納米及先進材料研發院有限公司
Nano and Advanced Materials Institute Limited

Development and Charaterisation of C-100 High Strength Concrete

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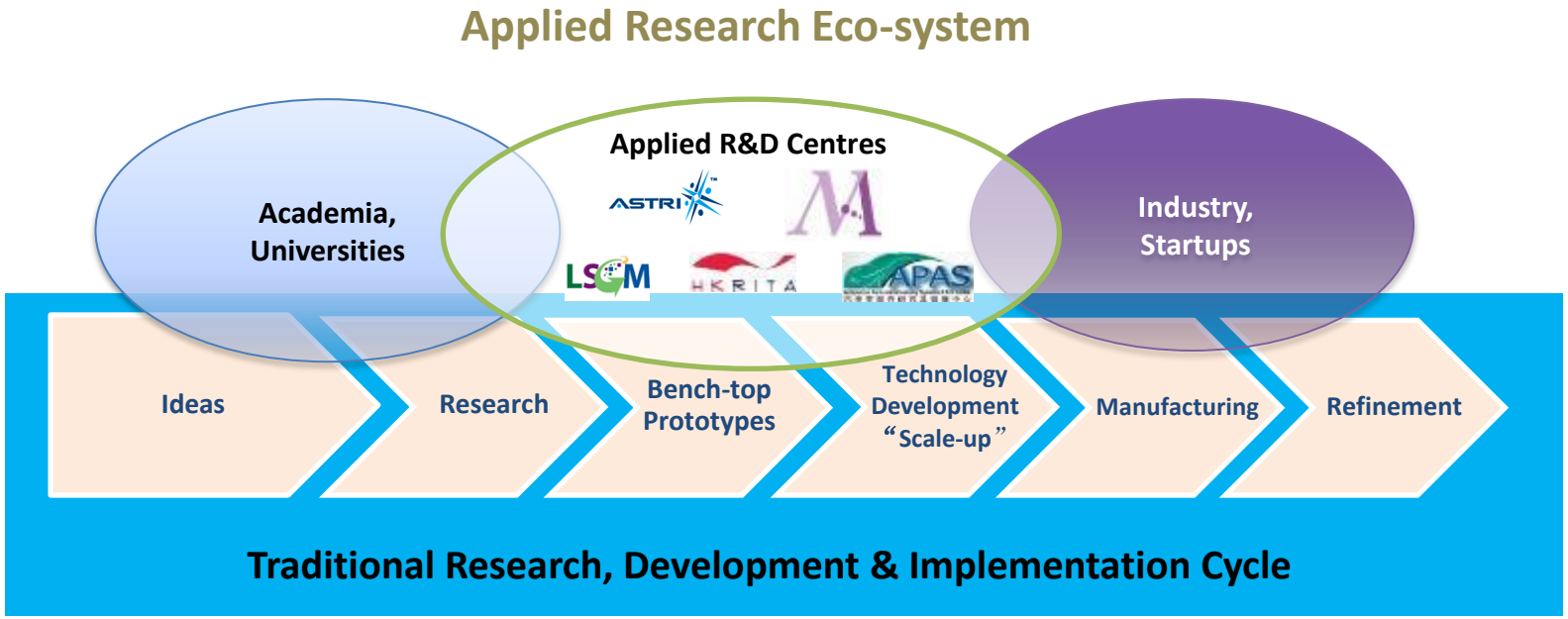
NAMI: *An Applied Research Centre*

NAMI established in 2006 by Hong Kong Government to be an integral part of the Applied Research Eco-system to offer technology upgrade to HK industries



NAMI

MISSION

- Cultivate research **Talent**
- Contribute to HK's **Technology** advancement
- Collaborate with industries for **Commercialization**

Business Model

- Demand-driven Research
- Materials-focused
- Industrial Collaboration

- University / Research Institute Cooperation

Value Proposition

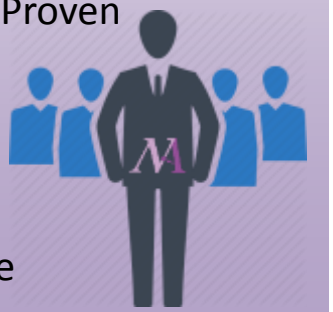
- Trained Researchers
- Extensive Equipment
- Innovation Technology Fund

- Dollar Efficient Research

Technology Clusters

- World Class

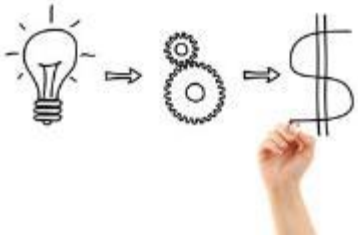
- Forefront, leading-edge R&D
- Applied & Proven



- Knowhow Cumulative

nami at a Glance

- **Focused on:**
  - **Applied R&D on Materials**
  - **Commercialisation**
- **Support HK industries**
- **11 years of history**



Annual R&D Investment
HK$150M+

Equipment
>$100M

Technical Talents
~200 (>50% PhD)

Lab area
40,000 ft²

Filed patents
400+

Market Sector & Core Competence

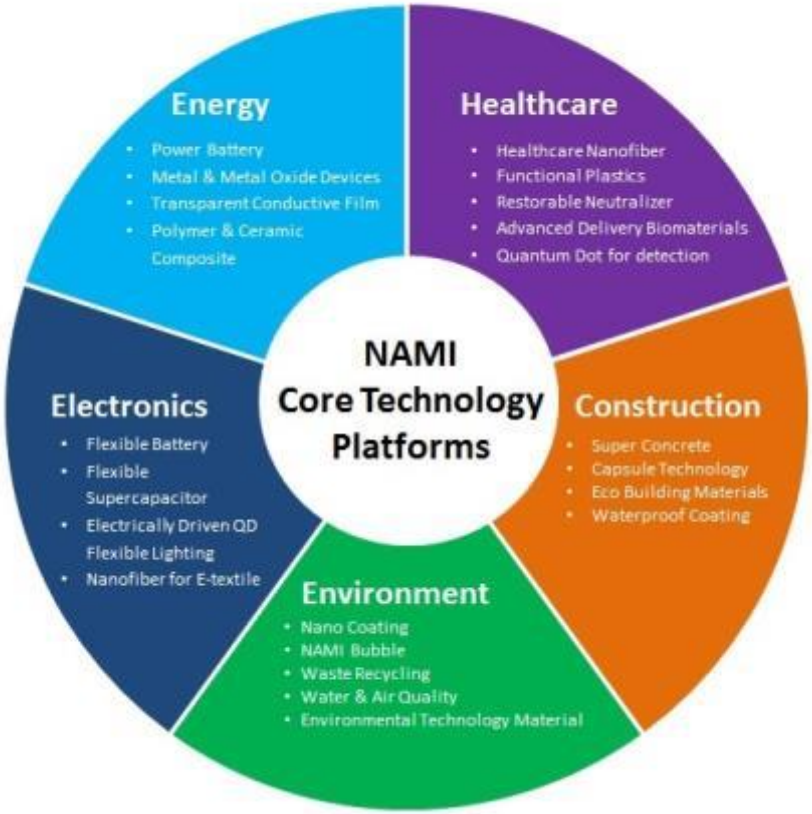
Energy

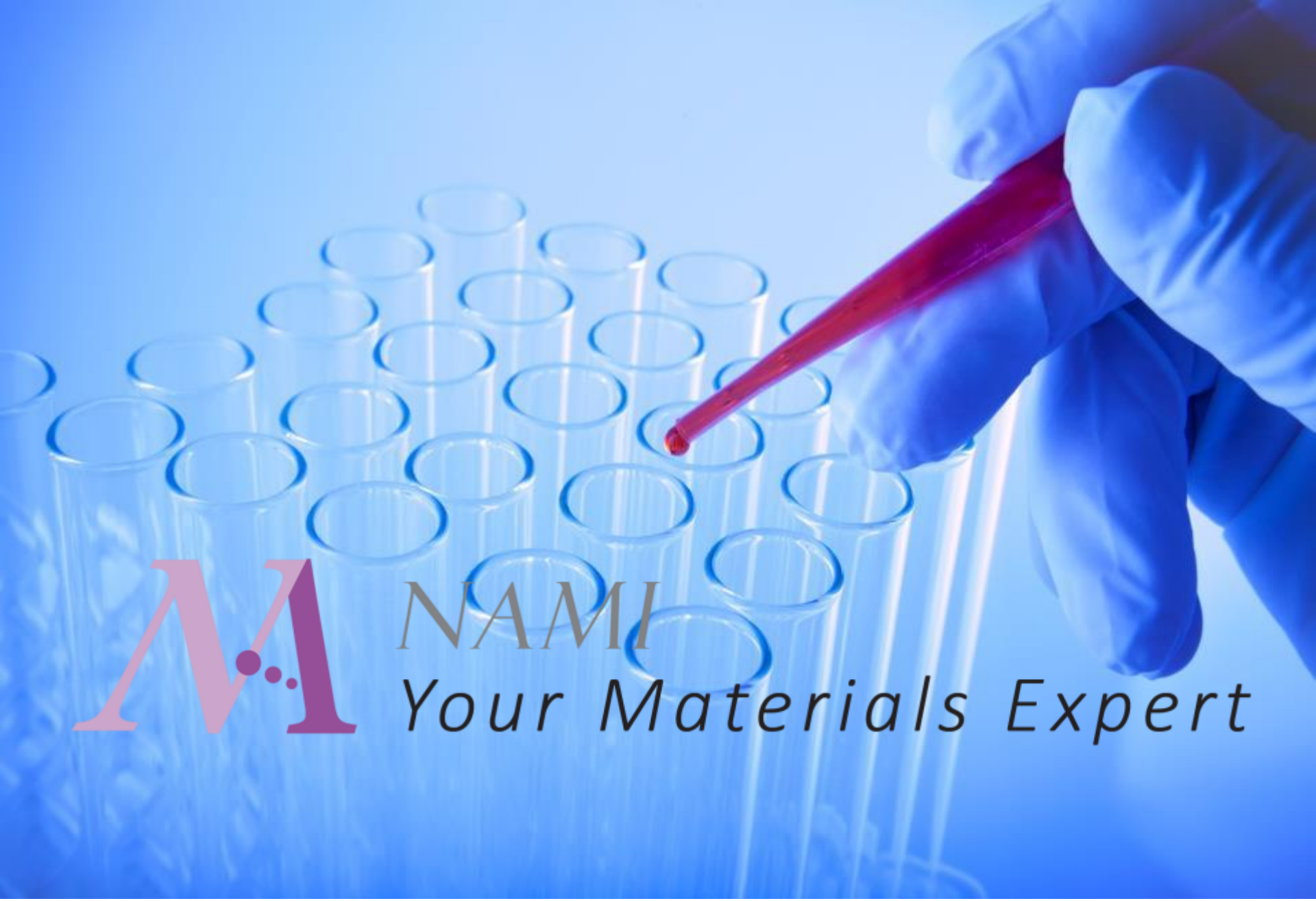
Healthcare

Electronics

Environment

Construction




NAMI
Your Materials Expert

Acknowledgement

- This project is funded by Innovation and Technology Commission, HKSAR

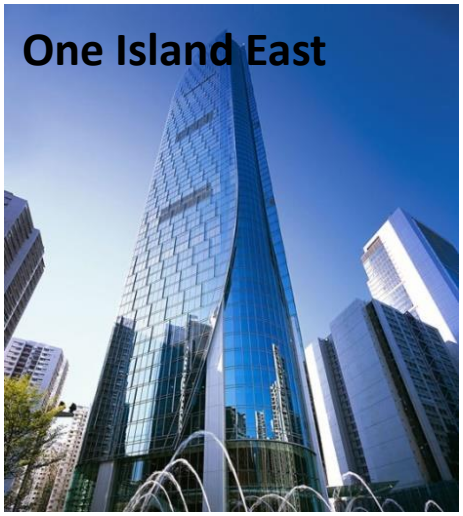
- All IPs and know-how in this project are open for industries to license.

Background

- Hong Kong has **the largest number (~315)** of **skyscrapers and high-rise buildings** over the world, 92% of high-rise buildings are made of concrete.

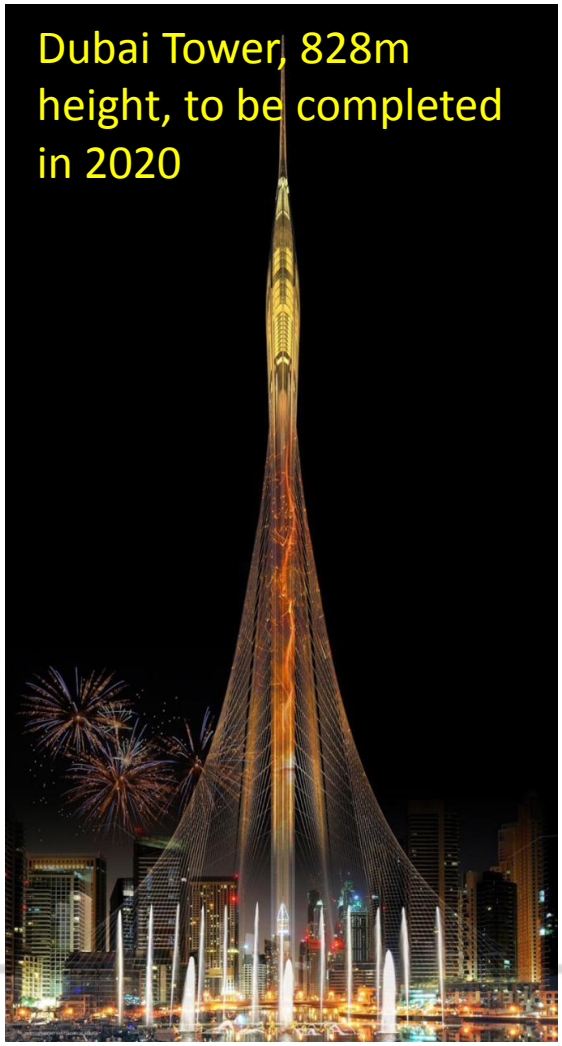
  Example: Grade 100 concrete in One Island East

  Grade 90 high modulus concrete in International Commerce Center (ICC)



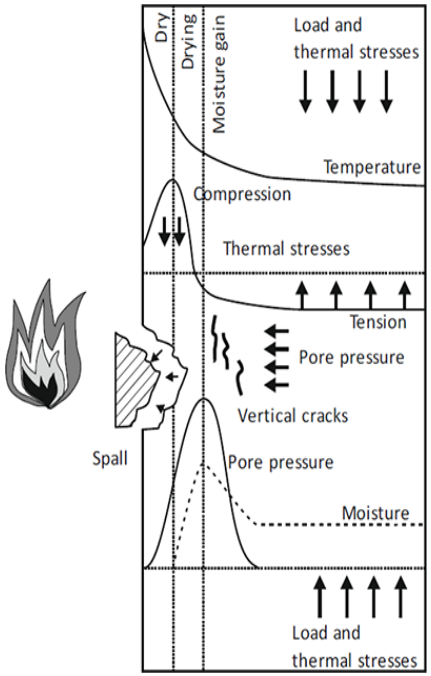
Market Need

- The market demands on **next generation concrete** materials are increasing, **aiming** at:
  - *Slimmer structures*
  - *Maximize usable floor area*
  - *Enhanced fire safety*
  - *Lower maintenance cost*
  - *Reduce carbon footprint*



Concrete Spalling at Elevated Temperature

- *Causes of explosive spalling –* ***build-up of pore pressure and thermal stresses***
- ***Lack of sufficient data*** *on design and performance of HSC under fire situation*



After Exposure to Fire

We have developed Grade 100 high strength concrete with following features:

- ***Compressive strength: > 120MPa***
- ***Fire resistance: At least 4 hours***
- ***Slump workability: > 150mm***

In Hong Kong Concrete Code (2013)

4.3.1.2 Methods to reduce risk of concrete spalling

At least one of the following methods should be provided.

(a) **Method A:** A reinforcement mesh with a nominal cover of 15mm. This mesh shall have wires with a diameter ≥ 2mm with a pitch ≤ 50 x 50mm. The nominal cover to the main reinforcement shall be ≥ 40mm; or

(b) **Method B:** Include in the concrete mix not less than 1.5 kg/m^3 of monofilament propylene fibres. The fibres shall be 6 – 12 mm long and 18 – 32 μm in diameter, and shall have a melting point less than 180°C; or

(c) **Method C:** Protective layers for which it is demonstrated by local experience or fire testing that no spalling of concrete occurs under fire exposure; or

(d) **Method D:** A design concrete mix for which it has been demonstrated by local experience or fire testing that no spalling of concrete occurs under fire exposure.

For high strength concrete exceeding C80, at least one fire test should be carried out to demonstrate that the main reinforcing bars of a structural member shall not be exposed during the design fire resistance rating. The test specimen should have moisture content not less than the highest moisture content that the structure may attain during its working life.

- ***Insufficient data for concrete > C80***
- ***Extra fire test is required for concrete > C80***

Project Objective

- **To develop NAMI's Fire resistant HSC which possess high strength and superior fire resistance**

Challenge of existing HSC:

- Uncertain fire resistance
  → *extra fire protection required that reduces usable space*
  → *necessitate costly fire test on case by case basis*
- Lowered workability due to addition of fibres for better fire resistance

NAMI's fire resistant HSC:

- Improved fire resistance
  → *eliminate extra fire protection*
  → *provide test data for exemption of case by case fire testing to save cost and time*
- Minimized workability reduction by optimized fibre efficacy

Our Approach in Developing Fire Resistance HSC

❖ Advanced Formulation Technique

- ➢ Select suitable ingredients such as OPC, Silica fume, PFA, GGBS, aggregates, admixtures etc.
- ➢ Optimize proportioning of ingredients to achieve strength, workability, temperature control and cost effectiveness

❖ Requirements for Fire Resisting Construction

- ➢ Hybrid Fibre Approach: Polypropylene (PP) fiber + Steel fiber
- ➢ To reduce risk of concrete spalling
- ➢ To minimize strength degradation under fire

Samples of Steel Fibers

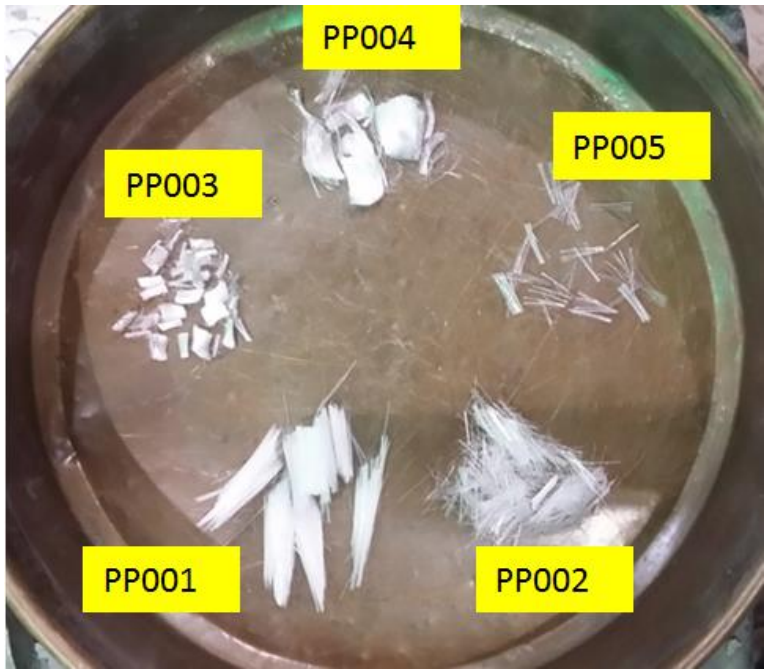
Samples of Polypropylene Fibers

Steel Fibers and Polypropylene Fibers

Hybrid Fibre Approach: Polypropylene (PP) fiber + Steel fiber

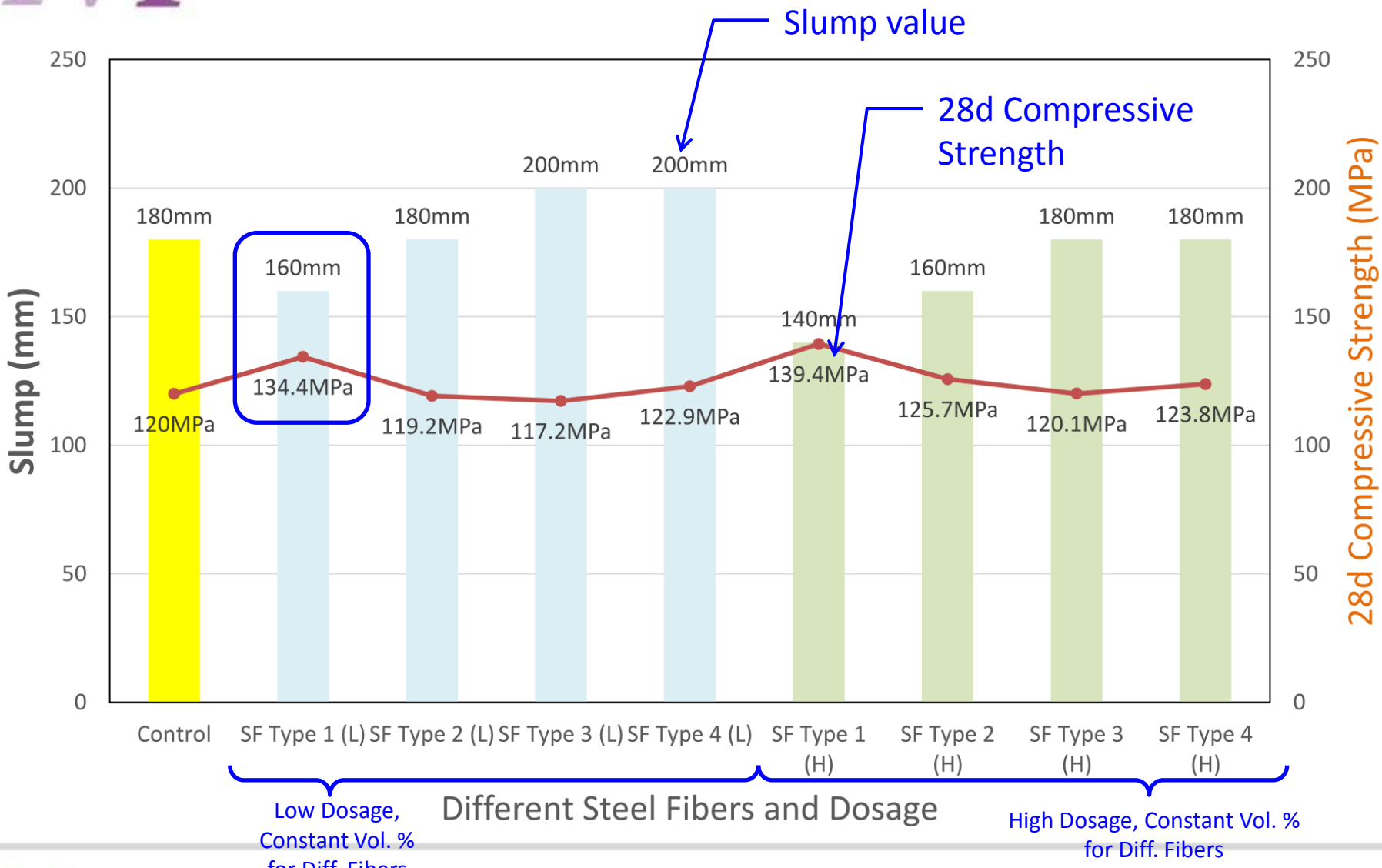
- Optimize the proportioning between steel and PP fibres
- Investigate the optimal geometry of steel fibre
- Study the length, cross-section size and effectiveness of PP fibre

Different types of Steel Fibers



Different types of PP Fibers

Effect of Steel Fibers on Slump and Compressive Strength



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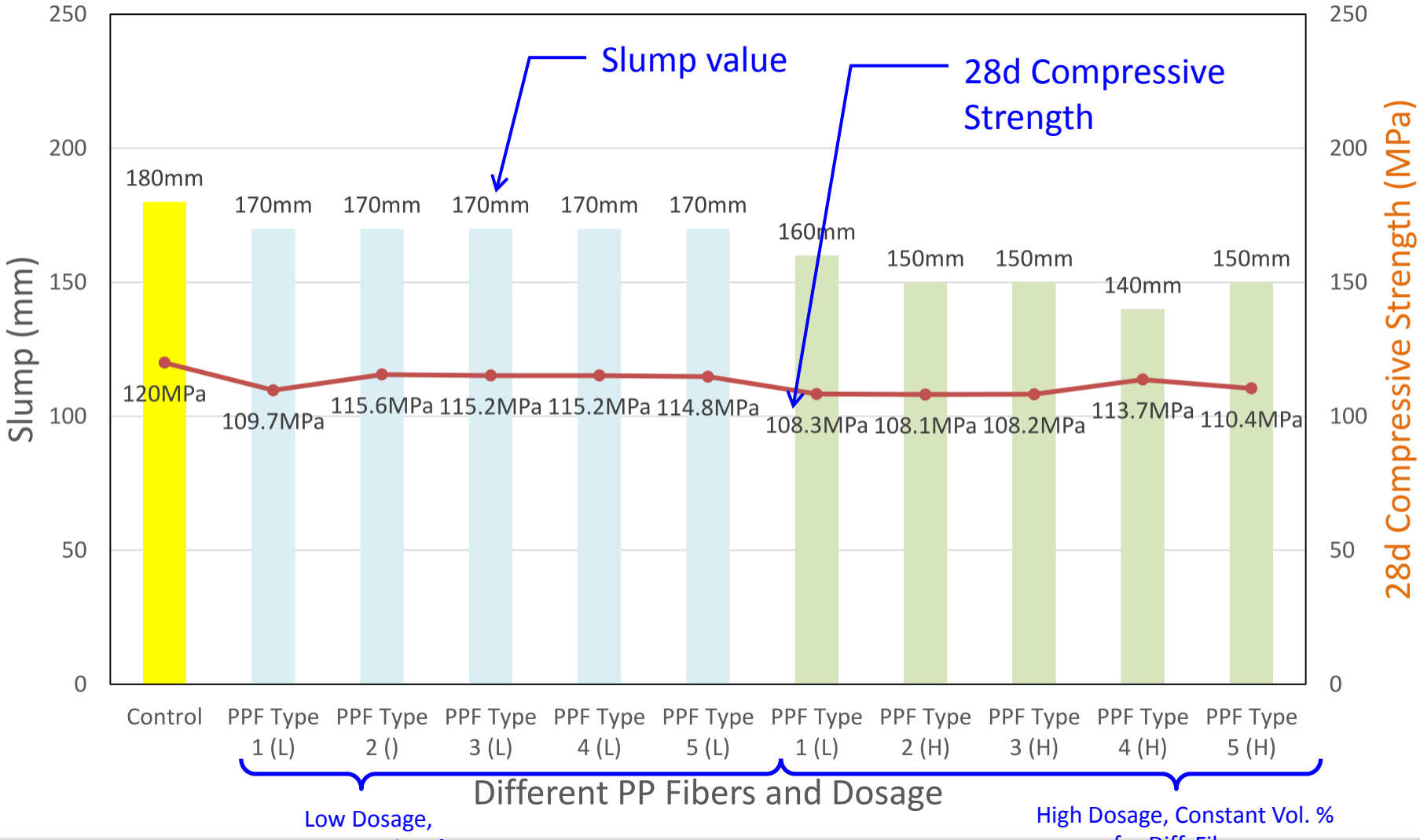


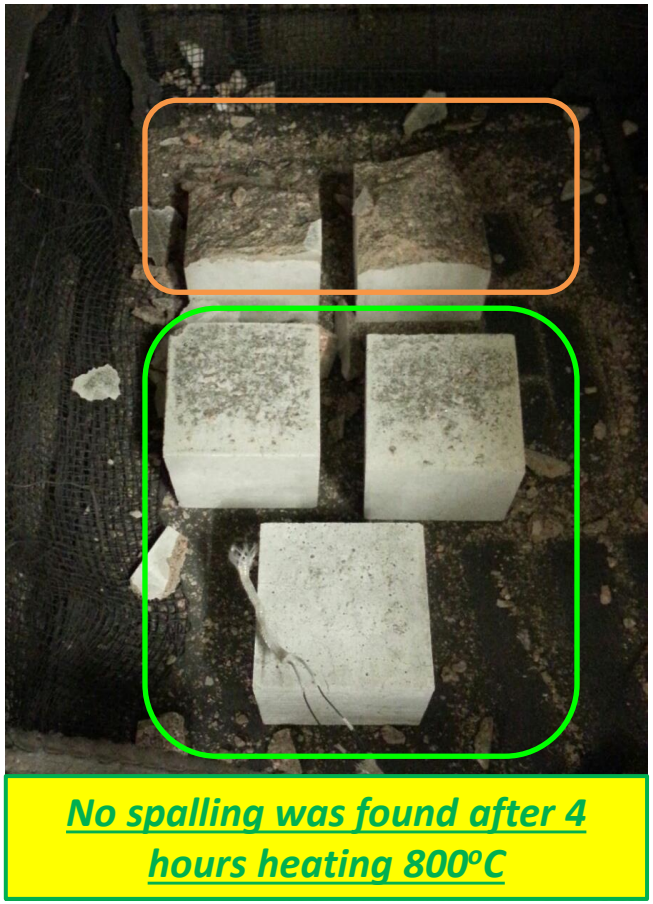
Compressive Strength and Elastic Modulus of NAMI's C80, C90 and C100

	C80	C90	C100
Slump	>150mm		
28d compressive strength	98.4MPa	111.8MPa	119. 4MPa
Elastic modulus	37.9GPa (>35.1GPa)	39.7GPa (>36.9GPa)	40.7GPa (> 38.7 GPa)

Small Scale Thermal Test at Lab

- The fire resistance of the developed formulations were evaluated by heating 100mm cube specimens in an oven that simulates temperature rise in fire test)

Control #1 Completely Destroyed

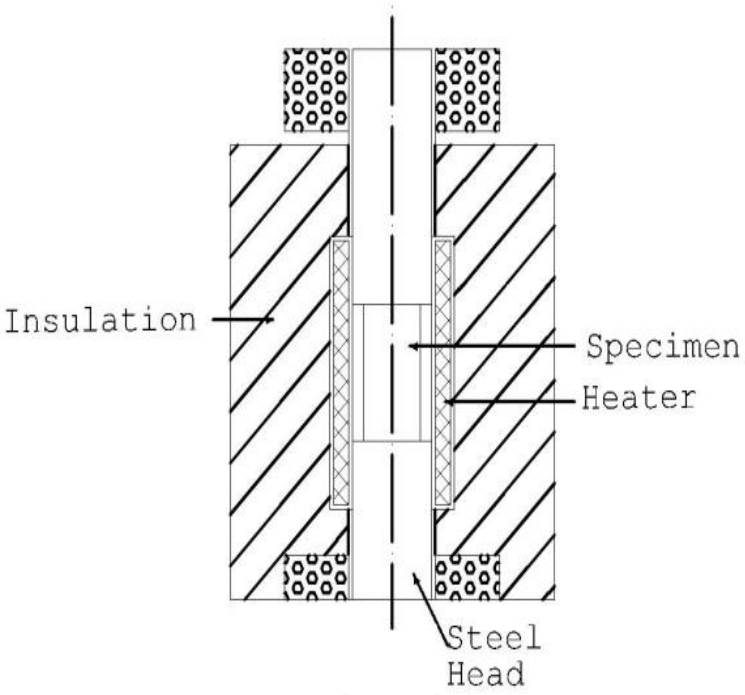


Control #2 Partially Spalled

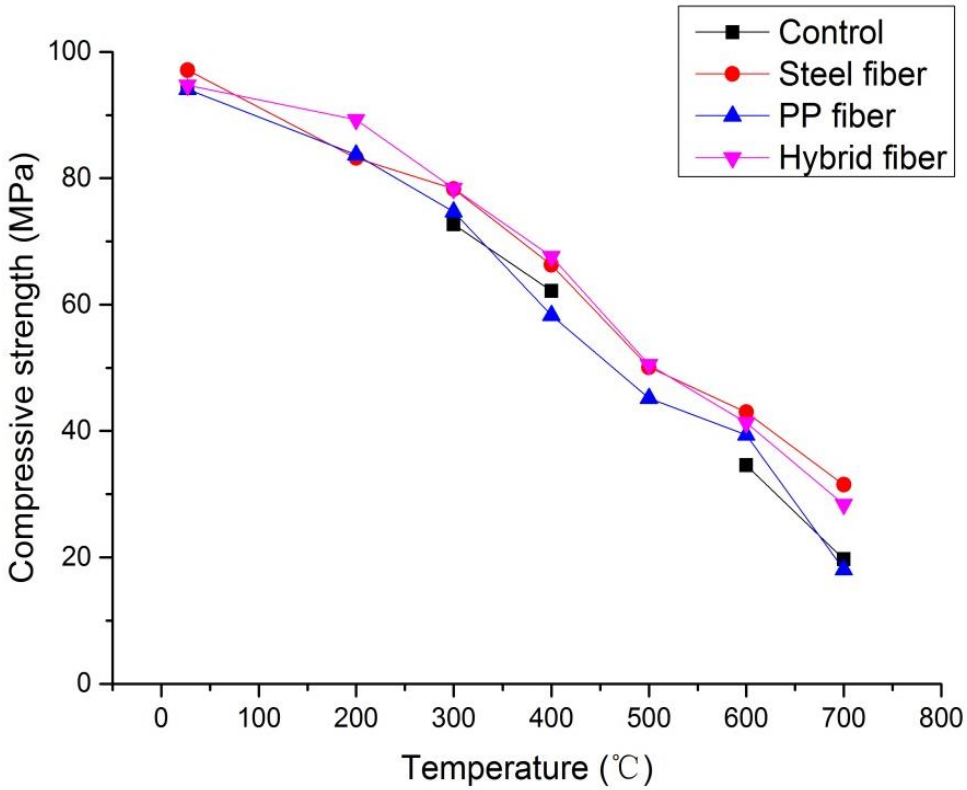
Specimen #3 Remain Intact

No spalling was found after 4 hours heating 800°C

Compressive Strength at elevated temperatures



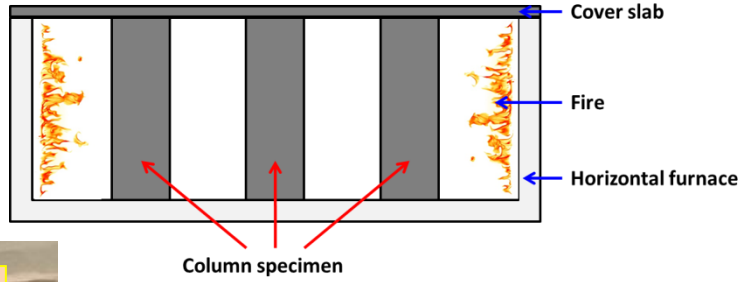
Schematic view of the furnace

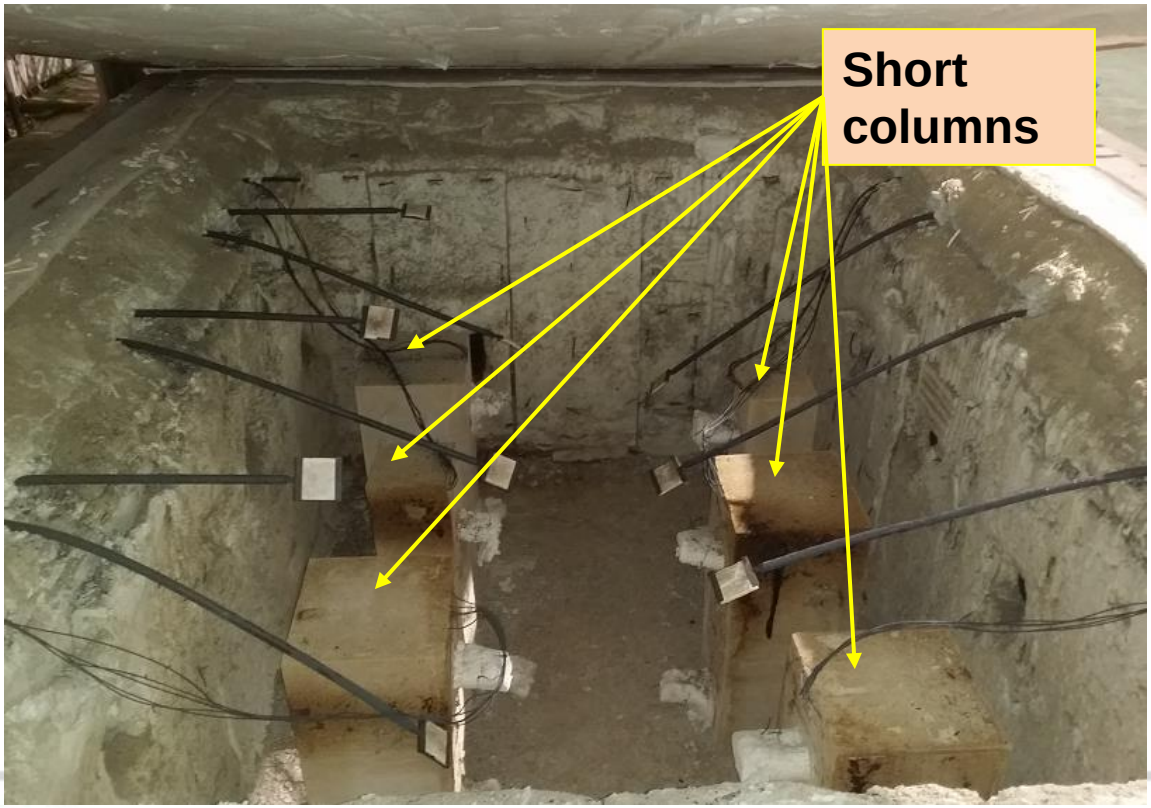


Fire tests on full-scale HSC columns (1/4)

Short column (1m long) in a furnace without loading (accorrding to BS EN 1365-1)

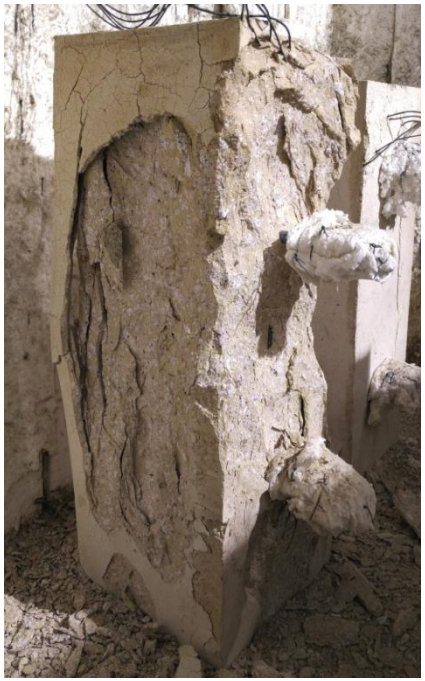
- **Exposure to fire for 4 hours**
- **Cover thickness: 30mm, 40mm**
- **Cross section: 250mm and 400mm SQ Columns**





Photos of HSC Samples after Fire Test

Fire tests on full-scale HSC columns (2/4)



Normal C100 HSC

Concrete cover spalled

NAMI's C80 **NAMI's C90** **NAMI's C100**

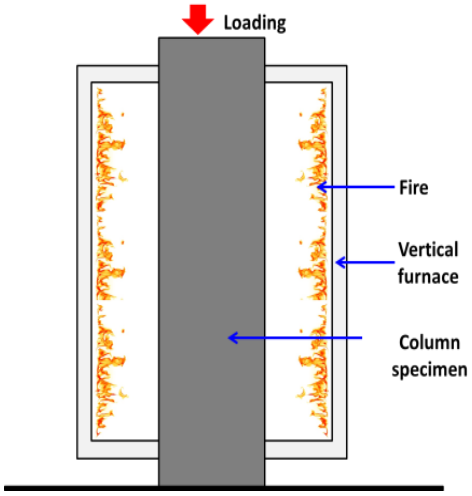
Structural integrity was maintained

Fire tests on full-scale HSC columns (3/4)

Long column (3.4m long) in vertical furnace

under loading (BS EN 1365-4)—testing up to 4 hours

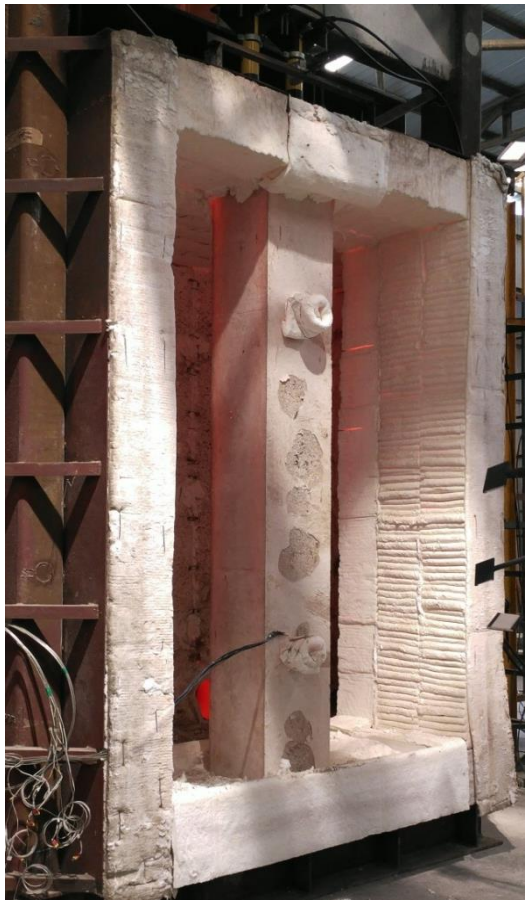
- **Cross section: 250mm SQ**



Construction of HSC Column Specimen

Fire tests on full-scale HSC columns (4/4)

2. Fire test on a long columns with loading



After 4 hours' fire test

- According to BS EN 1363-1, the NAMI's C100 concrete column was subjected to axial compression of 400 kN throughout the test
- The deformation was monitored during the fire test.
- NAMI's C100 concrete column exhibited positive elongation during the whole fire test and maintained its ability to support the test load during the test.

PASSED

Concluding Remarks

- **Fire resistant high strength concrete has been developed to support the growing demands from local market.**
- **This 100MPa+ concrete formulation has fulfilled HK Concrete Code, and can withstand 4 hours fire test.**
- **Strategic partnership with government, academia and industry is welcome to promote this technology for the benefits and sustainability of construction industry in Hong Kong.**


納米創意無止境
Thank you!