Improvement of Mechanical Performance of Fire-Damaged Concrete by Injecting Highly Permeable Silicate Solution

Tatsuya Kitada[1], Zhuguo Li[2]

1-Kyokuto Kowa Co., Ltd., Hiroshima, Japan, 2-Graduate School of Sciences and Technology for Innovation, Yamaguchi University

1. Introduction

Concern about environmental impact has led to the requirement of extending service life of concrete structure.

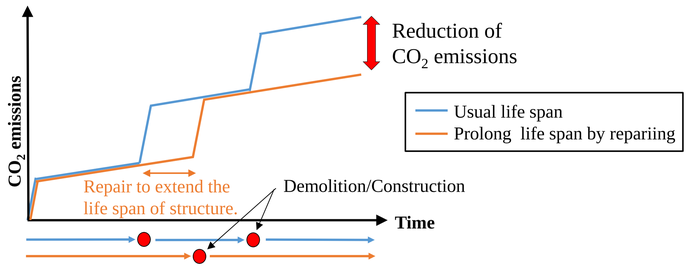
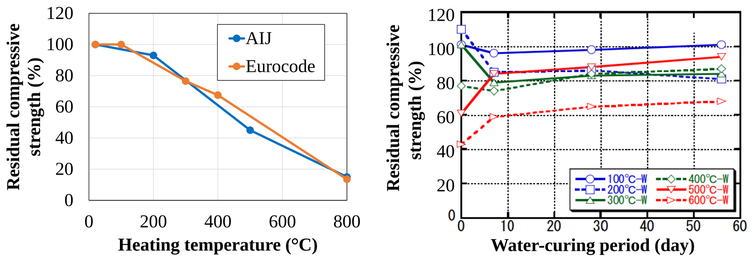


Fig. 1 Image of life cycle and CO_2 emissions of concrete structure

Fig. 2 Visual deterioration of concrete member after fire[1)]



(a) Heating temperature and strength loss[1), 2)] (b) Strength recovery by water-curing[3)]

Fig. 3 Strength loss and recovery of concrete after fire

Sources:
1) Eurocode 4, Design of Composite Steel and Concrete Structures - Part 1-2, CEN EN 19941-2:2005
2) Architectural institute of Japan (2017). "Guide Book for Fire-Resistive Performance of Structural Materials."
3) K, Ichise., T, Kakuhiro., N, Kawaguchi., S,Kawabe., "Strength Recovery of High-Strength Concrete Subjected to High-Temperature Heating.(Japanese)" Proceedings of the Japan Concrete Institute, Vol.25, No.1, 2003.

Objective: Development of repairing technique of fire-damaged concrete

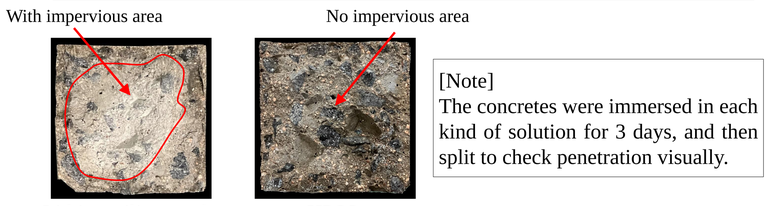
Contents : >Development of a repairing agent.
>Development of repairing method.
>Verification of strength recovery after repairing.

2. What is the repairing agent and how to repair?

Repairing material: Highly Permeable Silicate Solution (HPSS)

Table. 1 Chemical components of HPSS

SiO_2	Li_2O	H_2O	Na-based penetration enhancer
8.4%	1.26%	86.16%	4.16%



[Note]
The concretes were immersed in each kind of solution for 3 days, and then split to check penetration visually.

Fig. 4 Penetration of HPSS into concrete

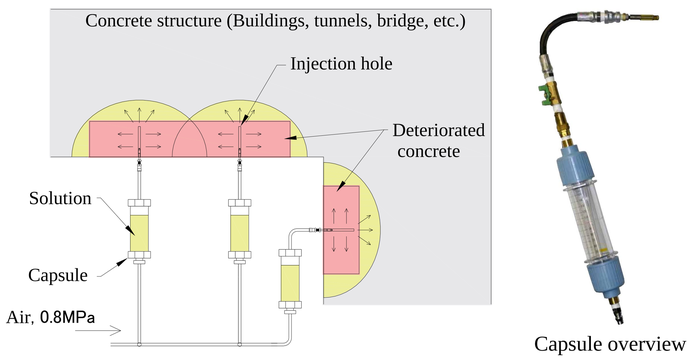


Fig. 5 Conceptual diagram of concrete repair by injection of HPSS

3. Experimental Program

① Preparation of concrete plates → ② Heating → ③ Repair by HPSS injection → Verification of repairing effectiveness

① Preparation of concrete plates

- Specimen size : 1,150 mm × 1,150 mm × 300 mm
- Compressive strength: 28.5 MPa (28-day old)
- Young's modulus : 34.1 kN/mm^2 (28-day old)
- Thermocouples were buried to measure inside temperatures of concrete plates during heating.

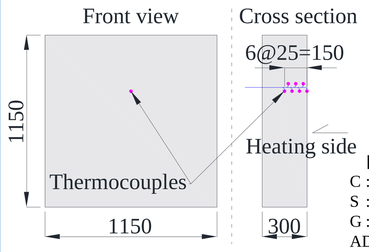


Fig. 6 Specimen outline

Table 2 Mix proportions of concrete used

W/C (%)	Unit mass (kg/m^3)				
	W	C	S	G	AD
84.8	190	224	987	924	0.67

[Notes]
C : Rapid hardening Portland cement (Density: 3.14)
S : Crush sand (Density: 2.64, F.M.: 2.68, Grading: 0-5 mm)
G : Crushed stone (Density: 2.68), F.M.: 6.70, Grading: 5-20 mm)
AD : Air entraining and high-range water reducer

② Heating

- Standard ISO 834 heating curve.
- Heating time : 50 minutes or 130 minutes.

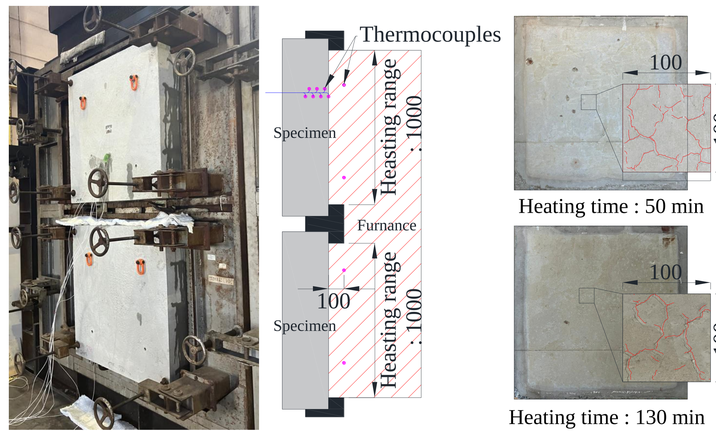
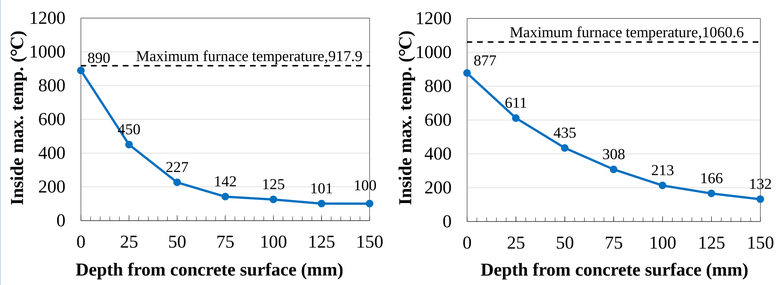


Fig. 7 Heating overview

Fig. 8 Cracks on the plate surfaces



(a) Heating time : 50 min (b) Heating time : 130 min

Fig. 9 Change of inside temperature with depth from heated surface

③ Repair by HPSS injection

- Capsules were attached to the injection holes (diameter 10 mm, depth100 mm) at the center of the heated plates.
- HPSS was injected at a pressure of 0.8 MPa.

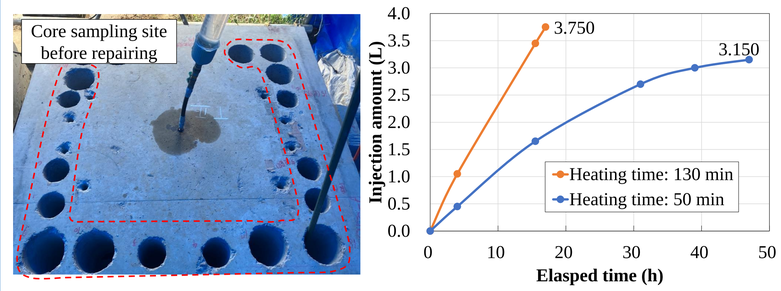


Fig. 10 HPSS injection **Fig. 11 Injection volume over time**

4. Verification of repairing effectiveness

① Strength estimation by mechanical impedance

Mechanical impedance was measured using a concrete tester, and calculated from the record of accelerometer embedded in the hammer using the reactive section.

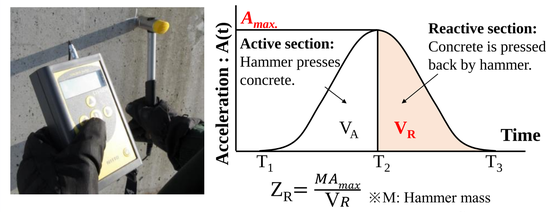


Fig. 12 Concept of Mechanical Impedance[4)]

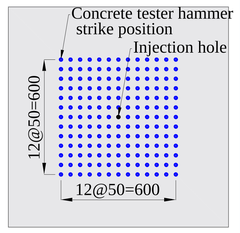
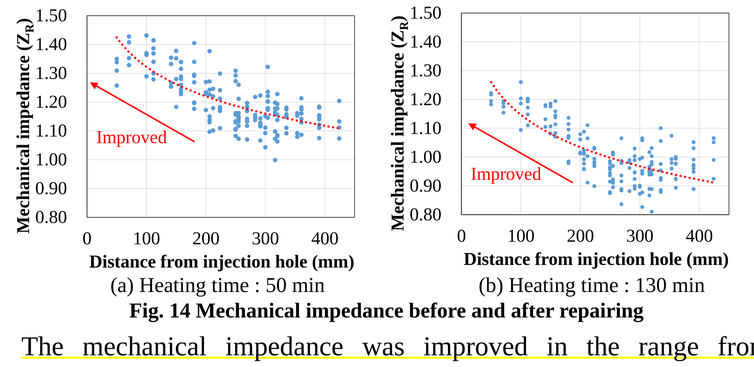


Fig. 13 Measurement positions

Source:
4) T. Tamai ., "On the Effects of Mechanical Impedance Test Methods." *Concrete Journal*, Vol.59, No.2, pp.157~164, 2021.



(a) Heating time : 50 min (b) Heating time : 130 min

Fig. 14 Mechanical impedance before and after repairing

- The mechanical impedance was improved in the range from injection hole to 200 mm.
- The closer to injection hole, the larger the mechanical impedance.

② Compressive strength of concrerte core

- Concrete core sampling
  > Before heating
  > Just after heating without repairing
  > After hearting and repairing/re-curing
- Re-curing
  > Air-curing of non-repaired cores: 20℃, 56 days
  > Water-curing of non-repaired cores: 20℃, 56 days
  > Air-curing of repaired cores: 20℃, 28 days

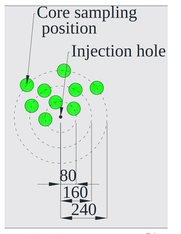
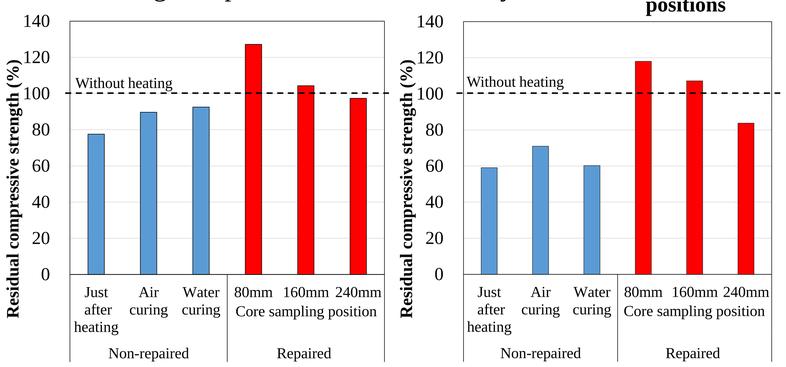


Fig. 15 Core sampling positions



(a) Heating time : 50 min (b) Heating time : 130 min

Fig. 16 Compressive strength before and after repairing

- Compressive strengths of the repaired cores were larger than those of non-repaired cores after heating, regardless of the core collection location and re-curing method.
- The cores taken at 80 mm and 160 mm after heating/repairing/re-curing had larger strengths than those taken before heating.

5. Conclusions

- Based on the mechanical impedance and the compressive strengths of concrete cores, the effective penetration range of HPSS under the injection condition of this study was judged to be about 200 mm.
- The closer to the injection hole, the more the strength recovery.
- The compressive strength of the concrete within the effective repairing not only exceeded that of the non-repaired but re-cured concrete, but also was larger than the strength before heating.