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EFFECT OF MICROSCOPIC THERMAL STRESS ON MECHANICAL PROPERTIES OF CONCRETE SUBJECTED TO HIGH TEMPERATURE

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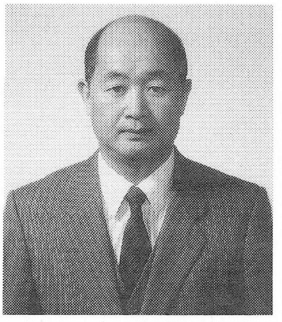
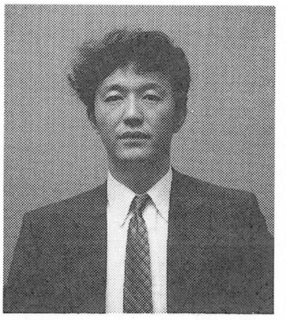

Kazutaka MINAMI   Ei-ichi TAZAWA   Shuji TERANISHI

SYNOPSIS

The AE signals were detected in concrete specimen by means of Acoustic Emission Method during heating or cooling of concrete. The temperature when the first AE signal is detected, is lower than that when the dehydration of moisture in concrete takes place. This result suggests that the reason for the change of property of concrete subjected to high temperature cannot be explained only by the dehydration of moisture in concrete. It is the purpose of this paper to point out that the microscopic cracks are developed by the microscopic thermal stress due to the difference between the thermal expansion coefficient of mortar and coarse aggregate. From the experimental results, it was proved that the mechanical properties of concrete subjected to the high temperature are influenced by the generation of microscopic stress and the formation of crack.

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1.INTRODUCTION

Since the concrete used under high temperature is subjected to the different temperature condition as the normal temperature, at which the cement is hardned and the structure of concrete is organized, the thermal and mechanical properties of concrete will be changed by the various types of shirinkage and expansion of component material in concrete[1].

The microcracking was observed in the pocesses of temperature rise and drop by means of the acoustic emission method[2][3]. According to the result obtained from this test, it was recognized that AE signals were detected at lower temperature before the dewatering in concrete and the accumulated AE counts increased rapidly in the process of temperature drop.

Concrete is a composite material which are composed of cement paste, fine and coarse aggregate. Since the coefficients of thermal expansion for mortar and coarse aggregate phase are not same and the change of length due to dewatering occurs in cement paste phase, the microscopic thermal stress field is generated in the vicinity of matrix-inclusion interface when concrete is subjected to temperature change. It seems that the microscopic thermal stress is the significant factor which develops the microscopic cracks and changes the thermal and mechanical propreties of concrete. Since the microscopic thermal stress is affected by the physical properties of component materials in concrete[4][5], the generation of microscopic thermal stress and the development of microscopic crack are different by the combinations of fine and coarse aggregate. Therefore, it is important to clarify the effects of mechanical properties and thermal expansion behaviors of component material in concrete on the microscopic thermal stress and mechanical properties in concrete when the deformation and strength of concrete under high temperature are estimated.

In this study, concrete specimens were made by using the fine and coarse aggregate with various thermal and mechanical properties, and the microscopic crack was observed when these specimens were heated and cooled. The microscopic thermal stress was calculated by using the thermal and mechanical data for mortar and material rock which constitute concrete specimen. Moreover, based on the measured results of thermal deformation and mechanical properties of concrete, the effects of microscopic thermal stress on the thermal and mechanical properties of concrete under high temperature is investigated.

2.OUTLINE OF EXPERIMENTS

2.1 Materials and Test Specimens

Ordinary portland cement was used for test specimens. Pelitic hornfels and limestone were selected as the base material for aggregate. Hornfels shows the largest thermal expansion coefficient of the material rocks which were extracted in Hiroshima district, Japan and limestone shows the smallest one. These rocks were crushed to prepare fine and coarse aggregate. They were prepared to become the standard grading defined by JSCE, and the particle-distribution of aggregates was a constant regardless of the type of aggregate. The concrete and mortar specimens shown given in Table 1 were made by using these aggregates, and the cement paste specimens were

Table 1. Specimen

Specimen	Fine aggregate	Coarse aggregate
Mortar	Hornfels	–
	Limestone	–
Concrete	Hornfels	Hornfels
	Hornfels	Limestone
	Limestone	Hornfels
	Limestone	Limestone

produced. The water-cement ratio of cement paste mixture and mortar mixture were both 50%, and the sand-cement ratio of mortar mixture was 2.45. The average flow values of mortar mixtures were 180. Concrete mixtures was designed so as to have the slump of 8cm and the air content of 4%. Its water-cement ratio was 50% and sand percentage was 60%. The cylindrical mortar and cement paste specimen have the diameter of 5cm and the height of 10cm and the cylindrical concrete specimen has the diameter of 10cm and the height of 20cm. To measure the inner temperature of specimen, the thermometer was buried in the center part of specimen. All specimens were cured in water of 20°C temperature for a week and continuously cured in a room of 20°C temperature and R.H.50% for two weeks.

2.2 Test Procedures

(1)Measurement of Thermal Expansion Strain

A pair of strain gages for the high temperature were stuck to the surface of specimen in the direction of longitudinal axis. The length of strain gage is 25mm and the available temperature range of strain gage is between -20°C and 300°C. The rise and drop of temperature in the constant temperature box were kept at the rate of 20°C per a hour, and then the thermal expansion strain of specimen was measured in the process of temperature change. Sticking the same type of strain gages to the surface of cylindrical quarts with the same length and diameter, it is enable to find the thermal expansion coefficient of specimen from the following equations.

The observed thermal expansion strain (ε_S) can be given as the function of the thermal expansion coefficient of gage (α_G) and the gage factor (K) determined by the change of temperature ΔT.

$$\varepsilon_S=[K+(\alpha-\alpha_G)]\cdot\Delta T \qquad (1)$$

The thermal expansion strain of quarts (ε_Q) can be obtained by the thermal expansion coefficient of quarts (α_Q) as follows.

$$\varepsilon_Q=[K+(\alpha_Q-\alpha_G)]\cdot\Delta T \qquad (2)$$

The characteristics of gage can be eliminated by substituting the term of K in Eq.(1) into Eq.(2).

$$\varepsilon_S-\varepsilon_Q=(\alpha-\alpha_Q)\cdot\Delta T \qquad (3)$$

Rewriting Eq.(3), the following equation is given.

$$\alpha-\alpha_Q=(\varepsilon_S-\varepsilon_Q)/\Delta T \qquad (4)$$

Since is of much less and neglecting it, we can obtain the thermal expansion coefficient of specimen (α) from the following equation.

$$\alpha=(\varepsilon_S-\varepsilon_Q)/\Delta T \qquad (5)$$

(2)Measurement of Mechanical Properties of Specimens

The compressive strength and the modulus of elasticity of material rock, cement paste, mortar and concrete were measured under such three conditions as the normal temperature, elevated temperature and high temperature cycle. The test at elevated temperature was carried out at a constant temperature after one hour since the temperature in the high temperature vessel was heated up to 200°C at the rate of 20°C per hour. In this test, the temperature at the inside of specimen was about 200°C. The specimen to be used for test at high temperature cycle was cooled to normal temperature at the rate of 20°C per hour by preserving constant temperature for two hours after the temperature in the high temperature vessel was heated to 200°C at the rate of 20°C per hour. The modulus of elasticity and Poisson's ratio were obtained by measuring the strains of specimen and quarts.

(3)Observation of Microscopic Cracks

The microscopic cracks due to the generation of microscopic thermal stress were observed by means of the acoustic emission (AE) method. The measuring system is shown in Fig.1. The wave guide was attached to the specimen in the constant temperature box, and the AE sensor was stuck to the pointed end of wave guide. The AE sensor has the diameter of 2.04cm and the length of 2.85cm. The characteristics of AE sensor is 175kHz for the resonance frequency, and has the temperature range between -150°C and 250°C for the heat resistance. The AE signals were amplified by the preamplifier, and were sent to the AE processor. The wave form of AE signal and the AE count can be obtained from the AE processor.

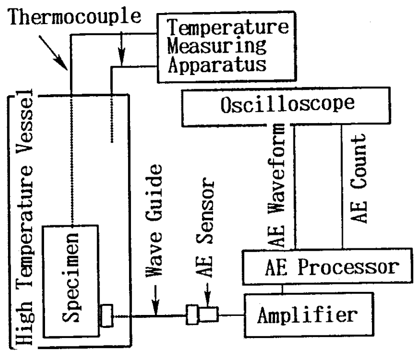

Fig.1. AE measuring system

3.Microcraking in Process of Temperature Rise and Drop

Fig.2 shows the relationship between the accumulated AE counts measured in the process of heating and cooling and the internal temperature of concrete which are produced by various combinations of fine and coarse aggregate. The accumulated AE counts is the total number of signal over the threshold value and they indicate the amount of microscopic crack. The AE signals begin to be detected early according to the increase of temperature, and the accumulated AE counts increase gradually. Since the moisture of concrete specimen rapidly decreases within the temperature range between 100°C and 180°C, the remarkable increase of accumulated AE counts may be caused by the change of internal structure of specimen due to the dewatering. Though the change of moisture of specimen is nearly equivalent regardless of the combinations of fine and coarse aggregate over all temperature range, the increase of accumulated AE counts within the temperature range between 100°C and 180°C are different by the types of aggregates used for specimen. It can be found from this result that the microcracking in concrete is affected by the combinations of fine and coarse aggregate in the process of temperature rise. Since the final accumulated AE counts in the process of temperature drop is quite different by the types of aggregates used for specimen, the microcracking in concrete may be affected by the combinations of fine and coarse aggregate. In the process of temperature drop, the accumulated AE counts hardly increase below the temperature of 100°C. Thus, this

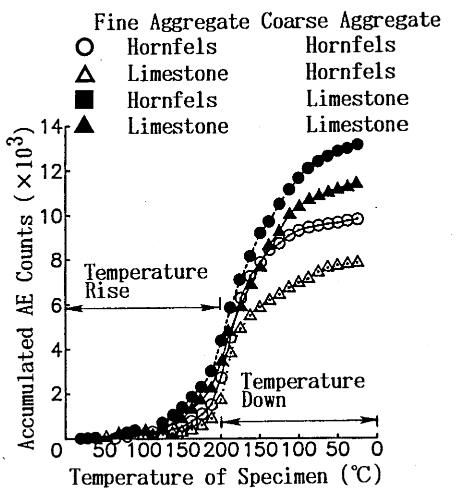

Fig.2. AE property of concrete

phenomenon may be strongly influenced by the thermal expansion behaviors of component materials in concrete.

4.MICROSCOPIC THERMAL STRESS IN CONCRETE

4.1 Property of Thermal Expansion of Component Material in Concrete

Figs.3 and 4 show the thermal expansion curves of material rock, cement paste and mortar, respectively. It can be seem from Fig.3 that in the process of the temperature rise, the thermal expansion strain of material rock linearly increases by a rise of temperature up to a temperature of 200°C. In the process of temperature down, the thermal expansion strain of material rock decreases linearly with a drop of temperature, and the magnitude of strain at a certain temperature is nearly equivalent to that in the process of temperature rise. When the internal temperature of specimen reached to the normal temperature, the permanent deformation was hardly appeared in the specimen of material rock.

The thermal expansion strain of cement paste increases linearly up to a temperature of 100°C, and in above temperature of 100°C, the specimen shrinks with a rise of temperature. This phenomenon may be caused by the evaporations of capirally and gel water in concrete. The proportion of shrinkage in specimen equals to the thermal expansion coefficient up to a temperature of 100°C, and the change of its shrinkage becomes linear. However, the permanent deformation in the cement paste specimen becomes relatively large when the internal temperature of specimen reached to the normal temperature.

In the case of mortar, the thermal expansion strain increases linearly up to a temperature of 100°C as well as the case of cement paste. Thereafter, though the specimen expand up to a temperature of 150°C, it slowly shrinks by the thermal expansion behavior of cement paste and reaches to the maximum expansion strain. This phenomenon shows that the thermal expansion deformation of fine aggregate phase is balanced with that of cement paste phase by the generation of microscopic thermal stress in the specimen and by the development of microscopic crack. Though the shrinkage of mortar specimen becomes approximately linear in the process of temperature down, the permanent deformation at the normal temperature is large, and the magnitude of permanent deformation depends on the types of fine aggregate. It can be found from this result that the

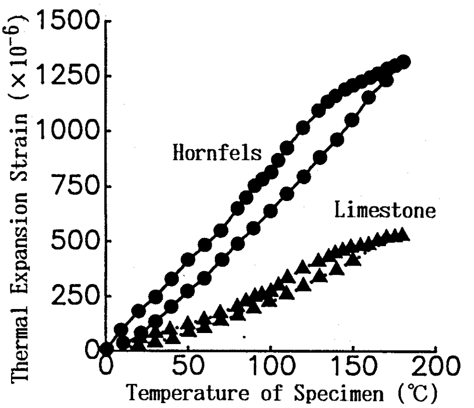

Fig.3. Thermal expansion curves of material rocks

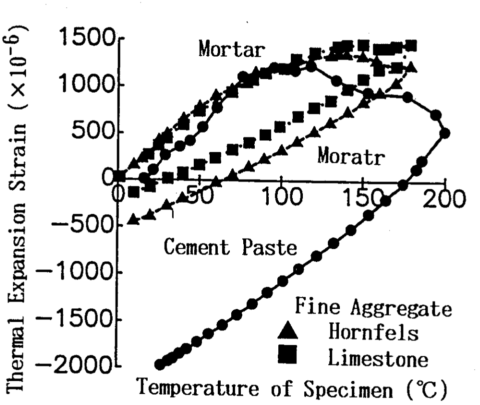

Fig.4. Thermal expansion curves of cement paste and mortar

balance between the cement paste phase and mortar phase is different by the types of fine aggregate and the changing condition of internal structure in the mortar specimen will differ.

4.2 Calculation of Microscopic Thermal Stresss in Concrete

When a concrete is subjected to high temperature, the thermal stress within a concrete is generated at the interface of coarse aggregate due to the difference of the thermal strains between cement paste and fine aggregate, or between mortar and coarse aggregate. In this paper, these stresses were calculated and then the stress condition in concrete subjected to high temperature was examined. The coarse aggregate phase was assumed the inclusion and the mortar phase was also assumed the matrix in the model concrete. Because, it is considered that the microscopic crack may cause the stress concentration in the same manner as the bleeding flaw in the vicinity of coarse aggregate.

The theoretical formula on the thermal stress which is generated between matrix and inclusion in composite, was proposed by J.Selsing[6]. In this formula, it is assumed that the matrix phase is the infinite body and the inclusion in the matrix is spherical.

By using the stress function[7] in the theory of elasticity, the stresses produced in the matrix at the distance of r from the center of inclusion can be found as follows. In the strict sense, this equation is not applicable to concrete in which inclusion is not perfect sphere and the distance between inclusions is comparatively small. However, since the properties of hardened concrete are not influenced by the non-elastic properties and this formula can be used in the field of the dynamics of ceramic[8][9], it was presumed that this equation would function as a first approximation.

Radial Stress: $\sigma_r = P \cdot (R/r)^3$ ------------------ (6)

Tangential Stress: $\sigma_t = -P \cdot (R/r)^3$ ------------------ (7)

where R is the radius of spherical inclusion and r is the distance from the center of inclusion. The value of P is given by

$$P = \frac{(\alpha_m - \alpha_p) \cdot \Delta T}{[(1+\nu_m)/2E_m] + [(1-2\nu_p)/E_p]} \quad \text{--------- (8)}$$

where, α, E and ν show thermal expansion coefficient, modulus of elasticity and Poisson's ratio, respectively. Suffixes m and p stand for the matrix and inclusion, respectively. ΔT is the difference between the temperature of specimen and the initial temperature. Though we assume that these parameters in Eq.3 are independent of the temperature and are given as constant values, it is found from this experiment that the value of E and ν in mortar and material rock depend on the temperature. In this study, E and ν in both matrix and inclusion may be given as a function of temperature . The values of each coefficients in the following equations are given in Tables 2 and 3.

$E = A - B \cdot T$ ------------------ (9)

$\nu = C - D \cdot T$ ------------------ (10)

where T :tempersture A, B, C, D:constant

The difference between the thermal expansion coefficients in Eq.3 was provided as - by using the difference of thermal expansion strains in the thermal expansion curve.

Table 2. Constants in equation (9) and (10)

Constant	Mortar Fine Aggregate		Material Rock	
	Hornfels	Limestone	Hornfels	Limestone
A	3.30×10^{5} (3.10×10^{5})	3.55×10^{5} (3.00×10^{5})	7.14×10^{5} (5.92×10^{5})	8.67×10^{5} (4.32×10^{5})
B	-1.10×10^{2} (-2.61×10^{2})	-3.06×10^{2} (-2.67×10^{2})	2.22×10^{2} (-3.89×10^{2})	1.44×10^{3} (-8.89×10^{2})
C	0.181 (0.225)	0.243 (0.265)	0.218 (0.254)	0.315 (0.352)
D	2.50×10^{4} (9.44×10^{-5})	1.39×10^{4} (2.61×10^{-4})	-8.33×10^{5} (9.44×10^{-5})	-7.78×10^{5} (1.17×10^{-4})

4.3 Condition of Generation of Microscopic Thermal Stress in Concrete

The microscopic thermal stresses obtained from above equations for a model consisting of mortar matrix and coarse aggregate are presented in Fig.5-8. These figures show the relationship between the internal temperature of concrete and the radial and tangential stresses generated in the vicinity of matrix-inclusion interface. Generally, when concrete is subjected to high temperature, the radial stresses become tensile and the tangential stresses become compression. The magnitude of these stresses increases up to a temperature of about 100°C and decreased gradually as mortar shrinks. And there are a case that the radial stresses changed into the compressive stresses at the final state. It seems that the bond cracks are developed along the periphery of aggregate because the radial tension might have reached the bonding strength between mortar and aggregate. The magnitudes of microscopic thermal stress changed and the conditions of microcracking is different by the combinations of fine and coarse aggregate.

Arrows in these figures indicate the possible initiation point of microcracking from the point at which the acoustic emission per unit volume exceeds 1 count/100cm^3. The temperature at this point ranges from 40 to 90°C and the corresponding stresses are within 7.6 to 11.8 MPa of radial tension and within 3.8 to 5.9 MPa of tangential compression. Before beginning the dewatering from

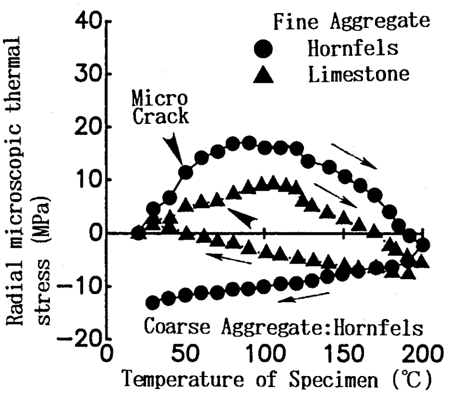

Fig.5. Radial microscopic thermal stress

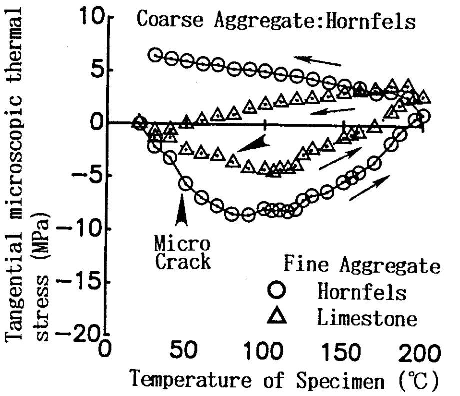

Fig.7. Tangential microscopic thermal stress

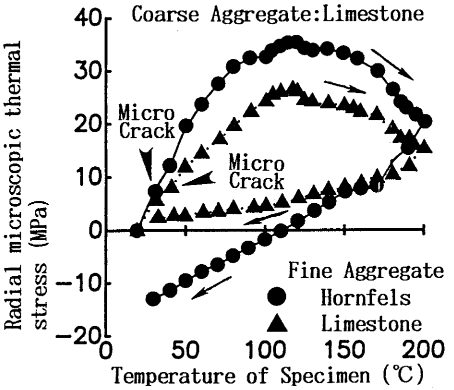

Fig.6. Radial microscopic thermal stress

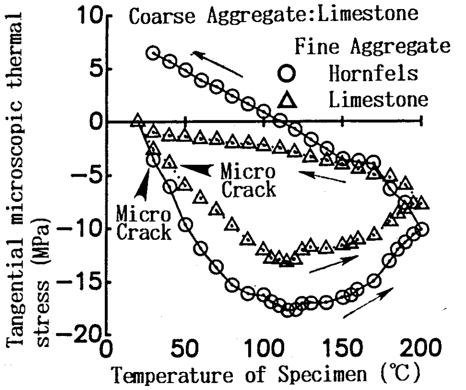

Fig.8. Tangential microscopic thermal stress

concrete, the microscopic cracks are already appeared, and the initiation temperature of microcracking depends on the combinations of fine and coarse aggregate. According to this result, by employing the microscopic thermal stress rather than the initiation temperature of microcracking, the possible initiation point of microcracking can be defined in the limited range. It should be noted that the microscopic cracks will not develop in the phase of cement paste by the compressive stresses in the tangential direction. The calculated values of tensile stresses in the radial direction is much larger than the tensile strength of cement paste or the bonding strength between cement paste and fine aggregate. Though it is hard to decide that the microscopic cracks will be developed by the tensile stress field in the vicinity of initiation point of microcracking, it may be considered that the development of microscopic crack is closely correlative to the generation of microscopic thermal stress in the radial direction.

As shown in Fig.7, in the case that limestone is used as a fine aggregate in concrete, the tangential stress became tensile even in the range of above temperature 180°C during temperature rise and the accumulated AE counts shown in Fig.2 rapidly increase. It should be noted that the increase of microcraking is affected significantly by the generation of microscopic thermal stress in tensile.

5.EFFECT OF MICROSCOPIC THERMAL STRESS ON MECHANICAL PROPERTIES OF CONCRETE SUBJECTED TO HIGH TEMPERATURE

5.1 Effect of Microscopic Thermal Stress on Compressive Strength of Concrete Subjected to High Temperature

Fig.9, shows the relationship between the ratio of compressive strength with reference to control specimen given in Table 1 and the maximum calculated value of microscopic thermal stress in the radial direction. Probably this stress does not exist actually since microscopic cracks are developed at much lower stress but it is assumed that it might be useful for an index of amount of maicroscopic cracks. In the both conditions at elevated temperature and after one cycle of heating, the ratio of compressive strength decreased gradually with an increase of microscopic thermal stress in radial direction. From the acoustic emission test result shown in Fig.2, it is recognized that the microscopic cracks will develop at much lower temperature. The decrease of compressive strength in concrete subjected to high temperature is caused by this microcracking and thus when the concrete specimen is loaded at high temperature, the numerous microscopic cracks already exist in concrete. Moreover, the microscopic cracks may be are developed when the microscopic thermal stress reaches to a constant value, and the increase of microscopic crack will be related to the reincrease of microscopic thermal stress released by the development of microscopic crack, which correspond to the inclines of curves in Figs.5 and 6. Therefore, the final amount of microscopic crack will depend on the combinations of fine and coarse aggregate.

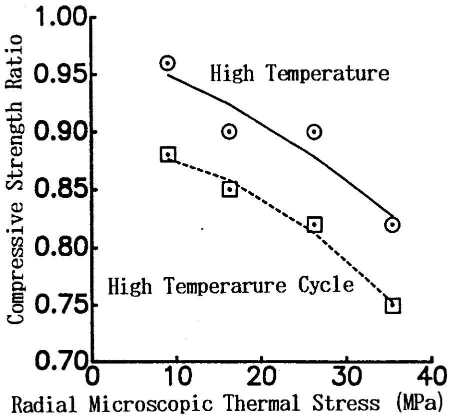

Fig.9. Infuluence of microscopic thermal stress on compressive strength ratio

Though the tensile stresses decrease at temperature drop in Figs.5 and 6, the microscopic cracks increase. This is the reason why the larger tensile stress may be generated in the vicinity of interface between cement paste and fine aggregate due to the permanent deformation of cement paste, and the microscopic cracks may be developed in radial direction of fine aggregate by this stress. The results obtained from this acoustic emission test may include the dpevelopment of these cracks. Since the maximum value of microscopic thermal stress can be determined by the difference between thermal expansion strains of material rock and mortar, the decrease of compressive strength in concrete subjected to high temperature is dependent on the combinations of fine and coarse aggregate.

5.2 Effect of Microscopic Thermal Stress on Modulus of Elasticity of Concrete Subjected to High Temperature

In Fig.10, the ratio of modulus of elasticity in concrete with reference to control specimen are plotted against the maximum calculated value of microscopic thermal stress in radial direction. The decrease of modulus of elasticity was larger than that of compressive strength, and the modulus of elasticity is reduced with an increase of microscopic thermal stress in radial direction. The reduction of modulus of elasticity for the specimens under the condition of heating and cooling cycle up to 200°C was larger than that for those under loading at high temperature. It can be found from these results that the deformation of concrete by compression is increased by microcracking due to the generation of microscopic thermal stress. Especially, the modulus of elasticity of concrete, which is subjected to heating and cooling cycle up to 200°C, is reduced because the microscopic cracks increase rapidly in the process of temperature drop.

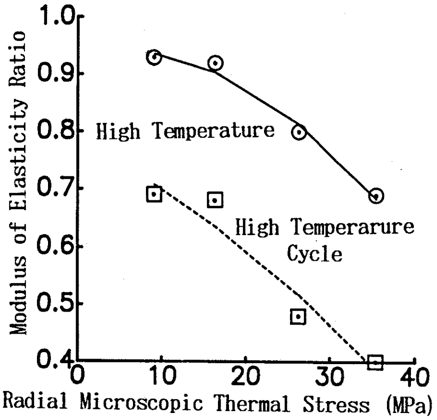

Fig.10. Infuluence of microscopic Thermal stress on modulus of elasticity ratio

5.3 Effect of Microcracking on Mechanical Properties of Concrete Subjected to High Temperature

The effects of microcracking at temperature rise and drop on the properties of concrete under compressive load can be analyzed by using the data obtained from acoustic emission test which was carried out at the same time to the compression test for concrete. In Fig.11, the volumetric strains and the accumulated AE counts are plotted against the stress level of concretes at normal temperature and under heating and cooling cycle. The stress level in which the accumulated AE counts will remarkably increase is about 0.9 for concrete at normal temperature, and is about 0.75 for concrete under heating and cooling cycle. The number of accumulated AE counts in concrete under heating and cooling cycle was larger than that for normal temperature. In the case of concrete under heating and cooling cycle, since the microscopic cracks are developed in the processes of temperature rise and drop by the microscopic thermal stress, the AE signals with higher level output begin to be detected. This result suggests that when the concrete specimen under heating and cooling cycle is loaded, the larger microscopic cracks will develop and propagate. Moreover, it is recognized that the position and form of microscopic cracks caused by the microscopic thermal stress are different from that of cracks by loading and this will originate the stress concentration in loading. The deterioration of modulus of elasticity in concrete under heating and cooling cycle may well be explained by the above considerations. Since the critical stress point in volumetric strain curve exists in the vicinity of stress level where the accumulated AE counts increase rapidly, it is considered that the internal structures of concrete begin to change remarkably from this point of time. The volumetric strain curve for concrete under heating and cooling cycle became non-linear at the lower stress level. The critical stress point of concrete under heating and cooling cycle has the lower value than that of concrete at normal temperature.

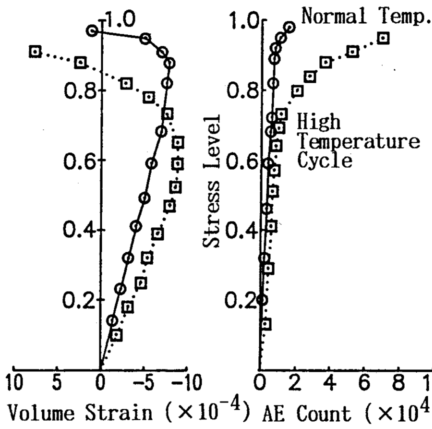

Fig.11. AE property of concrete

In Fig.12, the volumetric strains and the accumulated AE counts for concrete with various combinations of fine and coarse aggregate are plotted against the stress level. The curves of volumetric strain and the accumulated AE counts are changed by the combinations of fine and coarse aggregate. Since the accumulated AE count curves in the processes of temperature rise and drop will be changed by the combinations of fine and coarse aggregate, the conditions of microcracking on occasion of reaching at the normal temperature are different. Therefore, the deformation of concrete, which was subjected to heating and cooling cycle and compressive loading, may be

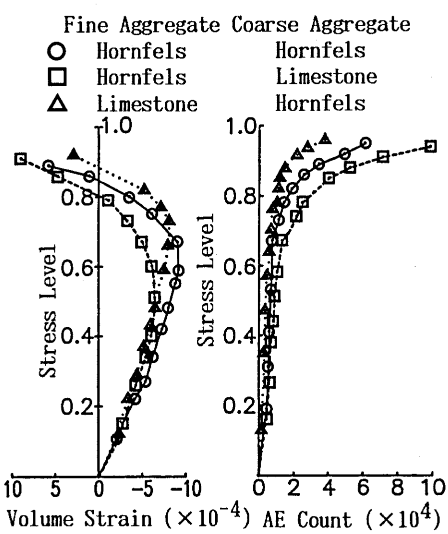

Fig.12. AE property of concrete

affected by the combinations of fine and coarse aggregate.

As shown in Fig.13, the data given in Figs.9 and 10 were again related to the accumulated AE counts per unit volume for compressive strength ratio and for ratio of modulus of elasticity. These two curves indicate that the accumulated AE counts is more effective to investigate the properties of concrete under high temperature. The extent of microcracking caused by the change of temperature before loading has a significant effect on the compressive strength and the modulus of elasticity of concrete. Higher is the extent to which microcracking developed, higher is the deterioration in mechanical properties become large. This tendency is serious in the case of modulus of elasticity. When concrete is kept under high temperature, the accumulated AE count per unit volume is smaller than 3 count/cm^3. Though there is no much difference in the compressive strength against the AE count per unit volume in this range, the difference of modulus of elasticity is large even under 3 count/cm^3.

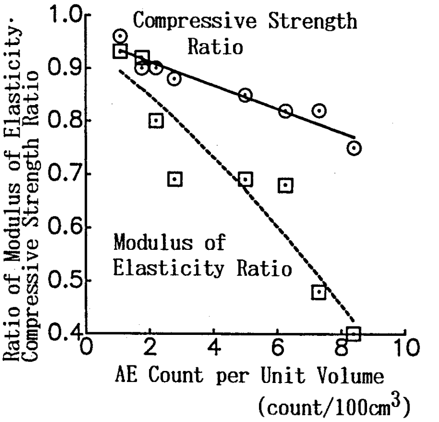

Fig.13. Influence of microcrack on mechanical property

6.CONCLUSIONS

The microscopic thermal stresses may be generated in concrete due to the heat change. In this study, the effects of microscopic thermal stress on the mechanical properties of concrete were experimentally investigated by examining the conditions of microscopic crack development. The obtained results can be summarized as follows.

(1)The mechanical properties when the concrete specimen was heated and cooled became clear from the results of AE test. The AE signals began to be detected at lower temperature, and the accumulated AE counts increases remarkably from about 100°C temperature which the capirally and gel water become to dehydrare. The accumulated AE counts changes by the combinations of fine and coarse aggregate at temperature above 100°C, and may be affected by the thermal and mechanical properties of composite material in concrete.

(2)Heated the concrete, the difference of thermal expansion strain is produced between mortar and coarse aggregate. Due to this difference, the microscopic thermal stress may be generated at the interface between mortar and coarse aggregate. The microscopic thermal stress can be estimated by assuming that the mortar is a matrix and the coarse aggregate is an inclusion in each element of concrete.

(3)The radial and tangential stresses at the interface of spherical aggregate bacome the tensile and compressive stresses respectively, in the condition that the microscopic thermal stress generates with the rise of temperature. These stresses increase upto about 100°C, and gradually descend by the shirinkage of mortar. Under certain circumstances, the direction of stresses may be reversed in the process of temperature drop. The magnitude of microscopic thermal stress changes by the combinations of fine and coarse aggregate.

(4)The calculated microscopic thermal stresses in the radial direction, when the

AE signal began to be detected or the microscopic crack is developed at first, are between 7.8 MPa and 11.8 MPa regardless of the combinations of fine and coarse aggregate. The temperature at which the microscopic crack is developed at first, changes within a wide range of temperature from 40°C to 90°C. Upon based this result, the start of microscopic crack development can be estimated in a limited range by considering the microscopic thermal stress.

(5)The compressive strength of concrete subjected to high temperature gradually decreases with the increase of microscopic thermal stress in the radial direction. In the case that the concrete subjected to high temperature cycle, the rate of decrease of compressive strength of concrete at a same value of microscopic thermal stress become larger than that in the concrete at elevated temperature.

(6)The decreasing rate of modulus of elasticity for concrete subjected to high temperature gradually increases with an increase of microscopic thermal stress in the radial direction. In the case that the concrete subjected to high temperature cycle, the modulus of elasticity remarkably decreases with an increase of microscopic thermal stress in the radial direction. It can be from test results found that the increase of compressive deformation of concrete is caused by the development of the microscopic crack due to the microscopic thermal stress.

(7)When the concrete under high temperature is subjected to a compressive load, the AE signals with high voltage is defected even at lower stress level. That is, the generation of AE signal, may be caused by the propagation and extension of microscopic cracks which are developed in the processes of temperature rise and down. Moreover, the accumulated AE counts in the concrete under high temperature becomes remarkably lager than that in the concrete at normal temperature, and the critical stress level in the volumetric strain curve decreases. There are some differences in the curves of accumulatedof AE counts and Volumetric strain by the combinations of fine and coarse aggregate.

(8)The decreasing rate of compressive strength and modulus of elasticity of concrete under high temperature become larger with an increase of generation rate of AE signal per unit volume.

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