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Study on Resistant Properties for Cracking Caused by Shrinkage with Volume Change of Concrete Using High Volume Blast Furnace Slag Cement

Jun-ichi Arai[1], Kousuke Ishizeki[2a], Tetsushi Kanda[2b], Masaro Kojima[3] and Toshiaki Mizobuchi[4]

[1] *Major of Civil and Environmental Engineering, Graduate school of Engineering and Design, Doctoral Program; HOSEI University, 2-33 Tamachi-Ichigaya, Shinjuku-ku, Tokyo, 162-0843, Japan Email: <arai@retec.co.jp>*

[2] *Building Construction Group, KAJIMA Technical Research Institute; KAJIMA Corporation, 2-19-1 Tobitakyu Chofu city, Tokyo, 182-0012, Japan* [2a]*Email: <ishizeki@kajima.com>,* [2b]*Email:<kandat@kajima.com>*

[3] *Takenaka Research & Development Institute; Takenaka Corporation, 5-1, 1-chome Otsuka, Inzai-city, Chiba, 270-1735, Japan E-mail: <kojima.masarou@takenaka>*

[4]*Faculty of Engineering and Design; HOSEI University, 2-33 Tamachi-Ichigaya, Shinjuku-ku, Tokyo, Japan, 162-0843 Email:<mizobuch@hosei.ac.jp>*

ABSTRACT

In this study, using a new high volume blast furnace slag cement type C developed in order to improve the effect of inhibition of thermal crack in concrete and the resistance of thermal crack by means of expansion strain in early age obtained by appropriately selecting the dosage of gypsum and calcium carbonate, experiments to evaluate the material were carried out using the testing device in which it was possible to simulate the behavior of thermal stress inside the member in existing structure in the laboratory in order to evaluate the resistance of cracking of concrete. As the result, it was confirmed to have the resistance of crack in which concrete used the new high volume blast furnace slag cement type C was more superior to concrete using Ordinary Portland cement and Portland blast furnace slag type B on the cracking time and stress at cracking. Furthermore, it was also confirmed to the effect of stress relaxation caused by creep in which concrete used the new high volume blast furnace slag cement type C was more superior to the above concrete.

INTRODUCTION

Cracks occurred in a concrete structure may sometimes influence in durability and aesthetics. In various causes of the cracking, as the factors of cracking caused by shrinkage with the volume change in the early age, there are thermal crack with heat of hydration of cement and autogenous shrinkage. It is important to take measures to control of crack considering these factors in reduction of the initial defect and improvement of durability of concrete structure. In the meantime, it is one of the effective measures to use the low heat cement of which heat of hydration of cement is variously small within any measures of control of cracking. However, most of low heat cement has the problem that the strength development is dilatory in early age. In addition, as temperature inside member of concrete using the convenient blast furnace slag cement which used to be the low heat cement rises further than that of concrete using ordinary Portland cement under the identical mix condition in hot weather by making the fineness of ground granulated blast-furnace slag fine in order to increase strength in early age, it has some problems that the probability of cracking caused by thermal stress increased and that the coefficient of thermal expansion is bigger than Portland cement and that autogenous shrinkage and neutralization rate of concrete using the convenient blast furnace slag cement are bigger than that of concrete using the ordinary Portland cement. On the other hand, it has also some advantages that enhancement of long-term strength is big for the concrete using blast furnace slag cement and the blast furnace slag cement is superior in seawater resistance and chemical resistance and the blast furnace slag cement is superior in environmental performance of reducing the discharge of CO_2, because it is possible to reduce the clinker content.

Then, in this study, in order to solve some problems on blast furnace slag cement shown above, a new high volume blast furnace slag cement type C (hereafter referred to as ECM), in which while the effect of the inhibition of thermal crack was improved, the resistance of thermal cracking by means of the expansion strain in early age obtained by appropriately selecting the dosage of gypsum and calcium carbonate was improved, was developed. In this study, in order to evaluate the resistance of cracking of concrete using developed ECM, the comparison with the resistance for crack of concrete using ordinary Portland cement and blast furnace slag cement under same condition was carried out by using the testing device (TSTM: Thermal Stress Testing Machine) that is in which it was possible to simulate the behavior of thermal stress inside the member in existing structure in the laboratory. In this report, while these experimental results are reported, the results of investigating on mechanical properties of tensile strength and creep which influence in the resistance of crack are also reported.

OUTLINE OF STUDY

In this study, as one for evaluating the potential of the resistance of crack in concrete using ECM, the resistance of crack of ECM was compared with that of ordinary Portland cement (hereafter referred to as N)and convenient Portland blast furnace slag cement type B (hereafter referred to as BB)used for many concrete structures by complementing measurement of time, stress and strain at the cracking under perfect restraint condition using TSTM in which it is the possible testing device to simulate the both behavior of temperature and stress in existing structure in the laboratory.

The property which is important when evaluating this resistance of crack is the tensile strength which is material potential of concrete and the creep in which the stress is made to reduce for the thermal stress and the autogenous shrinkage stress in the member of concrete. In this study, the difference between ECM and other cement was investigated from the viewpoint of the mechanical properties of tensile strength and property of creep which affect the resistance of crack.

The structure with the object in this study is the wall structure of 2.0 m thickness, 4.0m height and 20m length. The behavior of temperature and stress in the central of the member was the subject of investigation. The concrete as the target of investigation satisfies the condition of mix proportion in which the compressive strength at the age of 28 days reaches over 40N/mm^2, slump is 15cm and air content is 4.5%.

Method of investigation. The experiment using TSTM was carried out to three cases of concrete using ECM cement, concrete using ordinary Portland cement and concrete using convenient Portland blast furnace slag cement type B. Table-1 shows the cases studied. The concrete temperature at placement was 30^{o}C of the hot weather in which construction condition was severe. Table-2 shows mix proportion of each case.

Table 1. Case studied

Case	Type of cement	Target compressive strength at age of 28 days	Target slump (cm)	Degree of restraint (TSTM)	Concrete temperature at placement
1	ECM				
2	N	40N/mm^2	15.0	1.0	30^{o}C
3	BB				

Table 2. Mix proportions

Case	Type of cement	W/C (%)	s/a (%)	Unit quantity (kg/m^3)			
				Water	Cement	Sand	Gravel
1	ECM	42.0	44.0	178	424	732	968
2	N	51.6	45.0	168	326	794	996
3	BB	48.4	44.8	166	343	781	988

Overview of TSTM. TSTM was designed such that it could be used to control flexibly the temperature rise and the temperature drop due to heat of hydration of cement near the center of members in mass concrete structures from the start of concrete placement. A displacement control mechanism consisting of an actuator was installed so that the thermal expansion due to the heat of hydration and shrinkage due to the drop in temperature could be controlled under arbitrary restraint conditions. There were two kind of test specimens used in the TSTM. One is with arbitrary degree of restraint as shown in figure 1 (hereafter referred to as "restrained specimen") and another one is in the unrestrained condition (hereafter referred to as "unrestrained specimen"). The restrained specimens were of size $150 \times 150 \times 1500$ mm. The length of the specimen gripped in the restraining equipment is the effective length for the test. This length was 1000 mm. To minimize the pullout or slip in the area under tension in the part gripped by the restraining equipment, the width at the ends of the specimen was fanned out and tapered to a gradual curve so as to prevent stress concentration at the boundary of the gripped area and the restraining equipment. The test specimen was covered with sheet to prevent dissipation of water before performing the tests. Thermal analysis of the structure to be investigated was performed during prior investigations. The relationship between age and temperature were input in the personal computer, used as a control device of the simulator. For post analysis, the measured data were input together with the measurement times. Although time intervals are arbitrary, the interval of temperatures lying between the already-input temperatures was obtained by straight-line interpolation on the personal computer so that abrupt temperature changes were not considered.

Holes were made to form around the test specimen and hot or cold water can be passed through these holes for regulating the temperature and for achieving the preset historical curve of temperature. Insulating materials were used to cover the test specimen so that temperature changes in the ambient air did not affect the tests and heat dissipation from the holes was prevented. Temperature sensors were embedded at 5 locations in the restrained specimens and at 3 locations in the unrestrained specimens to confirm and control the temperature of restrained and unrestrained test specimens to the preset temperature. The temperature sensors at the center of the restrained and unrestrained specimens were used as temperature control sensors.

During the tests, the temperatures at the two locations mentioned above were measured at two-second intervals to check whether the temperature at that instant differed from the preset temperature. If the difference did exist, the temperature of water flowing through the holes was changed so that it coincided with the temperature of the specimen. The initial setting time was decided as the start of the test.

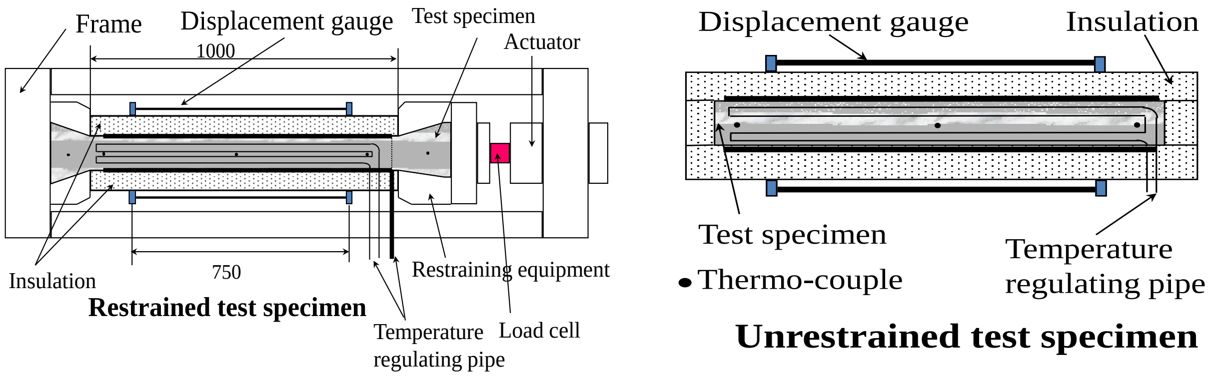

Figure 1. Overview of thermal stress testing machine

Mechanical property test. In each case, Compressive strength test, Splitting tensile strength test and Young's modulus test were carried out at age of 3days, 7days, 14days, 28days and cracking time.

RESULTS AND DISCUSSIONS

Thermal and strain properties. Figure 2 shows the preset historical curve of temperature and measurement of temperature in each case. As shown in figure 2, the behavior was almost similar to each case with preset historical curve of temperature. While figure 3 shows the strain history curve in the unrestrained specimen, figure 4 shows the relationship between temperature change amount and strain change amount from the test start. The strain of unrestraint specimen in this experiment (hereafter referred to as "free strain) is used as the result of adding thermal strain and autogenous shrinkage strain. As shown in figure 3 and figure 4, expansion strain of about 230×10^{-6} was occurred in spite of the temperature change amount being about 2ºC on ECM from the test start by temperature adjusted age of concrete of 15 hours (age of 9 hours). It seems that since the hydration with the calcium aluminate mineral (C_3A) formed the ettringite by appropriately selecting the dosage of gypsum and calcium carbonate which are one of the features of ECM, the expansion strain was occurred. In this expansion strain in the extreme early age, the expansion strain of concrete using ordinary Portland cement was 140×10^{-6} and that of concrete using Portland blast furnace slag cement was 360×10^{-6}, while the compressive strain of concrete using ECM cement at the age of 14 days was 410×10^{-6}. It seems that the expansion in the extreme early age according to some kind of effect of chemical pre-stress was brought about improvement of the delay at cracking age and the resistance of cracking by the increase in the cracking strength. From the relationship between temperature change amount and strain change amount from the test start, figure 5 shows the results of calculating the thermal expansion coefficient in each case.

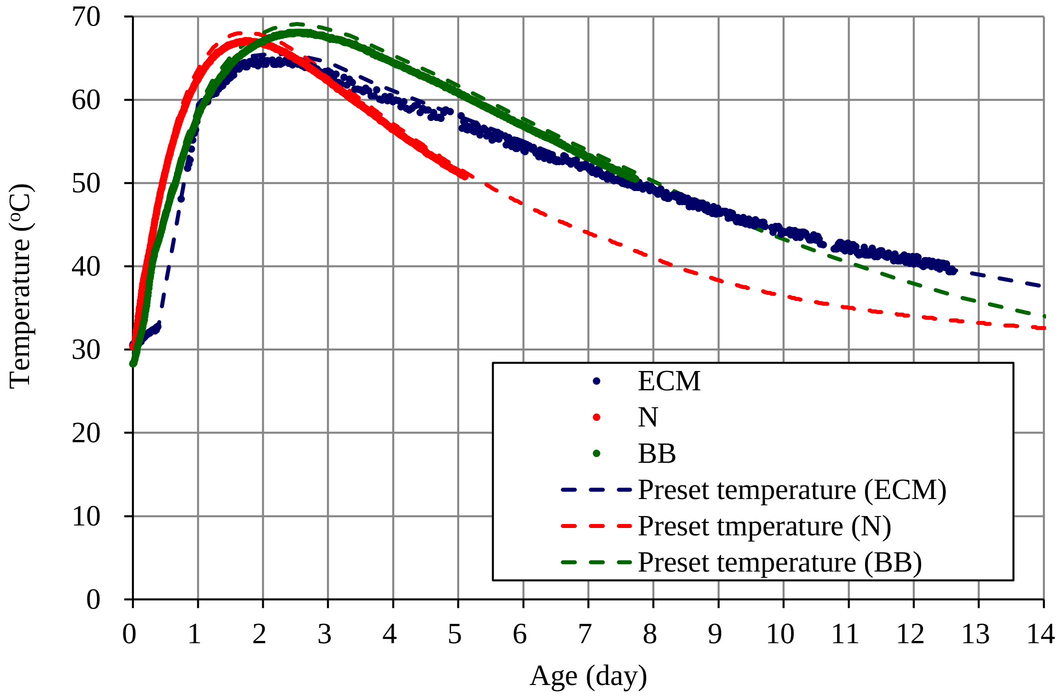

Figure 2. Historical curves of temperature

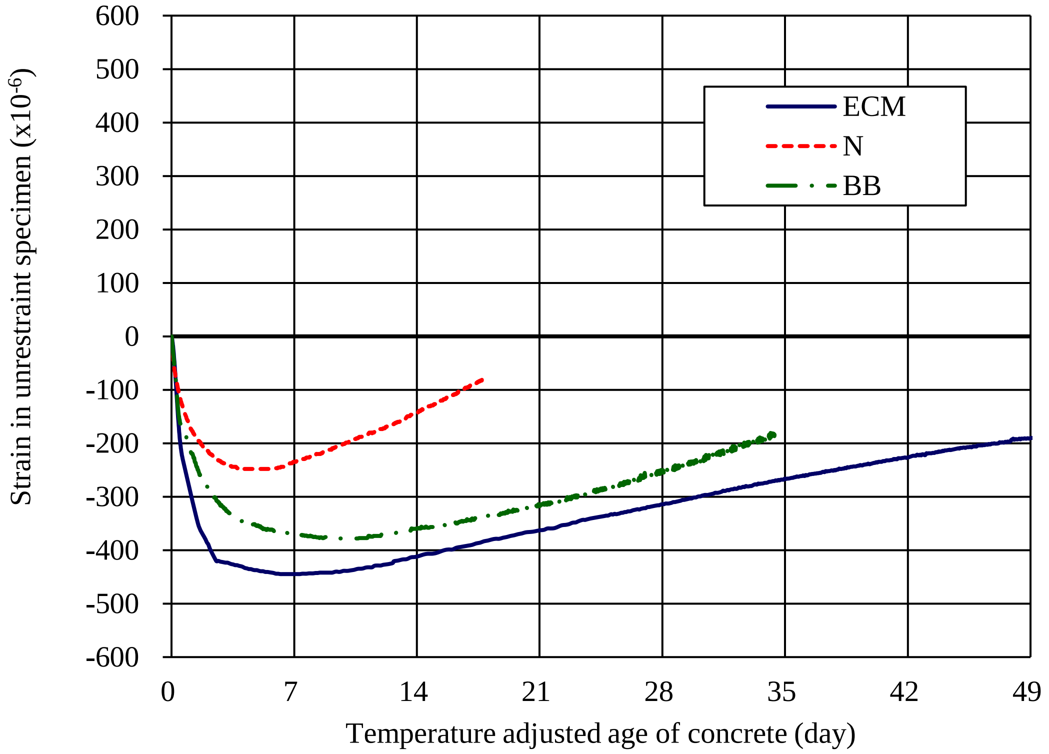

Figure 3. Historical curves of strain in unrestraint specimen

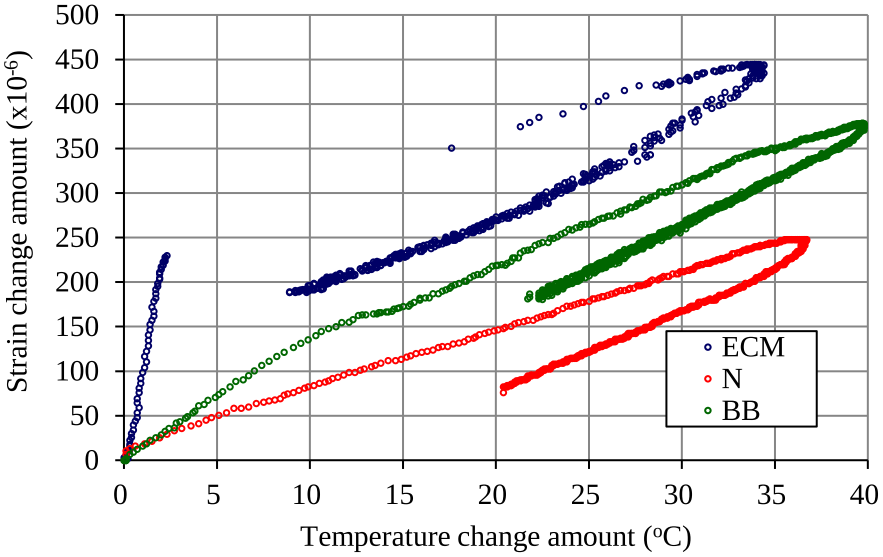

Figure 4. Relationship between temperature change and strain change

As shown in figure 5, by the expansion strain mention above, the apparent thermal expansion coefficient of ECM was about 96×10^{-6} from the test start to the age of 9 hours and was over ten times as large as another interval. The apparent thermal expansion coefficient since then was 5.75×10^{-6}/°C in the interval of temperature rise and was 5.05×10^{-6}/°C in the interval of temperature drop. On the other hand, the apparent thermal expansion coefficient of N was 6.75×10^{-6}/°C in the interval of temperature rise and was 10.1×10^{-6}/°C in the interval of temperature drop and the apparent thermal expansion coefficient of BB was7.69×10^{-6}/°C in the interval of temperature rise and was 11.3×10^{-6}/°C in the interval of temperature drop. As the reason why the apparent thermal expansion coefficient of ECM was smaller than another case, ECM was due to use the limestone crushed sand for the half of fine aggregate, while N and BB used only river sand for fine aggregate.

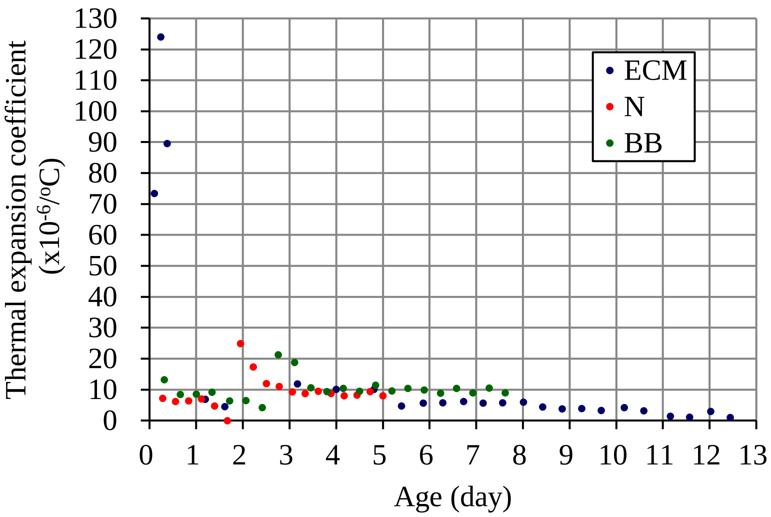

Figure 5. Relationship between thermal expansion coefficient and age

Stress property. Figure 6 shows the historical curve o stress measured in restraint specimen. As shown figure 6, in the case of concrete using ECM, crack was occurred at temperature adjusted age of concrete of 48 days in which tensile stress reached 2.58 N/mm^2. It is possible to evaluate that tensile stress and tensile strength were almost equivalent (crack index 1.05), though the stress in cracking is a little smaller than tensile strength (2.70N/mm^2) at that time. In the case of concrete using N, crack was occurred at the occasion in which tensile stress reached 1.92 N/mm^2. At that time, tensile strength was 2.35N/mm^2 and the crack index was 1.23. In the case of concrete using BB, crack was occurred at temperature adjusted age of concrete of 26 days in which tensile stress reached 2.18 N/mm^2. At that time, tensile strength was 2.63N/mm^2 and the crack index was 1.66.

From the above results, in the cracking age which was one of factors of the resistance of crack, ECM improved 2.7 times in that of N and 1.8 times in that of BB. Furthermore, in the stress of cracking, ECM improved 1.3 times in that of N and 1.2 times in that of BB. While the stress at the cracking of concrete using ECM has the potential which is almost equivalent to the tensile strength (splitting tensile strength) which is an index to the resistance of crack, that of concrete using N has only 0.8 times of potential that the tensile strength has and that of BB has only 0.6 times of potential of the tensile strength. From these points, while the resistance of crack is possible to be evaluated to some extent by the splitting tensile strength in ECM, it seems that it estimate the resistance of crack in dangerous side to be evaluated by the splitting tensile strength in the case of BB. Therefore, in case of BB, it is necessary that the potential of tensile strength is evaluated by reducing at about 40%, if this result is followed. It seems that the resistance of crack under the similar condition of mix proportion for the concrete using ECM is 20% to 30% higher than that of N and BB.

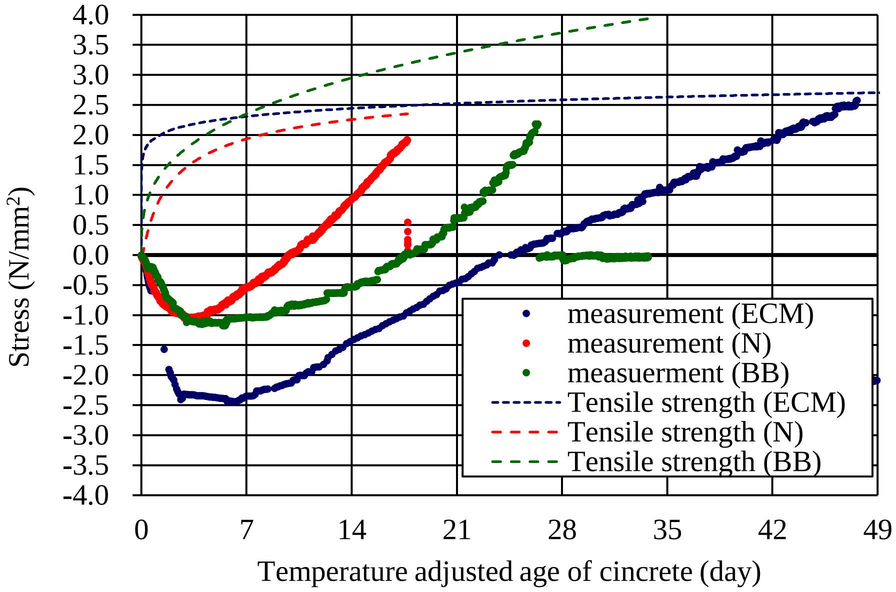

Figure 6. Historical curves of stress and tensile strength

Creep property. Next, the comparison on the apparent creep property of each case was carried out. First of all, from the results of Young's modulus test carried out at each age of 3days, 7 days, 14 days, 28 days and cracking, the relationship equation between temperature adjusted age of concrete and Young's modulus E_c in the following was calculated.

$$E_c = E_{28}\left(e^{\alpha\left[1-\left(\frac{28}{t_e}\right)^{0.5}\right]} \right)^{0.5} \tag{1}$$

Where, E_{28} is Young's modulus at the age of 28 days (N/mm^2), α is coefficient dependent on age and t_e is temperature adjusted age of concrete (day).

Apparent Young's modulus including creep was calculated by dividing the stress measured in the restraint specimen in the restraint strain ε_r which subtracted the free strain (thermal strain ε_t and autogenous shrinkage strain ε_{as}) in the unrestraint specimen from the total strain ε_a.

$$E_{eff} = \frac{\sigma_c}{\varepsilon_r} = \frac{1}{1+\phi} E_c \qquad (2)$$

Where, E_{eff} is apparent Young's Modulus (N/mm^2), σ_c is stress in the restraint specimen (N/mm^2), ϕ is creep coefficient. Here, apparent Young's Modulus was calculated from the interval which seemed to be the linear from the relationship between stress and restraint strain shown in figure 7. Figure 8 shows the historical curves of Young's modulus and apparent Young's modulus. On the basis of the historical curves of Young's modulus shown in figure 8, figure 9 shows the result of calculating the ratio between Young's modulus and apparent Young's modulus. In figure 8, in this study, as it is possible that the ratio between Young's modulus and apparent Young's modulus is considered a reducing rate of Young's modulus with the effect of creep, the reducing rate was divided into the interval where compressive stress increased, compressive stress reduced and tensile stress increased. As shown in figure 9, in the interval where compressive stress increased, the reducing rate of Young's modulus in BB showed 0.47 and was about 0.1 larger than that of another case, while the reducing rate of Young's modulus was 0.35 to 0.36 in ECM and N. In reducing interval after the compressive stress reached largest, the reducing rate of ECM was the largest because while the reducing rate in N did not almost change in the interval where compressive stress increased, as the reducing rate in ECM changed about two times between the interval where compressive stress increased and the interval where compressive stress reduced, it seemed that the apparent Young's modulus was calculated small compared with another case in the interval where compressive stress increased by the effect of the expansion strain in extreme early age.

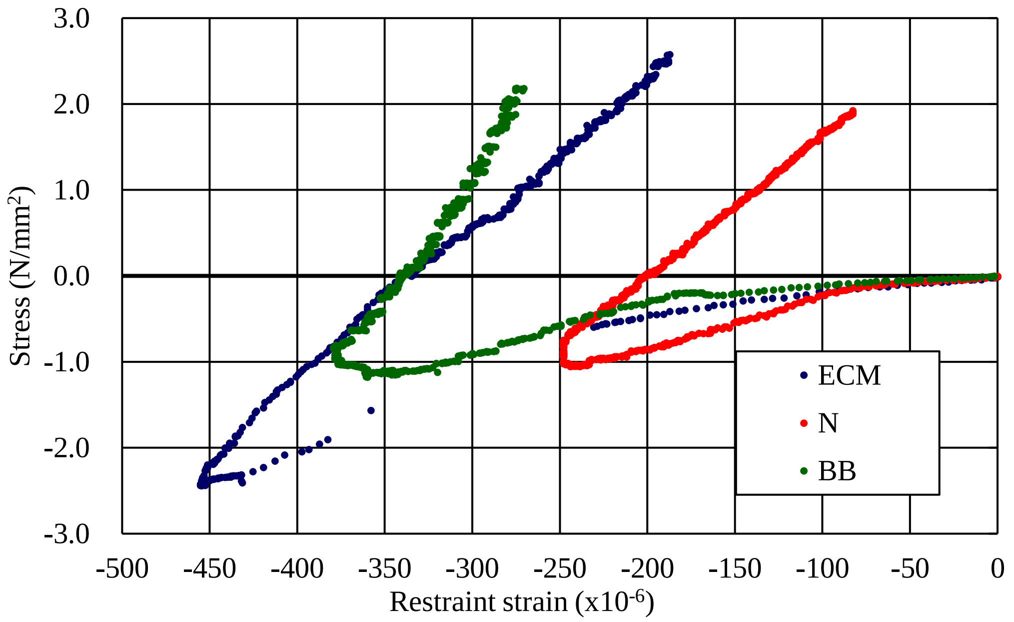

Figure 7. Relationship between stress and restraint strain in each case

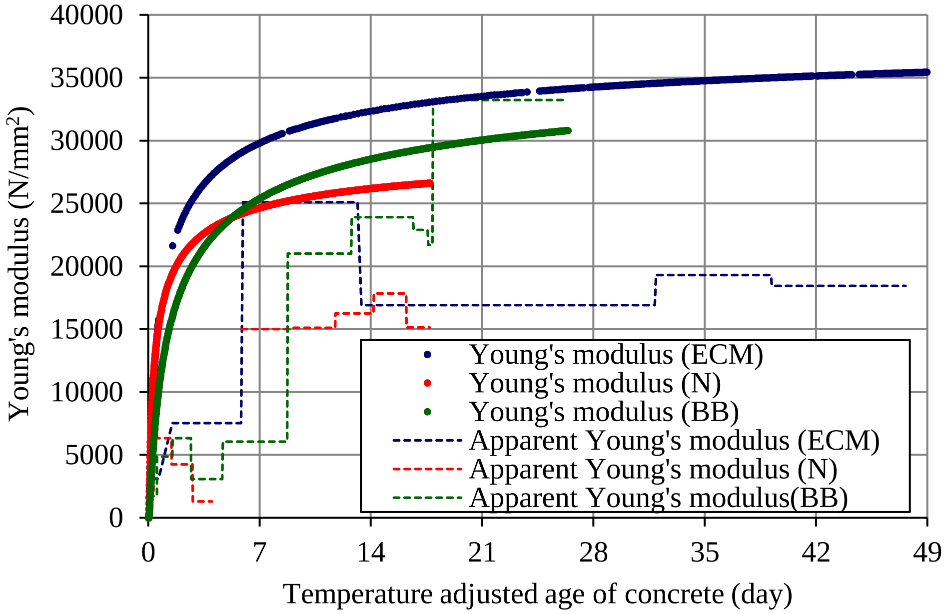

Figure 8. Historical curves of Young's modulus in each case

On the other hand, in the interval where tensile stress increased, the reducing rate of Young's modulus in BB showed 1.10 and stress of BB showed elastic behavior which did not receive the effect of the creep almost, while the reducing rate of Young's modulus was 0.53to 0.62 in ECM and N.

From the above result, as the effect of stress relaxation caused by shrinkage with volume change of concrete using ECM is larger than that of another case, it seems to be the effect of inhibition of thermal cracking in view of creep property.

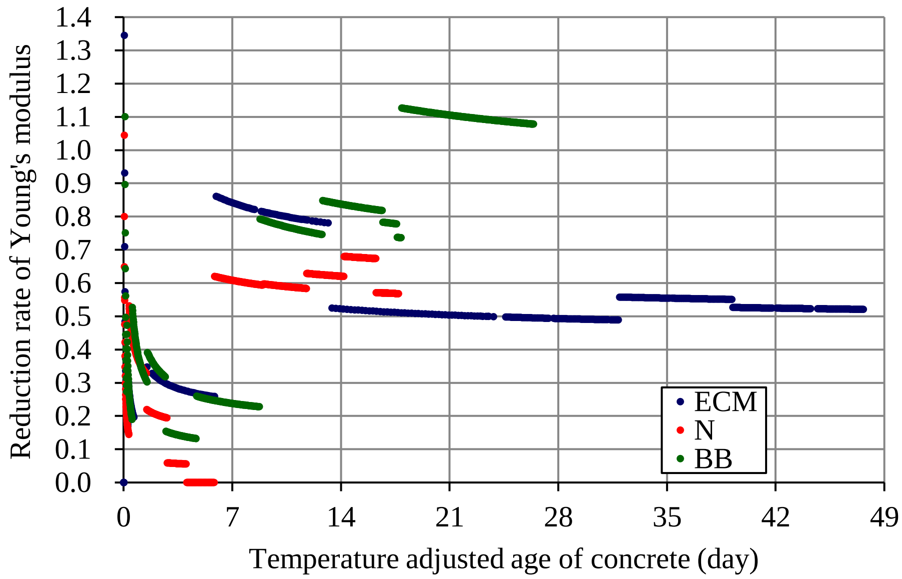

Figure 9. Reduction rate of Young's modulus in each case

CONCLUSION

In this study, as one for evaluating the potential of the resistance of crack in concrete using ECM, the experiments for evaluation of material properties using TSTM were carried out. As the results, it was confirmed that the concrete using ECM had the resistance of crack which was superior to concrete using ordinary Portland cement and Portland blast furnace slag cement type B in cracking time and stress at cracking. Furthermore, it was confirmed that concrete using ECM was superior to another case in the effect of stress relaxation by creep property. However, in this study, as the evaluation of mechanical properties was carried out under the condition considerably limited, the more extensive study of mechanical and thermal properties of concrete using the new high volume blast furnace slag cement type C will be carried out in future.

ACKNOWLEDGEMENTS

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