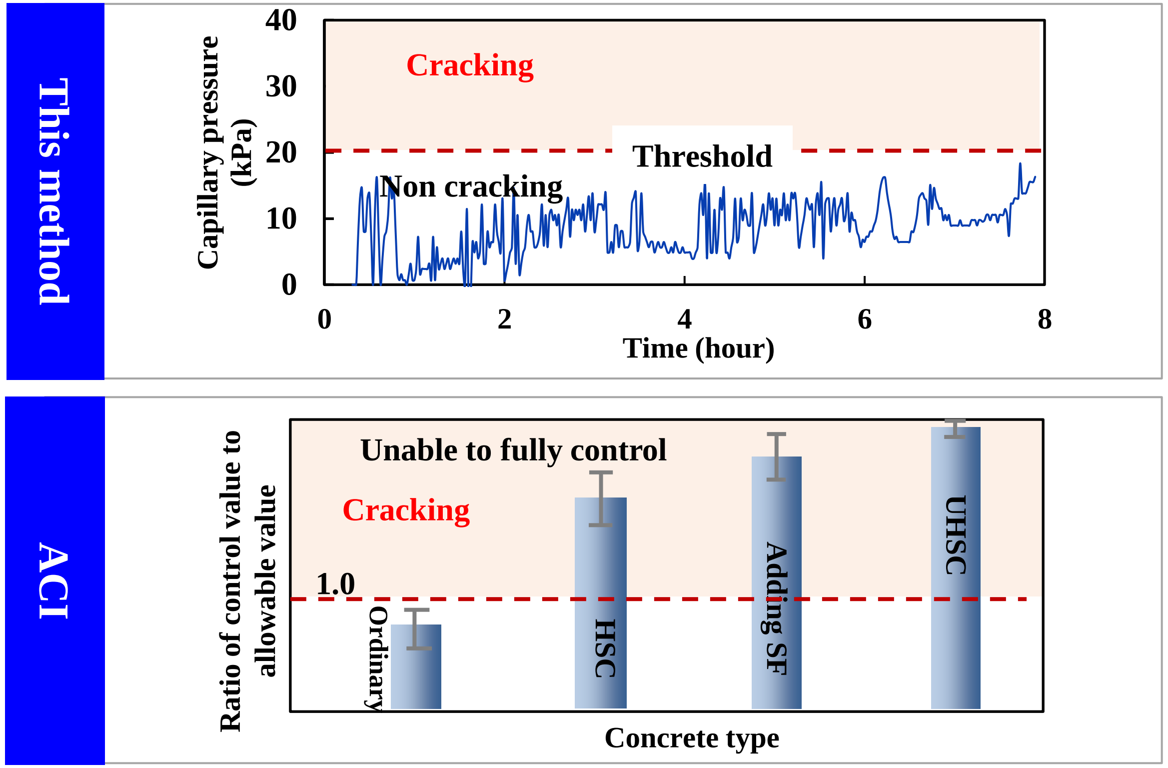
| | Plastic stage | | Hardening stage | Age |
|---|---|---|---|---|
| | Plastic shrinkage | Thermal shrinkage | Autogenous shrinkage | Drying shrinkage |
| Materials | Water evaporation retardant (ER) | Temperature rise inhibitor (TRI) | Calcium and magnesium oxide-based expansive agent (CMA) | Shrinkage-reducing polycarboxylate superplasticizer (SR-PCA) |
| Effect | reducing plastic shrinkage by 50% | Reducing thermal shrinkage by 15% | Full-stage shrinkage compensation can realize no shrinkage under isothermal and sealed condition | Reducing drying shrinkage by 20% |

**Efficiently reducing the thermal, autogenous, and drying shrinkages of concrete at different stages, ´suit the remedy to the case´**

# New technology 1 Evaporation retardants (ER)

- Evaporation retardant that forms self-assembled monolayers on the surface of concrete, along with intelligent curing technology was invented to control the plastic shrinkage stress below the cracking threshold

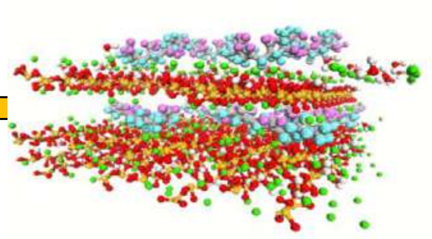


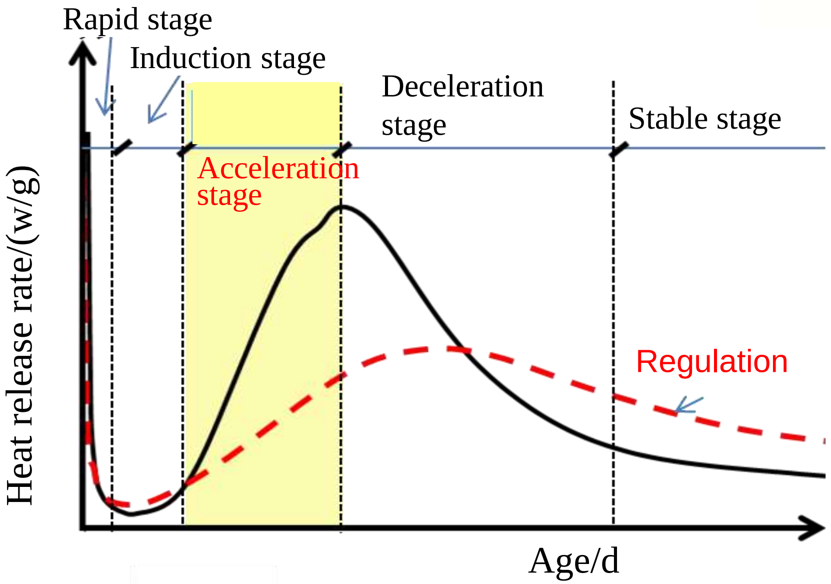

**Eliminating plastic shrinkage cracks before hardening**

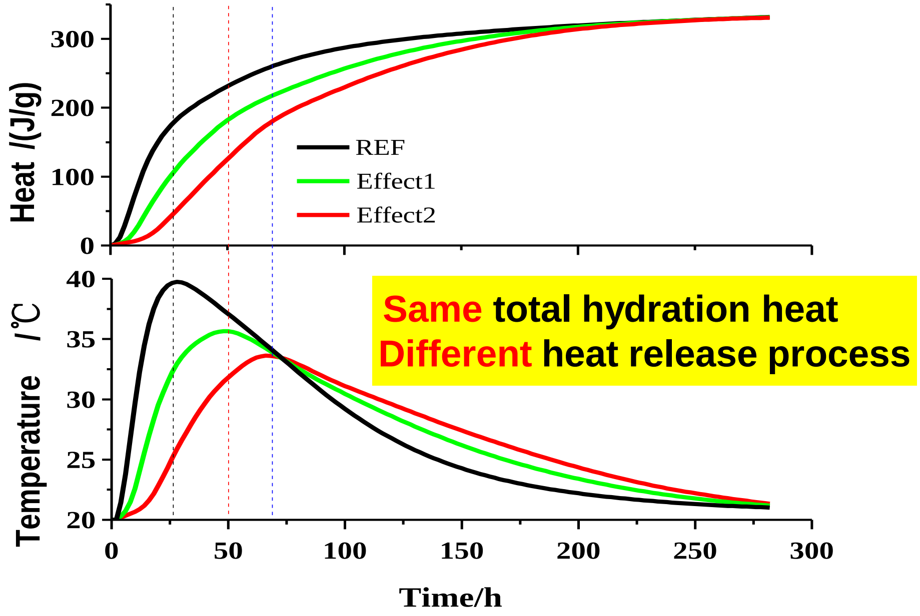
## Hydration rate regulation by TRI — Mechanism

**Regulating hydration rate at acceleration stage**



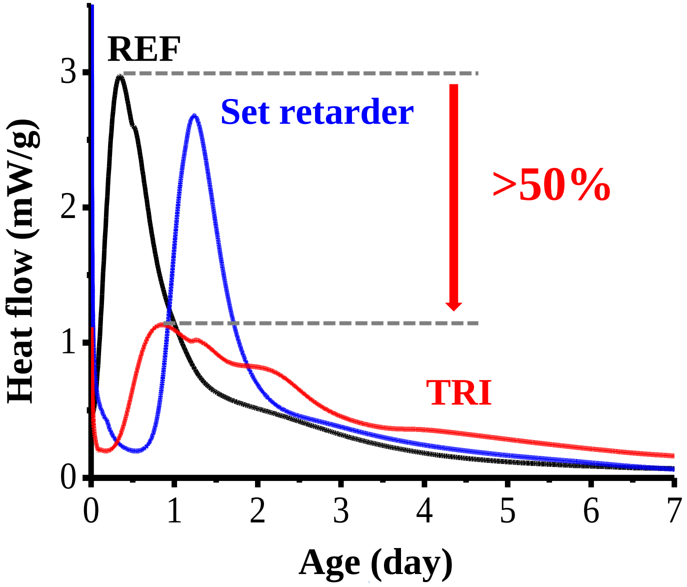
**The slower the heat release rate, the lower the temperature rise**

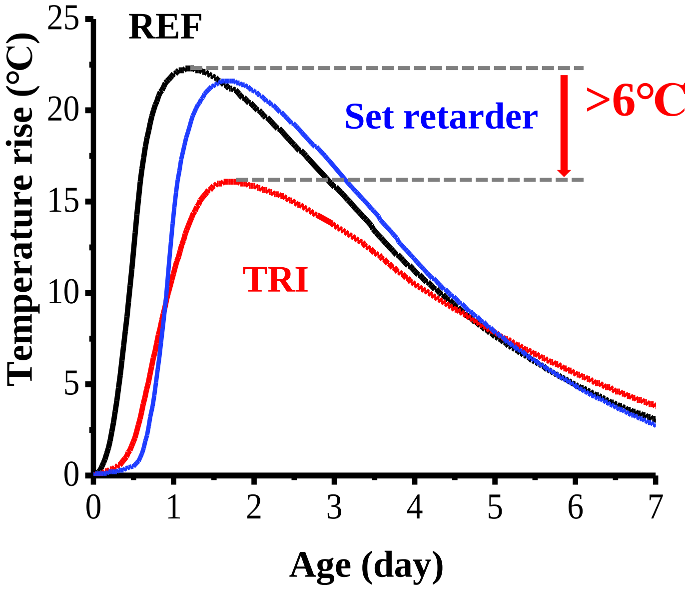


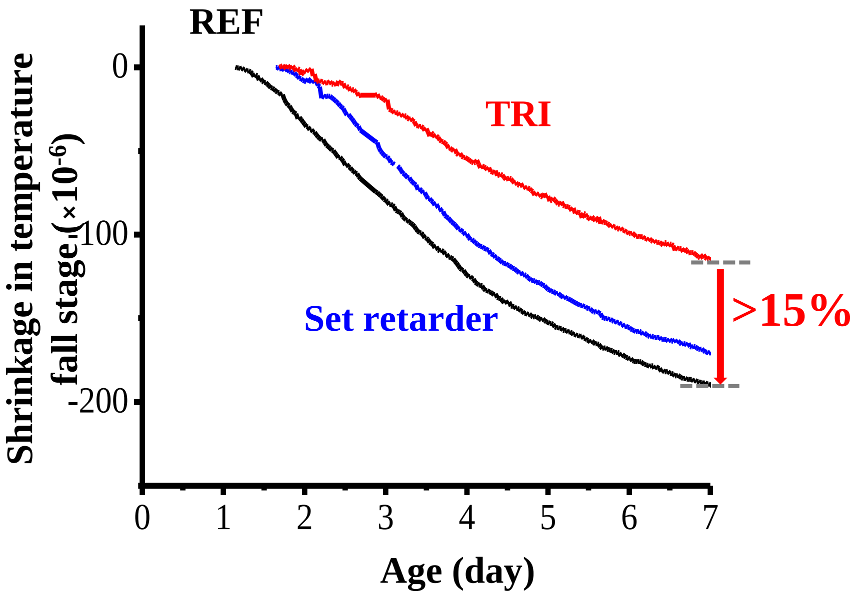




**By reducing the hydration rate at acceleration stage without changing the total heat release, the temperature rise of concrete can be significantly reduced**

## ☐ Hydration rate regulation by TRI — Effect



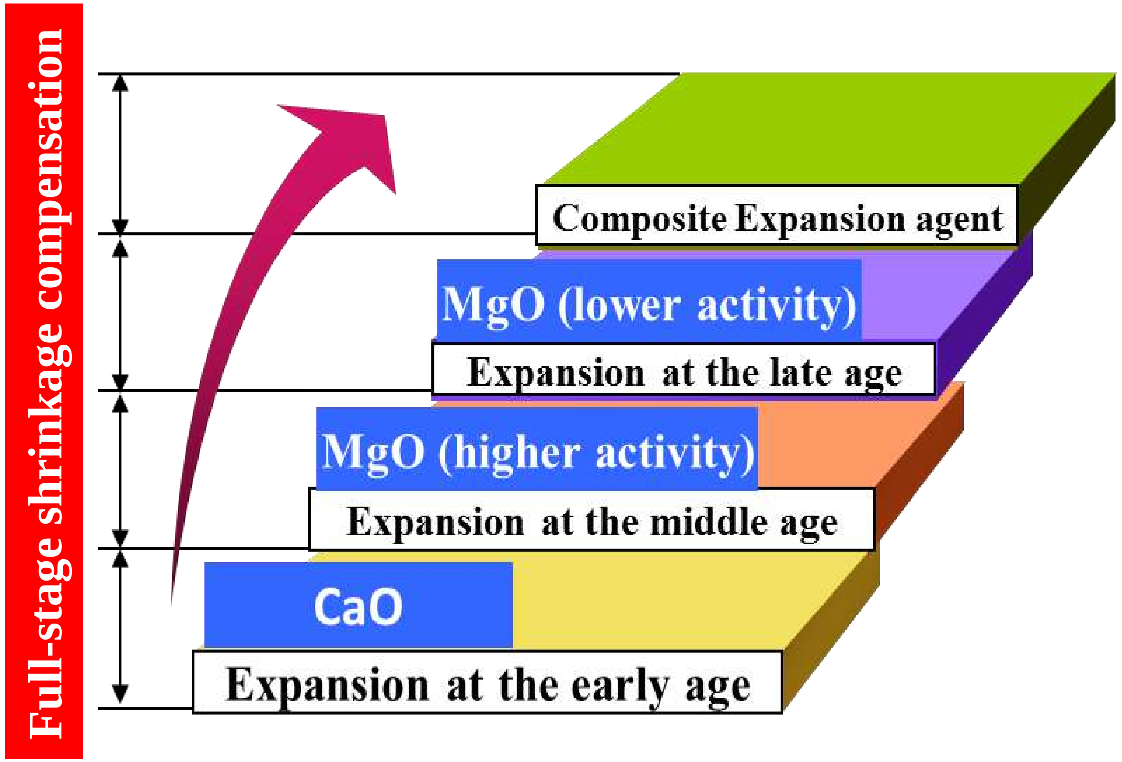



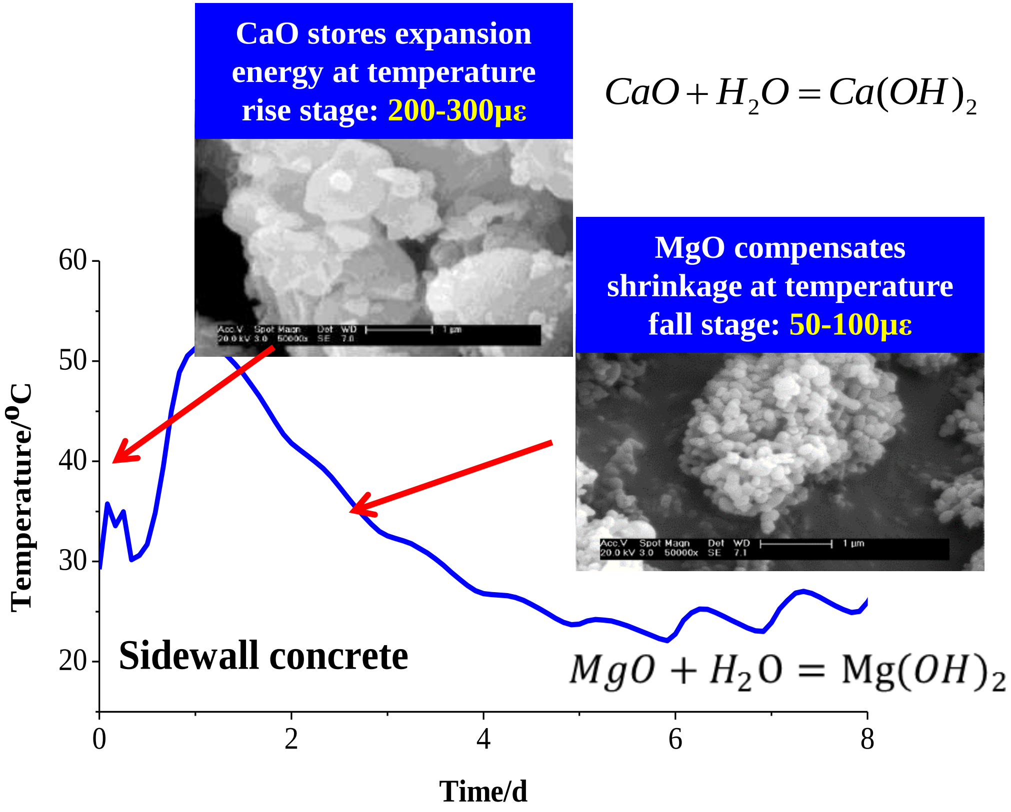

**Different from set retarder, addition of TRI could decrease the peak of cement hydration heat flow by more than 50% without changing the total heat generated, and reduce the temperature rise of concrete structure by more than 6℃**

**Providing key materials for reducing thermal shrinkage of concrete**

# New technology 3 Full-stage shrinkage compensation (FSC)

## Expansion process regulation — Technical ideas

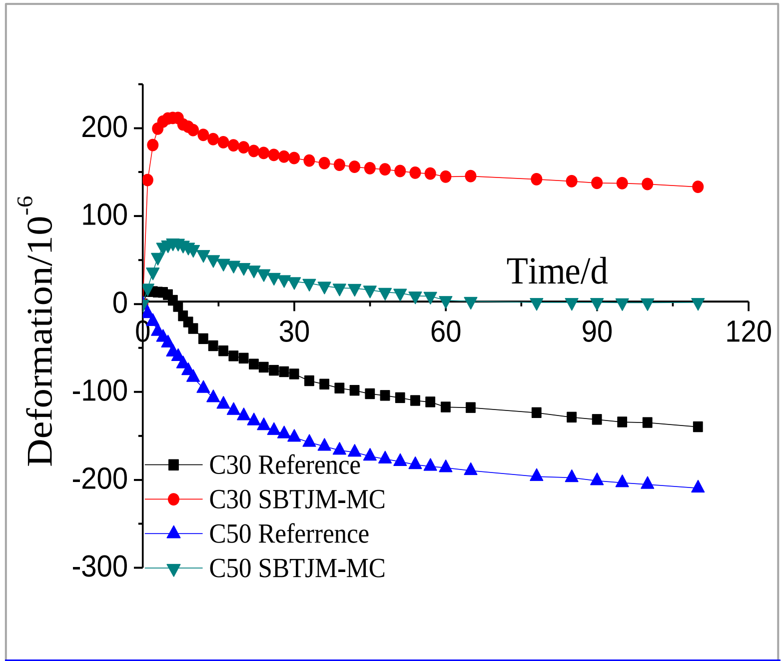


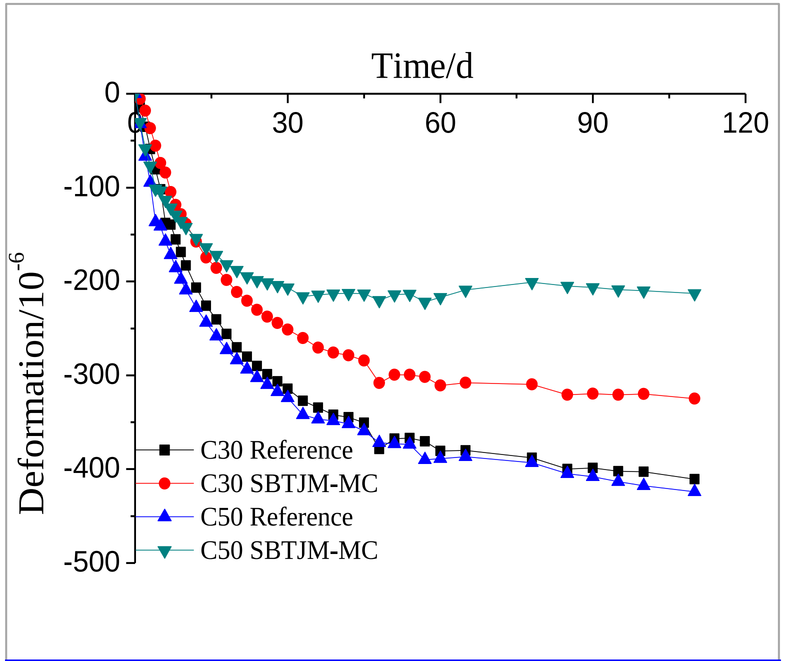

**Using multiple combination of expansive components with different relativities to compensate the shrinkage of concrete at different stages**

# New technology 3 Full-stage shrinkage compensation (FSC)

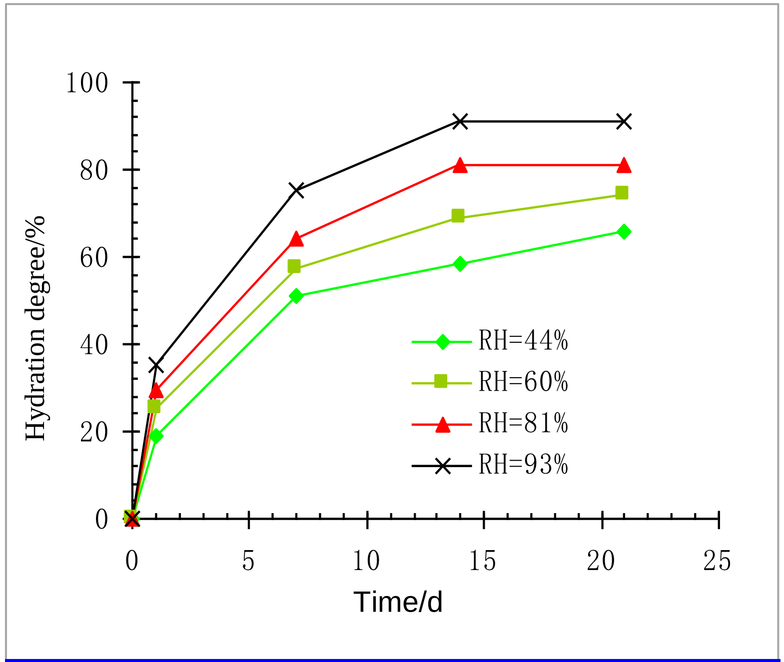
## Expansion process regulation — CaO expansive agent




Autogenous deformation



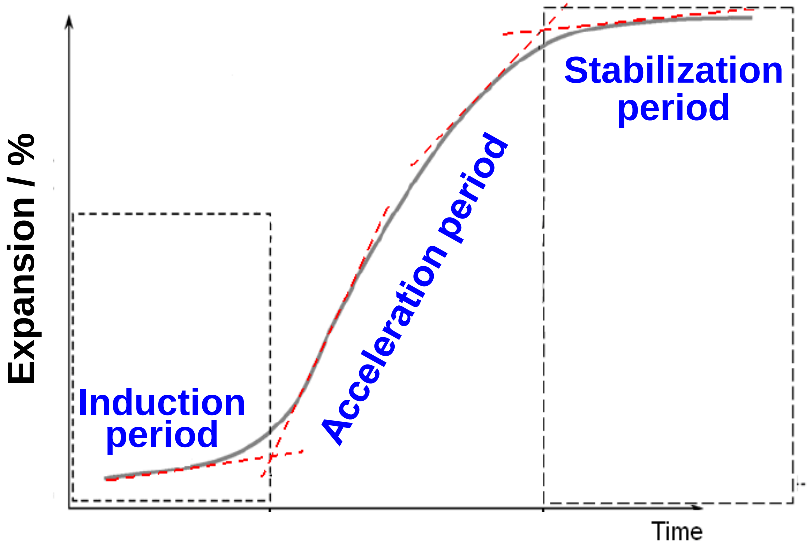

Drying shrinkage




Hydration degree of CaO

- **Large expansive capacity, low hydration sensitivity to humidity**
- **Effectively mitigating autogenous shrinkage and significantly reducing dry shrinkage**

## Expansion process regulation — MgO expansive agent




Expansion history of MgO expansive agent (MEA)

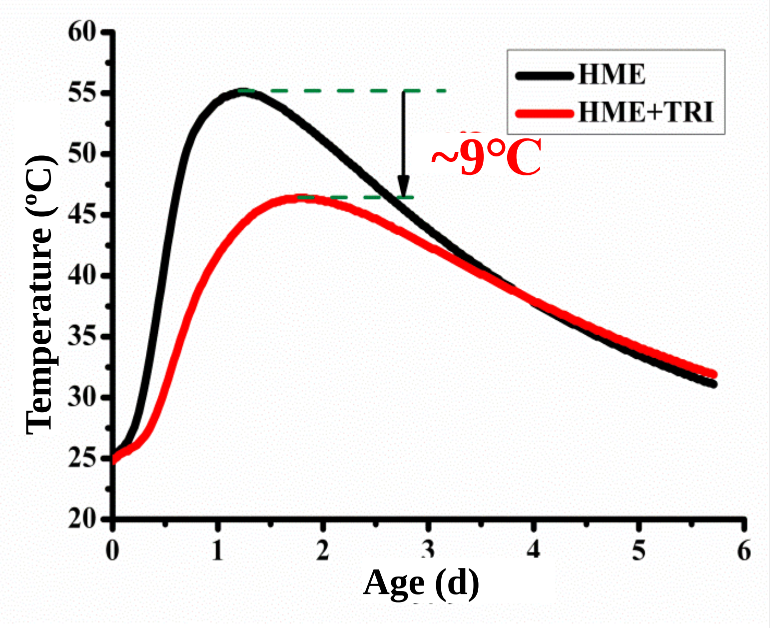
Expansion of cement pastes containing 5% MEA under water curing at 40℃ (Statistical data of test results)

| MEA | M58 | M75 | M100 | M150 | M190 | M250 |
|---|---|---|---|---|---|---|
| Reaction time (reactivity values)/s | 58 | 75 | 100 | 150 | 190 | 250 |
| Induction period/d | 0 | 2 | 5 | 7 | 12 | 21 |
| Stabilization time/d | 56 | 84 | 87 | 90 | 110 | 120 |
| Ultimate expansion/% | 0.12 | 0.22 | 0.27 | 0.33 | 0.37 | 0.55 |

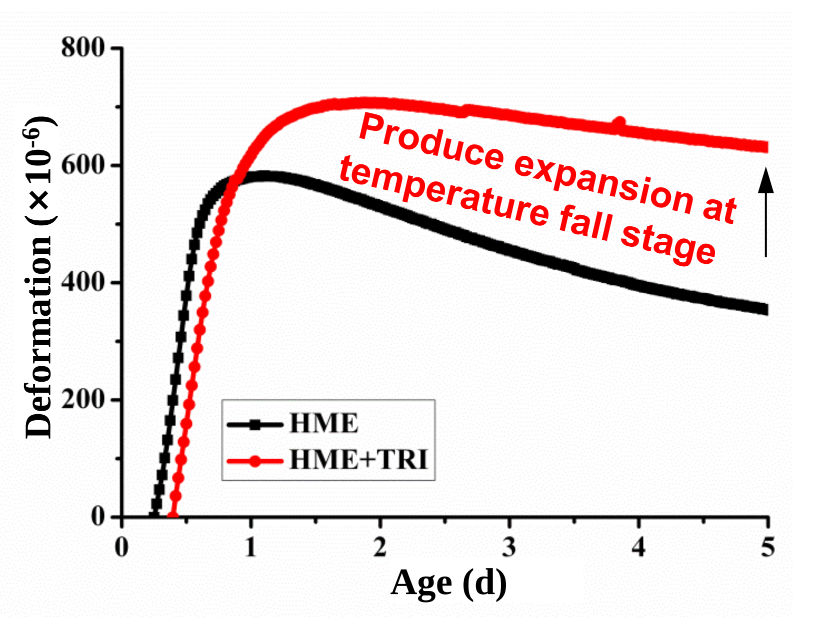
**MgO expansive agent (MEA) with different relativities show different expansion behavior**

## New technology 3 Dual-regulation technology

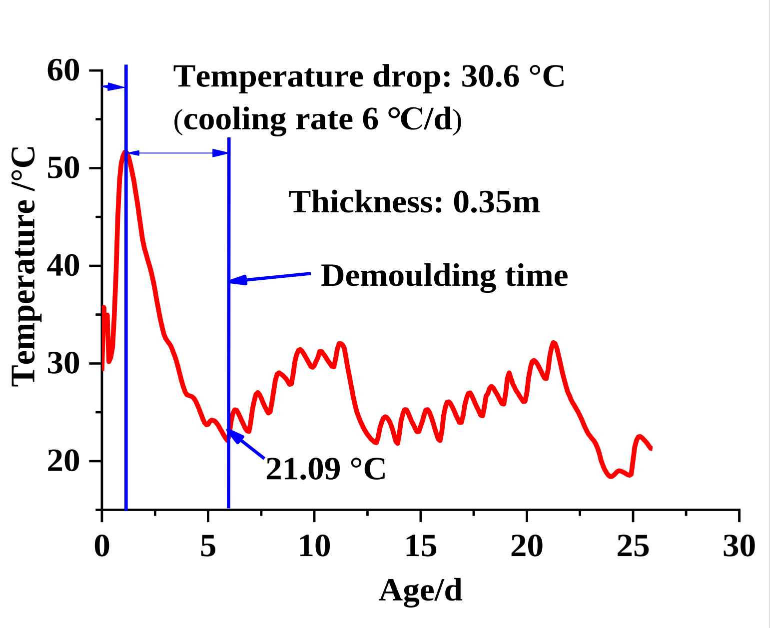
- Dual-regulation technology of hydration rate and expansion process can reduce temperature peak by 9℃ and compensate shrinkage by more than 300με, thereby reducing the cracking risk below threshold




Temperature rise inhibition effect




Full-stage shrinkage compensation




Temperature history of a sidewall

**Providing a new approach for shrinkage crack control in hardening stage for cast-in-place concrete**

# New technology 4 Shrinkage-reducing PCA (SR-PCA)

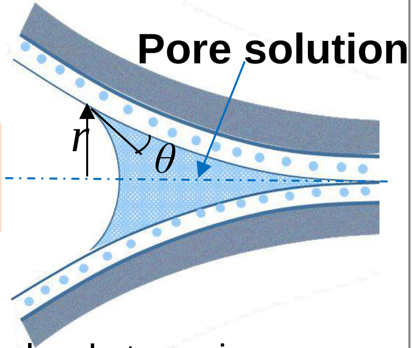
- **Shrinkage-reducing polycarboxylate superplasticizer significantly reduces the surface tension and $Na^+$ concentration of pore solution, thereby reducing shrinkage stress caused by drying**

**Surface tension** → **Reduced by 20%**

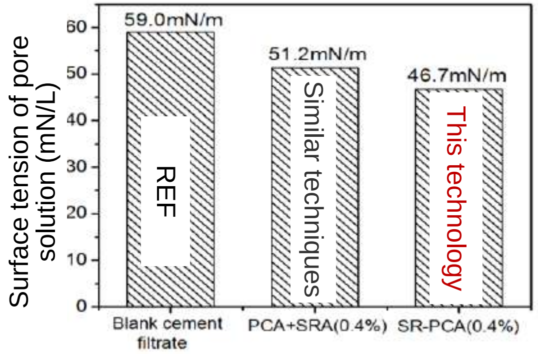
**$Na^+$ concentration** → **Reduced by 50%**

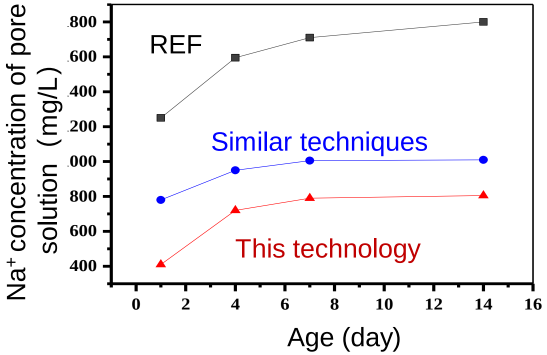
**Shrinkage stress**

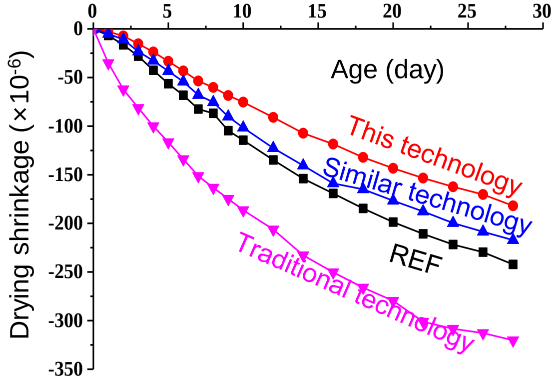
$$\Delta P = \frac{2\sigma\cos\theta}{r}$$




The decrease in humidity leads to an increase in drying and autogenous shrinkage




- **Reducing the 28d-drying shrinkage of concrete by more than 20%**
- **Shrinkage-reducing effect increased by 1.4 times compared to similar technology**

**Providing new materials for long-term drying shrinkage reducing**

# New technology 5 Thermal-insulation and moisture-retention curing technology (TMC)

## Traditional facade curing techniques

| Problems | Status | Consequence |
|---|---|---|
| • Tight schedule<br>• Lack of technical means | • Fast construction speed ⇨<br>• Premature demolding ⇨<br>• Poor curing ⇨ | Curing facilities cannot be rotated<br>Concrete temperature is still at peak or high level<br>Large cooling rate and severe surface water loss |

### Traditional techniques

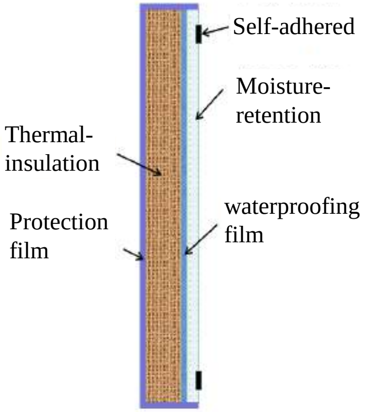
- Hanging film or geotextile
- Laying pipes at the top of the wall to spray water

Vertical parallel distributed thermal cracks

Random surface cracks due to drying

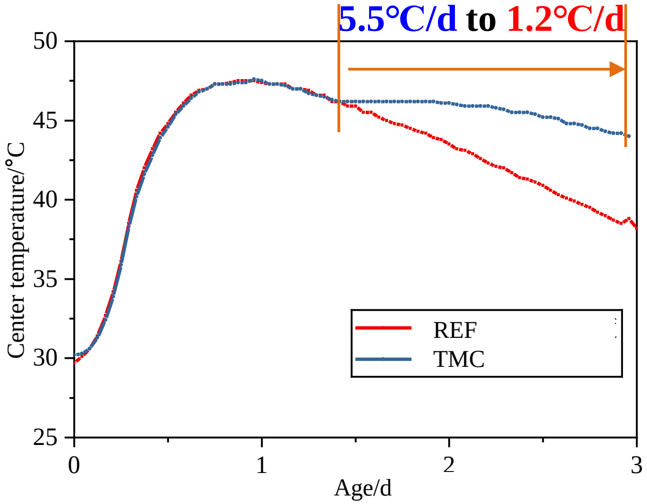
## Self adhesive curing cloth for facade thermal-insulation and moisture-retention

| | |
|---|---|
| Flexible geotextile ➡ | Moisture-retention |
| Rubber plastic sponge cloth ➡ | Thermal-insulation |
| PE film ➡ | Waterproofing |
| PVC film ➡ | Protection |
| PU materials ➡ | Self-adhered |

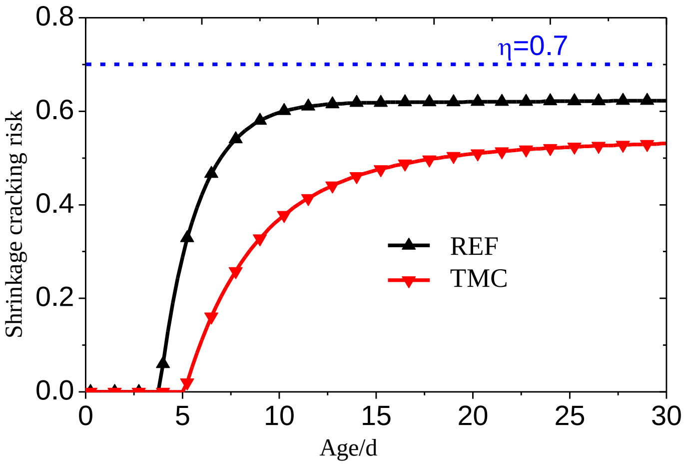



Rinse with water

Adhesion recovery




Thermal insulation effect



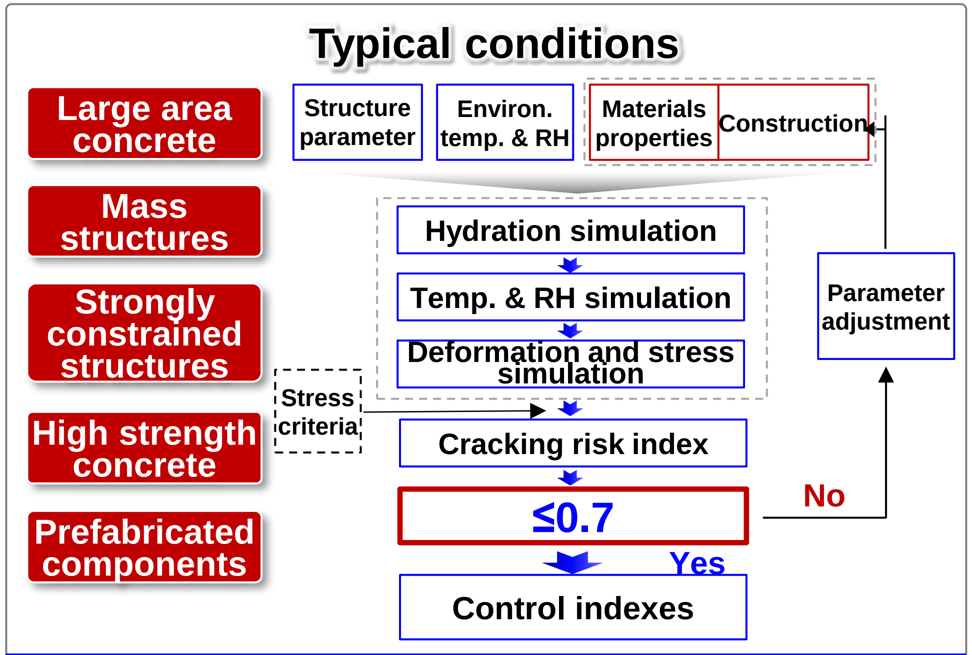

Shrinkage cracking risk

- Adjustable and controllable surface heat dissipation coefficient of the structure: 100~400kJ/(m²·d·℃)
- Adjustable temperature drop rate, capable of achieving ≤ 2.0 ℃/d
- Keeping the concrete surface long-term wetness
- Further reducing shrinkage cracking risk by more than 10%

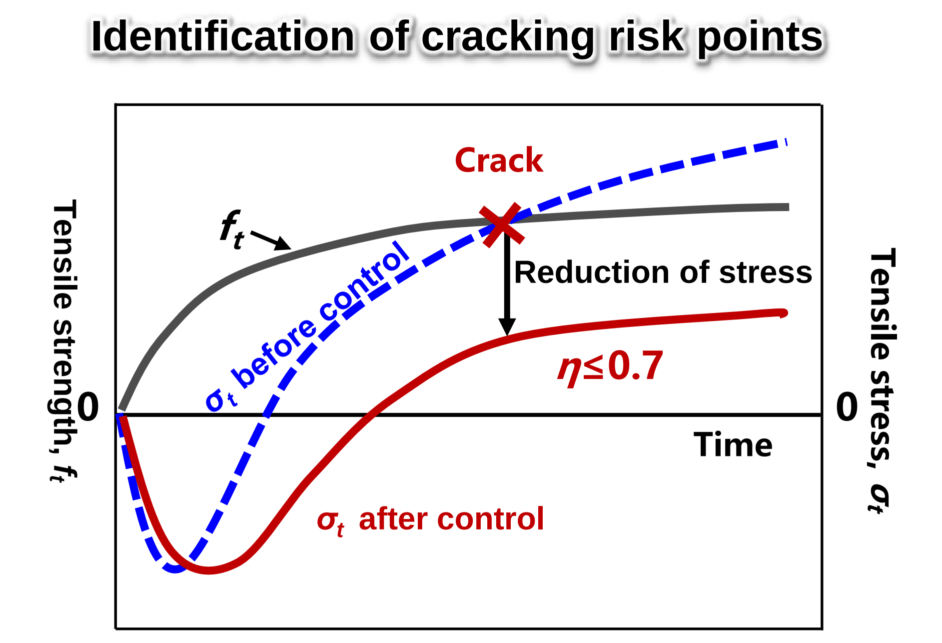
# 4 Typical applications

# General approach

- A simulation software and design system was developed to calculate the cracking resistance of concrete structures based on the prediction model
- Then, targeted crack resistance strategies can be designed to mitigate the shrinkage stress in whole process




Design method for high crack resistance concrete




Full-stage shrinkage stress control

**To control the cracking risk index ≤ threshold 0.7, and the non-cracking probability > 95%**

# Design method

## Design process

| | |
|---|---|
| Step 1 | Hydration and heat release |
| Step 2 | Temperature field |
| Step 3 | Shrinkage |
| Step 4 | Mechanical properties |
| Step 5 | Creep |
| Step 6 | Shrinkage stress and cracking risk |

### Inputting parameters

- Strength grade/composition of raw materials
- w/b

$$Q = Q_C \cdot P_C + k_1 \cdot 461 \cdot P_{SL} + k_2 \cdot 210 \cdot P_{FA}$$

$$\alpha_{\max} = \frac{1.031 \cdot w/b}{0.194 + w/b} + 0.50 \cdot P_{FA} + 0.30 \cdot P_{SL} \le 1$$

### Outputs

- Maximum heat release of cementitious materials
- Maximum adiabatic temperature rise

$$T_{a,\max} = \alpha_{\max} \frac{WQ}{C\rho}$$

Cement hydration heat （$Q_C$）

| Cement type | Cement strength grade | |
|---|---|---|
| | 42.5 | 52.5 |
| P·I, P·II | 430 | 465 |
| P·O | 365 | 420 |

Adjustment coefficient for the addition of admixtures

| Dosage | 0 | 10% | 20% | 30% | 40% | 50% |
|---|---|---|---|---|---|---|
| SL ($k_1$) | 0 | 0.9 | 0.7 | 0.6 | 0.5 | 0.5 |
| FA ($k_2$) | 0 | 0.5 | 0.45 | 0.42 | 0.4 | 0.35 |

Values taken based on strength during the design phase, when no concrete mix proportions

| Concrete strength grade | C30 | C40 | C50-C60 |
|---|---|---|---|
| $T_{a,max}$ （℃） | 45 | 50 | 55 |

# Applications

- The achievements have been applied to over 100 major projects, realizing no visible cracks in underground spaces, tunnels, long structures and mass concrete, etc.

| Type | Typical projects | Application effect |
|---|---|---|
| Underground spaces | Shanghai Metro Line 14, Xuzhou Metro Line 2, Qingdao Metro; Wuhan Pipe Corridor, Suzhou Binhu Underground Space, Suzhou Qidi Building | Mitigating the shrinkage cracking of compound or superimposed sidewall concrete |
| Tunnels | Taihu Tunnel, Xuanwu Lake Tunnel, West Lake Tunnel, Dushu Lake Tunnel, Jiuhuashan Tunnel, Gansu Ganjiangtou Tunnel | Solving the shrinkage cracking problem of super-long or mass concrete |
| Hydropower engineering | Xiangjiaba Hydropower Station, Pubugou Hydropower Station, Jinping Hydropower Station, Gongboxia Hydropower Station | Mitigating shrinkage-induced void in diversion tunnel concrete, or cracking in the panel |
| Bridge engineering | Bridge tower of Shanghai-Suzhou-Nantong Yangtze River Bridge, Main Tower of Pingtang Grand Bridge, Liujing Yujiang CFST Arch Bridge, etc. | Solving the shrinkage cracking or shrinkage-induced void of high strength mass concrete |
| Railway engineering | Lanzhou-Urumqi High-speed Railway, Zhengzhou-Xuzhou High-speed Railway, Shenyang - Dandong Passenger Dedicated Line, etc. | Eliminating plastic cracking in extreme dry environments, reducing the shrinkage and void of filling layer in CRTS III slab ballastless track |

**Promoting the crack control of concrete from passive repair to active prevention**

Application case 1

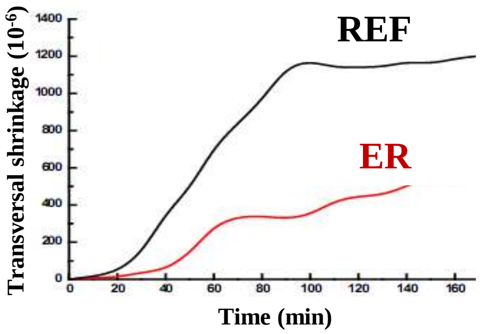
# Large area concrete—Lanzhou-Urumqi High-speed Railway

## ☐ Extremely dry environment

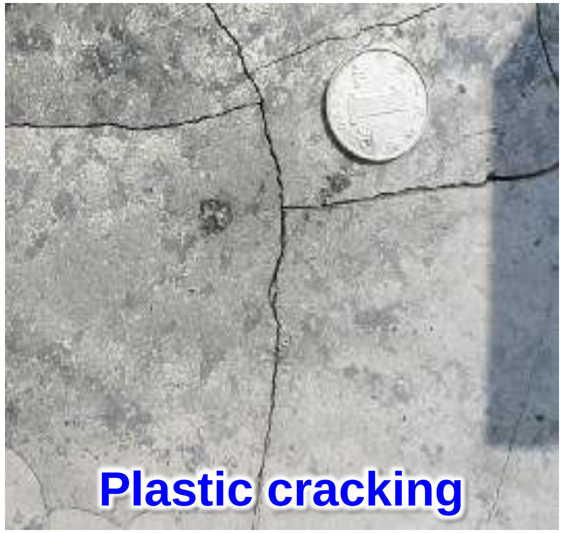
| | |
|---|---|
| Relative humidity | <30% |
| Wind speed | >8m/s |
| Land surface temperature | >50℃ |

Water evaporation rate of concrete is extremely fast

Early-age curing




Low humidity, strong wind and high land surface temperature in summer



Plastic cracking


用户意见书

| | |
|---|---|
| 工程名称 | 兰新铁路第二双线 |
| 应用单位 | 中铁十七局集团第四工程有限公司 |
| 产品生产单位 | 江苏苏博特新材料股份有限公司 |
| 产品使用起止时间 | 2012.1-2013.12 |

Plastic cracking and crusting of early-age concrete were avoided

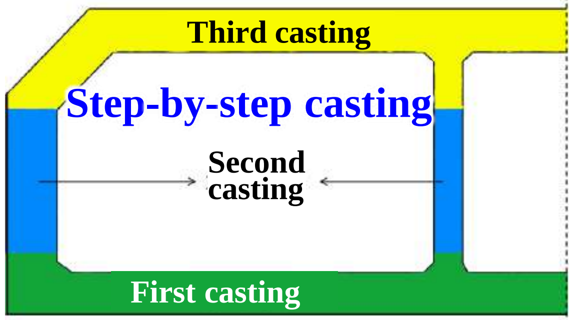
**Crusting, peeling and plastic cracking were avoided under extremely dry environment**

## Application case 2

## Super-long mass concrete—Taihu Tunnel

### ☐ Super-long mass concrete with high temperature rise, large shrinkage, and strong constraints

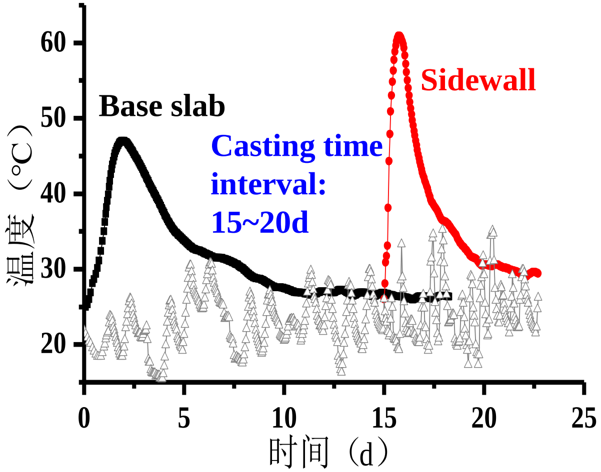
| | |
|---|---|
| Length | 10.79km |
| Width | 43.6m |
| Thickness | 1.0/1.2-1.5m |



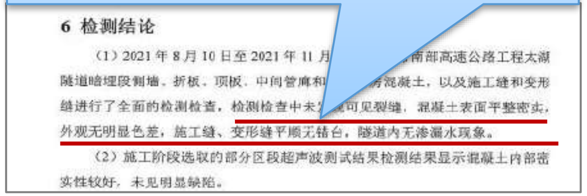

**Crack resistance design based on the calculation of 800+ conditions**

- ✓ Cracking risk < 0.7
- ✓ Base slab: HPC+ insulation curing
- ✓ Sidewall, top slab: HPC+TRI&CMA+TMC


The longest and widest cofferdam tunnel




No visible cracks were observed, … no water leakage in the tunnel



6 检测结论

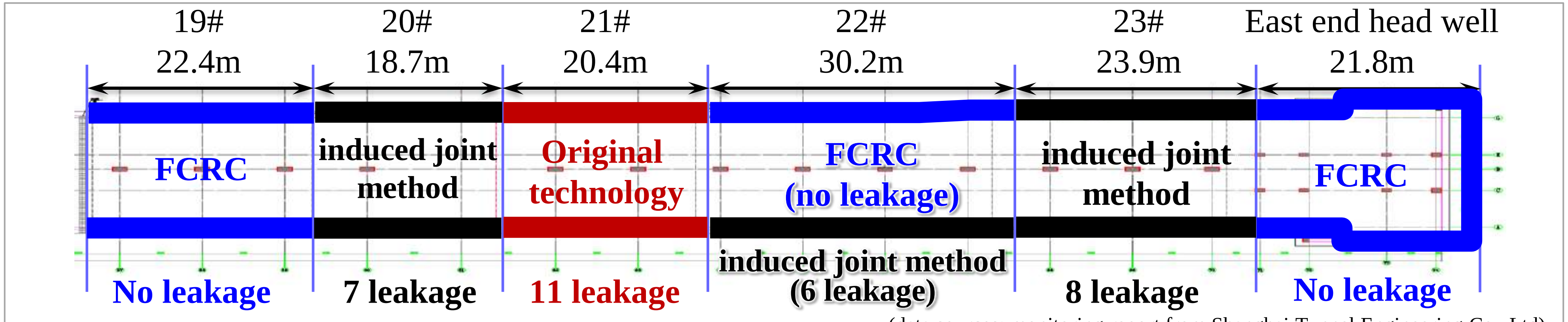
（1）2021 年 8 月 10 日至 2021 年 11 月 南部高速公路工程太湖隧道暗埋段侧墙、折板、顶板、中间管廊和 浇混凝土，以及施工缝和变形缝进行了全面的检测检查，检测检查中未 可见裂缝，混凝土表面平整密实，外观无明显色差，施工缝、变形缝平顺无错台，隧道内无渗漏水现象。

（2）施工阶段选取的部分区段超声波测试结果检测结果显示混凝土内部密实性较好，未见明显缺陷。

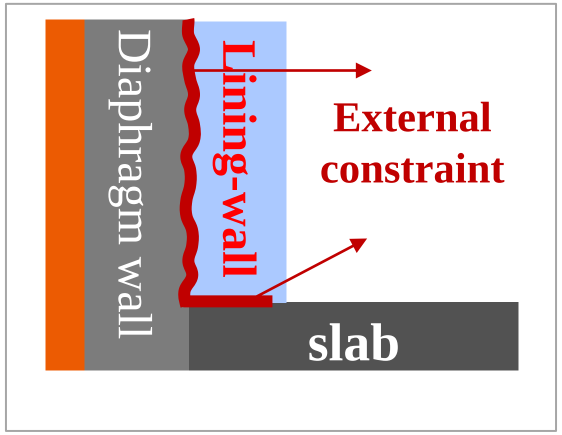
**A benchmark project for shrinkage crack control and leakage prevention of cast-in-place concrete tunnels**

# Strong Constraint—Underground station in Shanghai Metro Line 14

- Strong constraint superimposed sidewall structures, serious cracking and leakage problems




(data sources: monitoring report from Shanghai Tunnel Engineering Co., Ltd)




Hydration rate and expansion process

**Dual-regulation technology**

Under the same conditions……
FCRC is the optimal solution

**Preventing cracking in super long and strong constraint wall to ensure the same service life of waterproofing and structure**

# High strength concrete—Changzhou-Taizhou Yangtze River Bridge

## ☐ Diamond shaped cable tower, mass concrete, high strength

Strength: C60, max thickness: 3.5m, max girth: 42m

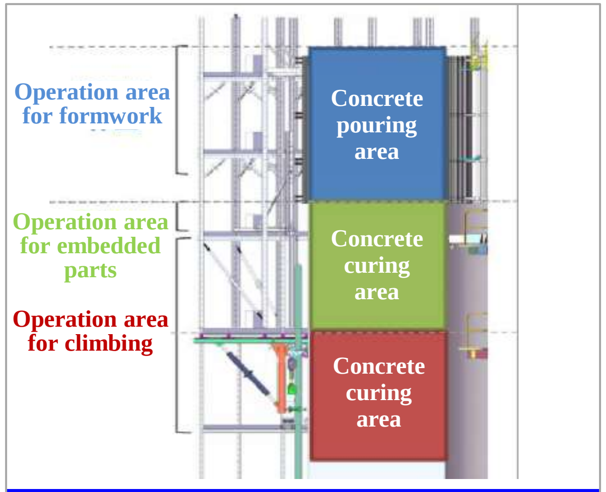
Strong constraint: casted old concrete segment with strength > 60MPa and modulus >35GPa

Demolding at 3-5d, windy, difficulty in curing

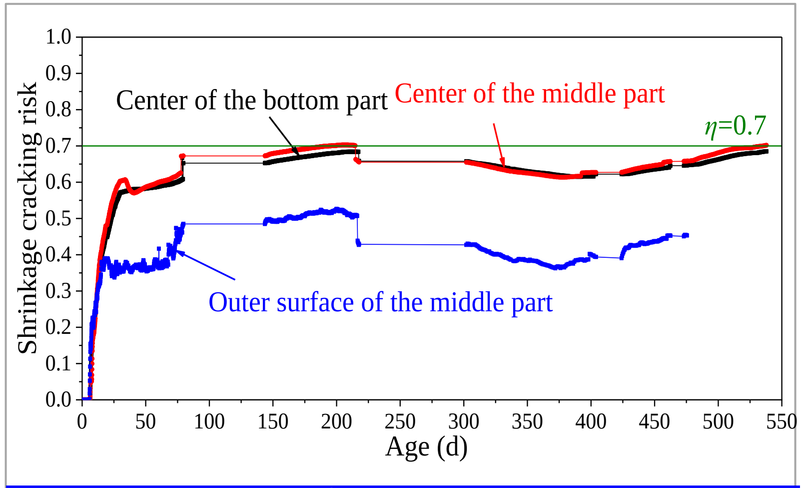
TRI+CMA
Rheological modified
Cooling water pipe
External insulation

**Cracking risk < 0.7**

Span: 1208 m, height of main tower: 350 m




three-story tower construction



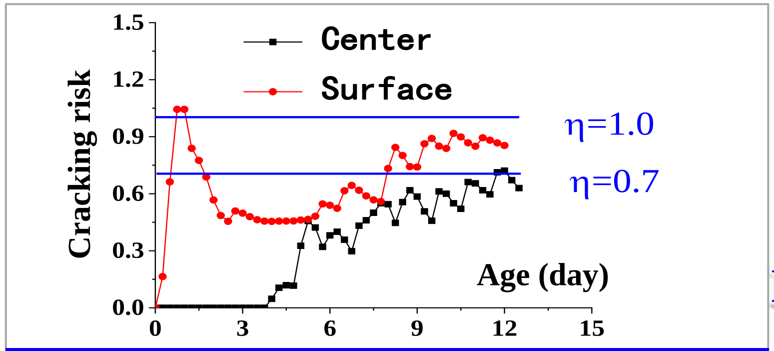

Inversion results of the shrinkage cracking risk of concrete in beams and pillars

**No visible cracks in beams and pillars of cable tower**

# Application case 5

## Precast concrete—immersed tunnel of Hong Kong-Zhuhai-Macao Bridge

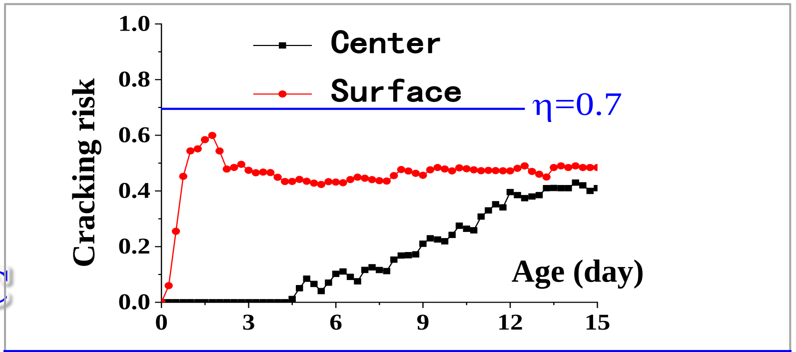
### □ The world's largest precast concrete immersed tube




High shrinkage cracking risk

**TRI+SR-PCA**

**Molding temperature ≤26°C**




Control the cracking risk ≤ 0.7

Precast concrete immersed tunnel

Each tube weighs about 80,000 tons


技术成果应用证明

Shrinkage-reducing PCE & Temperature rise inhibition technology …help to **prevent the cracking** in the immersed tunnels

**No visible cracks and leakage were found in the immersed tunnel, meeting the design requirements of 120 years service life**

# Application case 6

## Radiation-shielding mass concrete—Proton center of Shandong Cancer Hospital

- **Heavy weight aggregates (magnetite) was applied for concrete with high requirements for crack resistance and radiation shielding**

Length: > 60m, thickness: 2.0~3.5m, density: 3.8t/m$^3$

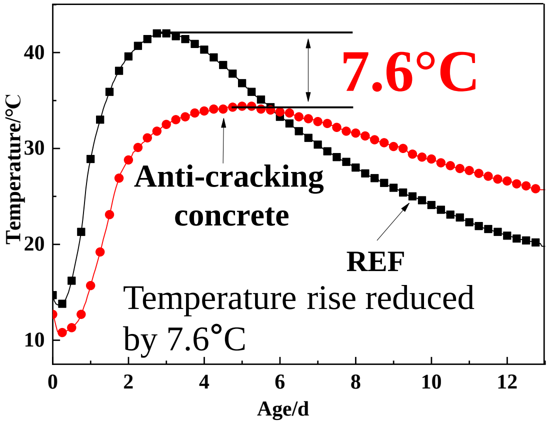
Higher thermal expansion coefficient (>14με/ºC) and shrinkage (increased by 20%) of heavy concrete

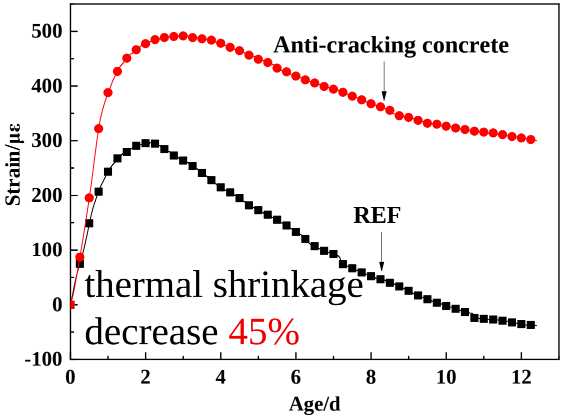
High temperature rise and temperature difference, cooling water pipe cannot be used, cracking risk > 1.5

Dual-regulation technology

Design & prepare high anti-cracking heavy concrete to ensure no cracking (reliability probability > 95%)

Proton medical center of Shandong Cancer Hospital



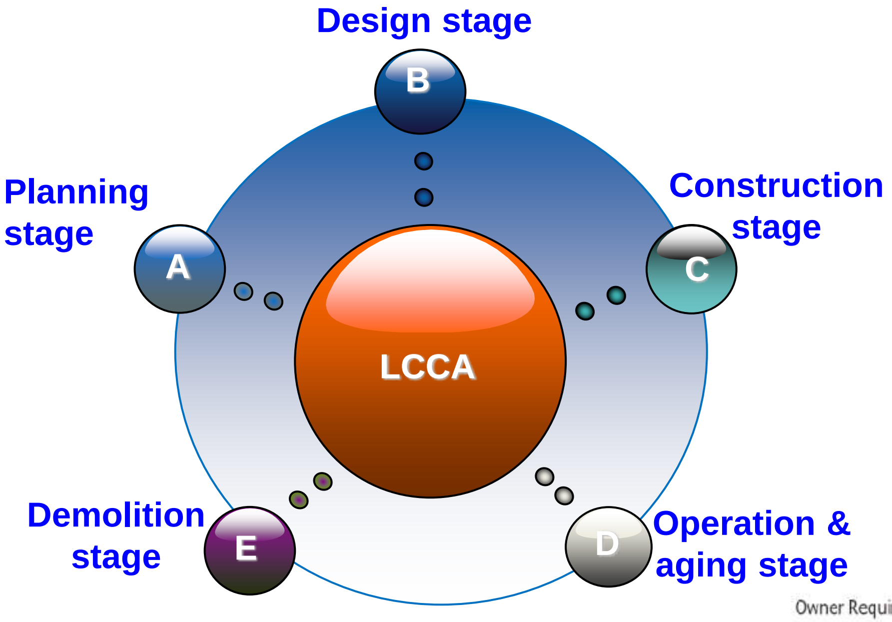

Preparation of low temperature rise and high crack resistance concrete by dual-regulation technology

No cracking

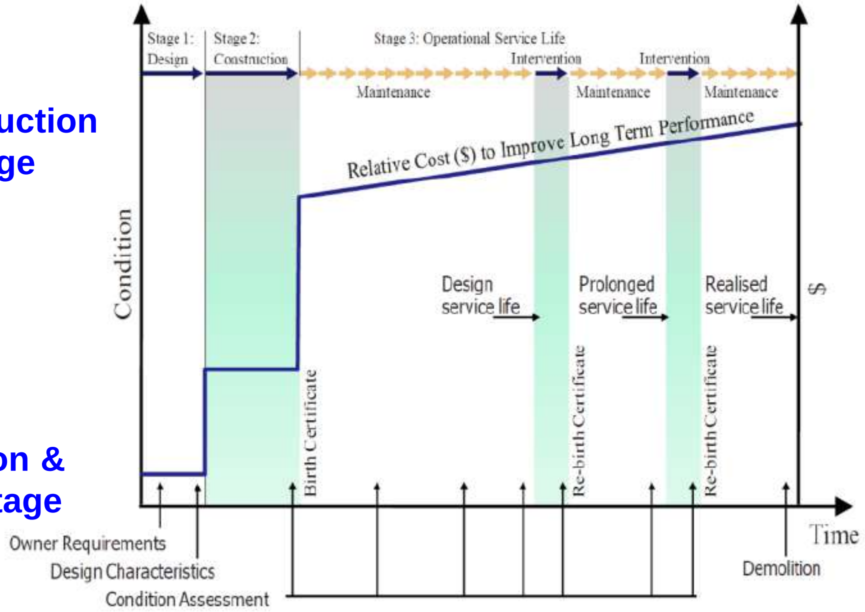
**No cracks were found, ensuring radiation shielding effect**

# Cost analysis

## ☐ Life Cycle Cost Analysis




**Evaluate the costs of projects throughout the entire life cycle**




### "Five-fold law"

- During construction, save $1
- When steel corrosion is found, taking measures costs an extra $5
- When concrete cracking, additional maintenance costs $25
- When serious damage, additional maintenance costs $125

- **Cost of crack resistant functional materials: 40-60 yuan/m$^3$**
- **Cost of construction measures: casting temperature control costs about 3 yuan/℃, insulation, etc**

**Crack resistant concrete improves durability, which can reduce comprehensive costs of construction and maintenance**

# 5 Conclusions

## Conclusions

- By adopting full-stage cracking risk control method (FCRC), the crack resistance performance of concrete can be designed, the mitigation strategies can be implemented, and the crack resistance effect can be detected
- Concrete crack resistance should be specially designed, the multi-field (hydro-thermo-hygro-constraint, HTHC) coupling model is a scientific method that can be used for crack resistance design of modern concrete
- High performance concrete is the foundation, and new materials technologies such as water evaporation retardant(ER), temperature rise inhibition (TRI), full-stage shrinkage compensation(FSC) and shrinkage-reducting PCA(SR-PCA) are effective ways to mitigate cracking

# Conclusions

- **Precise construction measures such as casting temperature control, thermal-insulation and moisture-retention etc., are also very important to realize the shrinkage crack control**
- **Avoiding harmful cracks not only benefits the present, but also benefits the future.**

# 祝贺ACI新加坡2024混凝土技术年会圆满成功！

**Congratulations on the complete success of**
**ACI-Singapore Chapter 2024 Annual Seminar for Concrete Technologies!**

# Thank you!

**刘加平 Jiaping Liu   101011659@seu.edu.cn, 13805180390**