4. SHRINKAGE CRACKING CHARACTERIZATION

4.1 Restrained shrinkage

Figure 9 shows the restrained shrinkage strain results for the ring test. **Table 4** shows the occurrence of cracks in each test piece and the number of days until the occurrence of cracks. First, the shrinkage was started after casting, about 10 hours for CN11, 11 hours for CN9, after 12 hours for CN11, and after 36 hours for CN0. In particular, in the case of adding CN, shrinkage gradually occurred about 6 hours after casting. After that, cracks occurred in the process of increasing shrinkage. The cracking dates were 2.8 days for CN11, 3.6 days for CN9, and 4.4 days for CN7. Cracks tended to occur faster as the amount of CN increased. The restrained shrinkage strain at the time of cracking were 25μ for CN11, 27μ for CN9, 30μ for CN7. On the other hand, in the case of CN0, no cracks occurred during the measurement period of this experiment.

4.2 Restraint tensile stress and crack potential

The restraint tensile stress can be calculated by **Eq. (1)** using the radiuses of the concrete and steel ring, restrained shrinkage strain, and the elastic modulus of the steel ring assuming that the concrete poured into the ring specimen had uniform shrinkage in the shear plane with linear behavior **[11][12][13]**.

$$\sigma_{\theta imax} = \frac{({\gamma_{os}}^2 - {\gamma_{is}}^2)}{2{\gamma_{os}}^2} \cdot \frac{({\gamma_{im}}^2 + {\gamma_{is}}^2)}{({\gamma_{om}}^2 - {\gamma_{im}}^2)} \cdot E_{st} \cdot \varepsilon_{st} \quad (1)$$

Here, $\sigma_{\theta imax}$ refers to the restraint tensile stress, γ_{is} and γ_{os} refer to internal and external radii of the steel ring, γ_{im} and γ_{om} refer to the internal and external radii of the concrete, E_{st} refers to the elastic modulus, and ε_{st} refers to the restrained shrinkage strain.

Figure 10 shows the restraint tensile stress calculated by **Eq. (1)**. The restraint tensile stress tended to increase as the restraint shrinkage strain increased. The maximum restrained tensile stress was 1.8N/mm^2 for CN11, 1.9N/mm^2 for CN9, and 2.1N/mm^2 for CN7, and cracks occurred after reaching maximum tensile stress. The restrained tensile stress increased as the amount of CN added increased due to the increase in pressure generated in the inner steel ring. It was confirmed that this accelerates the occurrence of cracks in the mortar. It is considered that the stress relaxation was reduced by the tensile creep. On the other hand, the cracking potential was calculated by the ratio of restraint tensile stress/tensile strength. **Figure 11** shows the change in tensile strength over time, and **Figure 12** shows the crack potential in each case. The tensile strength was calculated by **Eq. (2)** using the result of the compressive strength **[14][15]**.

$$\sigma_B = 0.291 \cdot Fc^{0.658} \quad (2)$$

Here, σ_B refers to the tensile strength and Fc refers to the compressive strength.

In the case of adding CN, the cracking potential increased between the age of 1 day and 2 days. The possibility of the occurrence of cracking became very high at an early age, compared with the case of not adding CN. From this result, in the restraint conditions in this test, as the amount of CN increased, the shrinkage increased and the crack occurrence possibility increased.

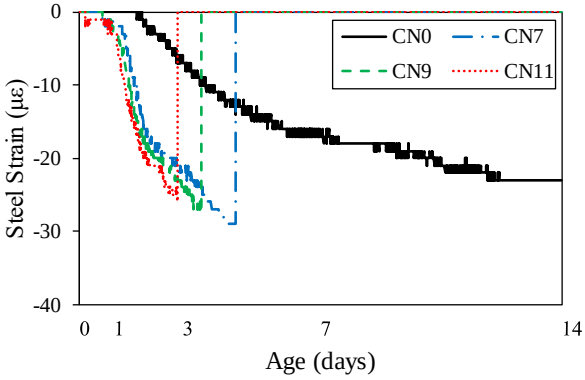


Figure 9. Restraint shrinkage

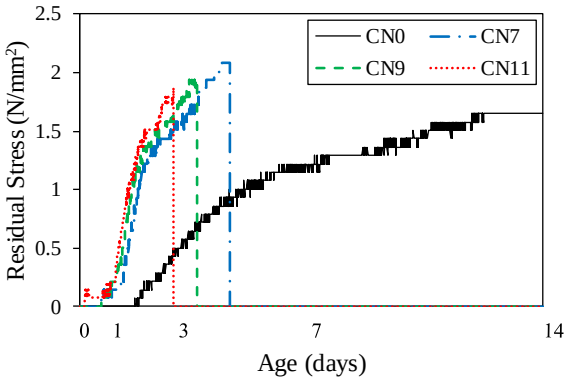


Figure 10. Restraint tensile stress

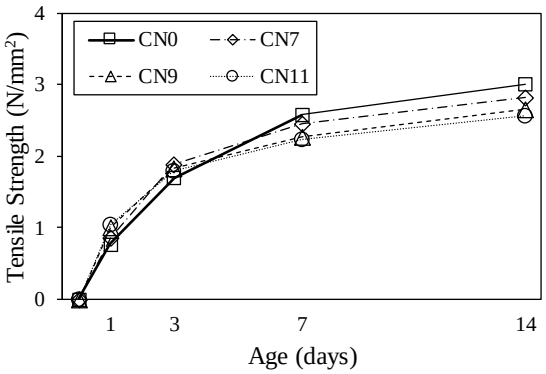


Figure 11. Tensile strength

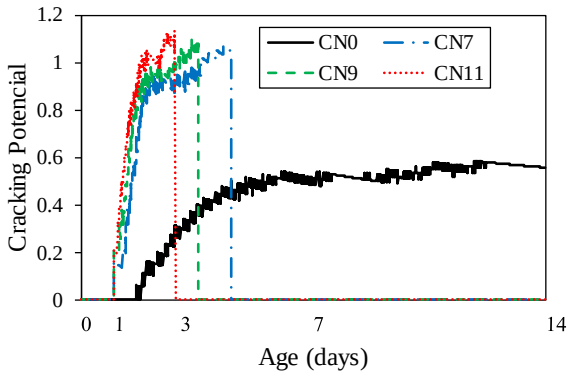
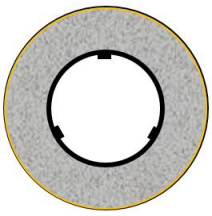
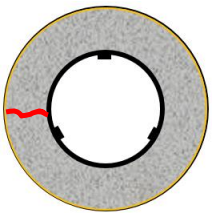
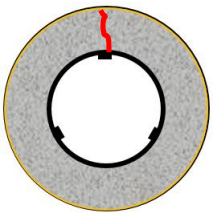
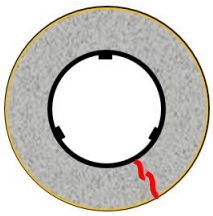


Figure 12. Cracking potential

Table 4. Crack configuration and cracking days

Cracking				
Case	CN0	CN7	CN9	CN11
Days of cracking	-	4.4 day	3.6 day	2.8 day

5. CONCLUSION

This study investigated the shrinkage and the cracking of concrete using a large amount of nitrite-based accelerator. The study results obtained the following conclusions.

1) When the amount of CN increased, hydration was accelerated, the mortar temperature increased immediately after casting, and the fluidity decreased.
2) At day 1, the addition of a large amount of CN promoted hydration and formed a large amount of nitrite/nitrite hydrate, resulting in dense voids and increased strength.
3) As the amount of CN increased, shrinkage increased and the start time of shrinkage became earlier.
4) In the restraint conditions in this study, from the results of the restraint shrinkage strain and the cracking potential, as the amount of CN increased, the shrinkage and the crack occurrence possibility increased.

REFERENCES

1. Architectural Institute of Japan: Cold-concrete concrete construction guidelines / commentary, 5th edition, 1st edition, pp.252-254, 2010.1
2. Material Society of Japan: Concrete Admixture Materials Handbook, pp.172-175, 2004.4
3. Ministry of land, Infrastructure and Transport (Japan); anti-freezing agent operation manual(draft), March, 2005
4. M. IWASAWA, M. INOUE, H.S. CHOI, Y. SUDOH：Study on fresh properties and strength development of mortar using nitrite-based accelerator and various water reducing agents, Proceedings of the Japan Concrete Institute, Vol.40, No.1, pp.243~248, 2018.
5. Ramachabran, V.S.：Concrete Asmixture Handbook, Noyes Publications, U.S.A., pp.741-799, 1995
6. Japanese Architectural Standard Specification for Reinforced Concrete Work JASS5 2018
7. Yukio Hama, Eiji Kamada:Effects on Protection Fresh Concrete Against Frost Damage by Non-chloride and Non-alkali Type Antifreezing Admixtures, Concrete Research and Technology , Vol. 7, No. 1,pp.113-122, Jan. 1996
8. P. Kumar Mehta, Paulo J. M. Monteiro：CONCRETE, Microstructure, Properties, and Materials Second Edition, Mc Graw Hill, pp.181-227, 1995
9. M.Balonis et al.：Influence of calcium nitrate and nitrite on the constitution of AFm and Aft cement hydrates, Advanced in Cement Research, Vol.23, issue 3, pp.129-143, 2011
10. Heesup CHOI, Masumi INOUE, Hyeonggil CHOI, Jihoon KIM, Yuhji SUDOH, Sukmin KWON, Bokyeong LEE, Akira YONEYAMA：Physicochemical Study on the Strength Development Characteristics of Cold Weather Concrete Using Nitrite･Nitrate-Based Accelerator, Journal of the Materials, Vol.12, No.17, pp.1~14, 2019.
11. Hossain AB, Weiss WJ.：Assessing residual stress development and stress relaxation in restrained concrete ring specimens, Cement and Concrete Composites, Vol.26, No.5, pp.531~540, 2004
12. Weiss WJ, Fergeson S.：Restrained Shrinkage Testing: The Impact of Specimen Geometry on Quality Control Testing for Material Performance Assessment: Concreep 6, Creep, Shrinkage, and Durability Mechanic of Concrete and other Quasi-Brittle Materials. Ulm FJ, Bazant ZP, and Wittman FH, eds., Elsevier, Cambridge MA, pp.645~651, 2001.
13. Ugural AC, Fenster SK.：Advanced Strength and Applied Elasticity, 3rd ed. America, New Jersey, Prentice Hall PTR, Inc., pp.327~334, 1995.
14. Noguchi T, Tomozawa F.：Relationship between compressive strength and various mechanical properties of high strength concrete, Journal of Structural and Construction Engineering, Vol.60, No.472, pp.11~16, 1995.
15. Choi HG, Lim MK, Kitagaki R, Noguchi T, Kim GY.：Restrained shrinkage behavior of expansive mortar at early ages, Construction and Building Materials, Vol.84, No.1, pp.468~476, 2015.