Pull-Out Strength of a Cast-In-Place Anchor Bolt in Concrete Exposed to High Temperature

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ABSTRACT

Many anchor bolts are used in nuclear-related facilities in order to fast some equipments and pipes. About these anchor bolts, the possibilities should exist in being exposed to high temperature due to accident. However, little information is available regarding the effects of high temperatures on the behavior of anchor bolts. To obtain basic experimental data and to examine the response of cast-in-place anchor bolts to high temperature exposure, pull-out strength of an anchor bolt during heating and after heating was examined. The maximum temperature in this test is 500℃. Tests results show that the pull-out strength under high temperature up to 500℃ decrease significantly. Based on these results, a linear relationship between pull-out strength and temperature is empirically formulated.

1. INTRODUCTION

Some recent research on high temperature behavior of concrete shows that its strength will decrease with further increase of temperature and other mechanical properties also get worse, due to drying shrinkage, thermal stress and so on.[1)] It is also reported that the spalling happens on the surface of concrete subjected to elevated temperature.[2)]

In nuclear facilities, many anchor bolts are embedded in concrete structures in order to support equipments and pipes. There is possibility that these anchor bolts will be exposed to high temperature in a short time by some accident, and that the pull-out strength will decrease. However, little information is available regarding the effects of high temperatures on the behavior of anchor bolts. Therefore, they are usually designed without consideration for high temperature effects. In this research, pull-out tests of cast-in-place anchor bolt were carried out at different temperatures up to 500℃. The objectives are to obtain basic experimental data and to examine the response of cast-in-place anchor bolts to high temperature exposure.

At present, there are formulas to determine pull-out strength of a cast-in-place anchor bolt. ACI[3)] proposes the formula as follows;

$$P = 1.1\phi\sqrt{\sigma_B} \times A_c \tag{1}$$

$$A_c = \pi h(h + d) \tag{2}$$

Where, P: pull-out strength (kg), ϕ :reduction factor, : compressive strength of concrete (kg/cm^2), Ac: effective area of cone failed surface (cm^2), h: embedment depth (cm) and D: diameter of a stud (cm).

In "Design Recommendation for Composite Construction"[4)] published by the Architectural Institute of Japan is given as follows;

$$P = A_c\sqrt{\sigma_B} \tag{3}$$

Another formula proposed by R. Eligenhausen[5)],

$$P = k\sqrt{\sigma_B} \times h^{1.5} \tag{4}$$

where, k is the empirical coefficient (=15.7kg/cm).

2. EXPERIMENT

2.1 SPECIMEN

In all, twenty-three specimens were prepared. The dimensions and details of the specimens are illustrated in Fig.1. All of specimens are square concrete blocks with a side length of 240mm considering the cone failed area, and with a depth of 120mm. An anchor bolt used in this study is JIS standardized M12-bolt with a nominal length of 80mm, and with a thread length of 30 mm as shown in Fig.2. In order to prevent tension failure, a headed stud bolt was embedded at the center of the top surface of all the specimens, and the embedment depth from the top surface of the concrete to the upper surface of the bolt head is 30mm as shown in Fig.3. Four square nuts and steal pipes were installed to be fixed with the testing apparatus. Only five specimens equipped with thermo-couples to measure the temperatures of the concrete and the bolt inside the specimen during heating. Two thermo-couples are to measure the temperatures of anchor bolt and the others are to measure the temperature of concrete. (See Fig.1)

Ordinary normal concrete was used with design compressive strength of 350kg/cm^2. Six hours after casting of concrete, the specimens were cured by covering wet sand. This curing sand removed on the day of testing. The ages of the concrete at the test were 48~94days. The results of compressive and split tests of concrete cylinder during the testing days are shown in Fig.4. The average of compressive and splitting tensile strength of the concrete cylinder at the testing was 479kgf/cm^2 and 35kgf/cm^2, respectively.

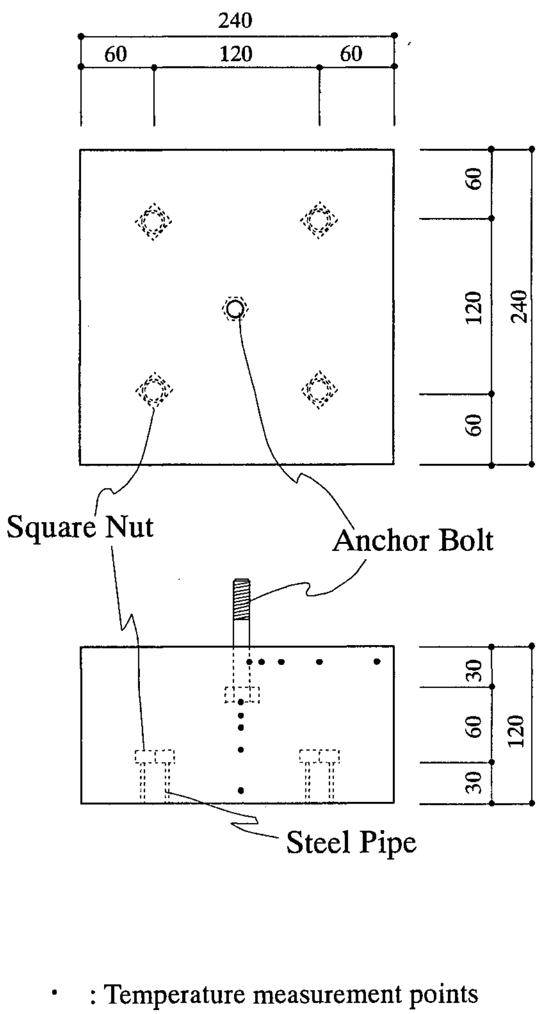


Fig.1 Detail of specimen

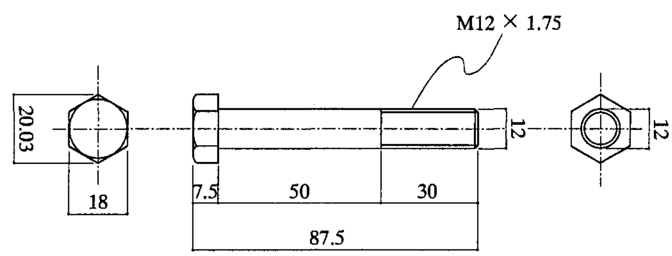


Fig.2 Detail of Anchor bolt

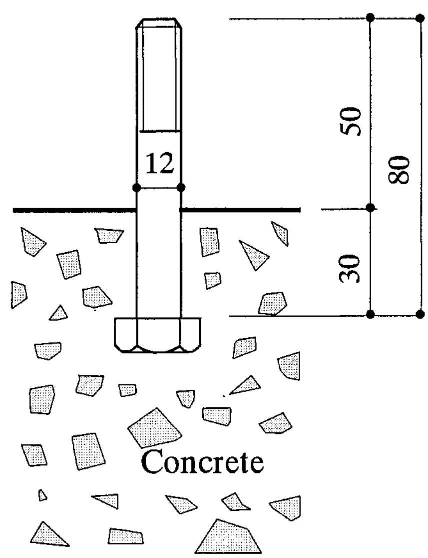
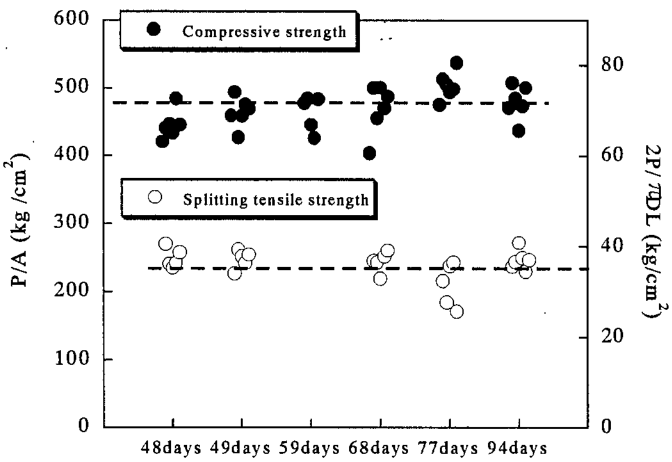


Fig.3 Detail of embedment



Diameter and height of cylinder:
10cm ϕ 20cm (for compressive strength test)
10cm ϕ 10cm (for splitting tensile strength test)

Fig.4 Results of compressive and split test of concrete cylinder

2.2 PULL-OUT TESTING AND HEATING METHOD

The apparatus for pull-out test is illustrated in Fig.5. The specimen was fixed to the testing apparatus with four bolts as shown in Fig.6, then its anchor bolt was connected to the end of the loading beam. To examine the ratio of forces of these four bolts during the pull-out test, the strain gauges were fixed on each of bolt. (See Fig.7) This measurement was carried out on four specimens. Fig.8 shows the detail of connection of the loading beam and anchor bolt. At first, anchor bolt was connected with treaded steel bar by using coupler. Then, this treaded steel bar was connected to loading beam. The tensile load is applied to an anchor bolt by applying loads to the other end of loading beam. Here, the tensile load from the loading beam was previously measured.

The detail of heating the specimen is illustrated in Fig.9. To improve thermal efficiency, the insulators were installed around the specimen and the heaters. One side of specimen with anchor bolt was heated by hot air by increasing its temperature using the electric heater with Nichrome wires. Above the specimen, a thermo-couple was employed to measure the air temperature near the heating surface of specimen. (See Fig.10) This temperature was controlled with the processes of heating as shown in Fig.11. Unless the specimens fracture at earlier stage, each temperature (150℃, 300℃, 500℃) was kept constant for two hours. However, the initial temperature increase depends on the performance of the heaters and was not controlled.

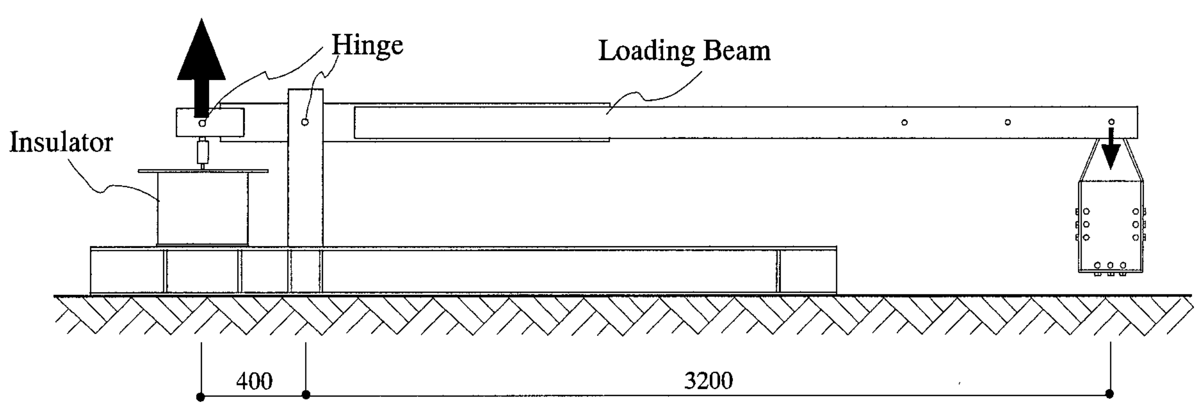


Fig.5 Apparatus for the pull out test

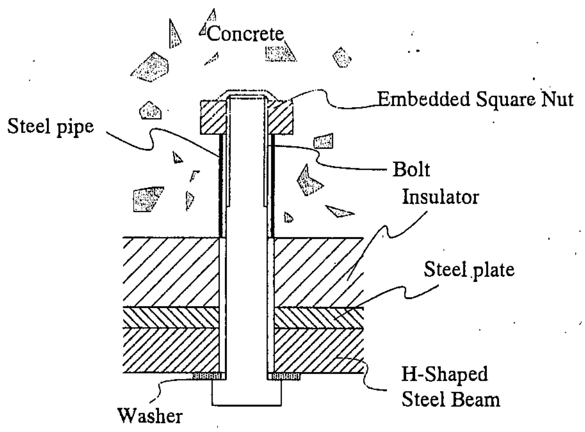


Fig.6 Detail of method to fix specimen to apparatus

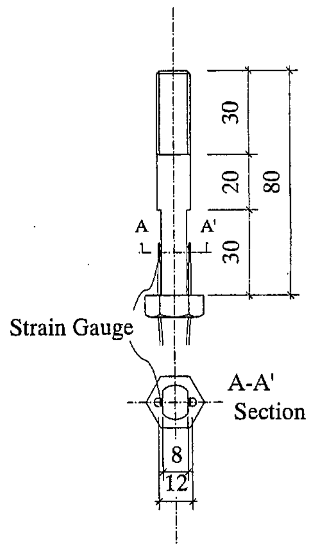


Fig.7 Detail of bolt with strain gauge

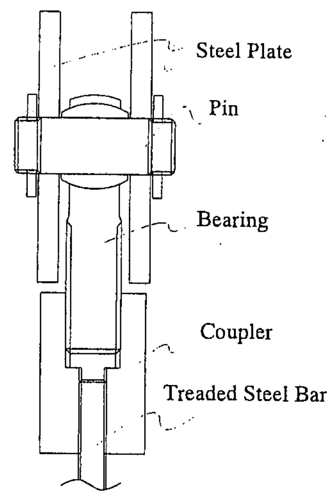


Fig.8 Detail of connection of loading beam and anchor bolt

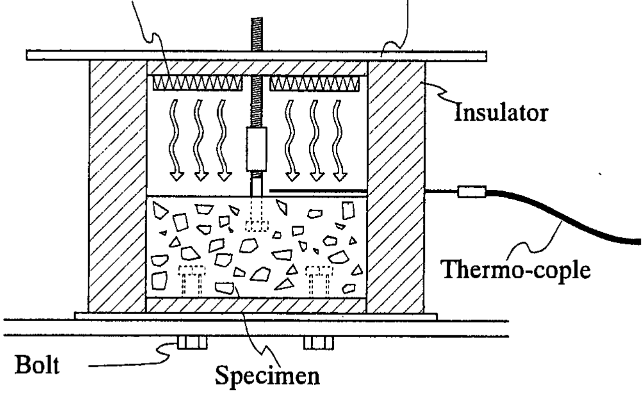


Fig.9 Method of heating

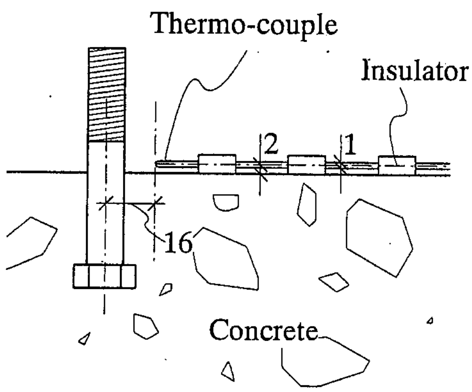


Fig.10 Detail of thermo-couple to measure air temperature

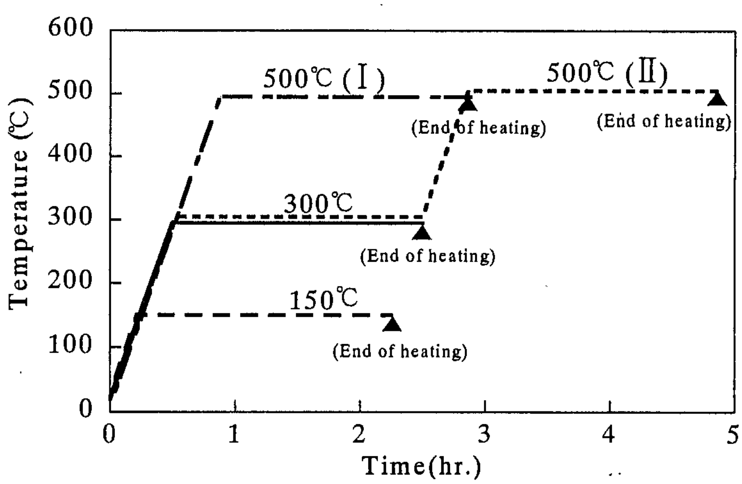


Fig.11 Process of heating

2.3 SUMMARY OF EXPERIMENT

In this experimental investigation, twenty-three specimens, as shown in Table 1, were tested. These specimens were divided into three main series. In series No.1, pull-out strength under normal temperature was examined. To examine the effect of high temperature on pull-out strength, fifteen specimens were tested in series No.2. The specimens are heated while applying constant tensile load on the anchor bolt. The tensile load was decided based on the pull-out strength under normal temperature, that is the results of series No.1, and the results of specimens tested earlier in the same series. Five specimens were tested in series No.3 to study temperature transient inside the specimens. About No.3-a, the effect of succession of heating on concrete was examined by heating four times up to 300℃. For the specimens of series No.2 that did not fail during heating and the specimens of series No.3, pull-out test was carried out after their temperatures go down to normal temperature. Here, the specimen was cooled with or without insulators, and the effect of difference of process of cooling on pull-out strength was examined.

Table 1 List of specimens

Name of specimen	Tesile load (P)	Process of heating
No.1-a	Pull out test under normal temperature	
b		
c		
No.2-a	1.31 t $(0.7P_0)$ ※1	300℃
b		
c		
d ※2	0.935 t $(0.5P_0)$	300℃
e		
f		
g		
h		500℃(Ⅰ)
I		
j	0.56 t $(0.3P_0)$	500℃(Ⅰ)
k	0.29 t	500℃(Ⅰ)
l	0.42 t $(0.23P_0)$	500℃(Ⅰ)
m	0.8 t	500℃(Ⅱ)
n	0.7t	500℃(Ⅱ)
o	1.31 t $(0.7P_0)$	150℃
No.3-a	300℃ (4times)	
b	300℃ (2times) (with and without insulators)	
c	500℃(Ⅰ)	
d	500℃(Ⅱ)	
e	150℃	

※1 P_0 : Average of pull-out strength of normal temperature

※2 About only No.2-d, the process of heating was changed in testing, and the load was also changed during heating.

3. EXPERIMANTAL RESULT

3.1 THE RATIO OF STRAIN OF BOLTS

Fig.12 indicates the relation of the ratio of strain of four bolts used to fix the specimen to the testing apparatus and the load applied to an anchor bolt. It can be observed from this figure that, even though the load applied to anchor bolt was increased, the ratio of strain of four bolts was constant during pull-out testing. The measured ratio of strain of bolts of four specimens is also shown in Fig.12. From this figure, it can be seen that, as to two specimens, the load applied the anchor bolt was evenly distributed to the four bolts. On the other hand, the load was unevenly distributed as to the others, and the minimum strain was 70% of the maximum strain.

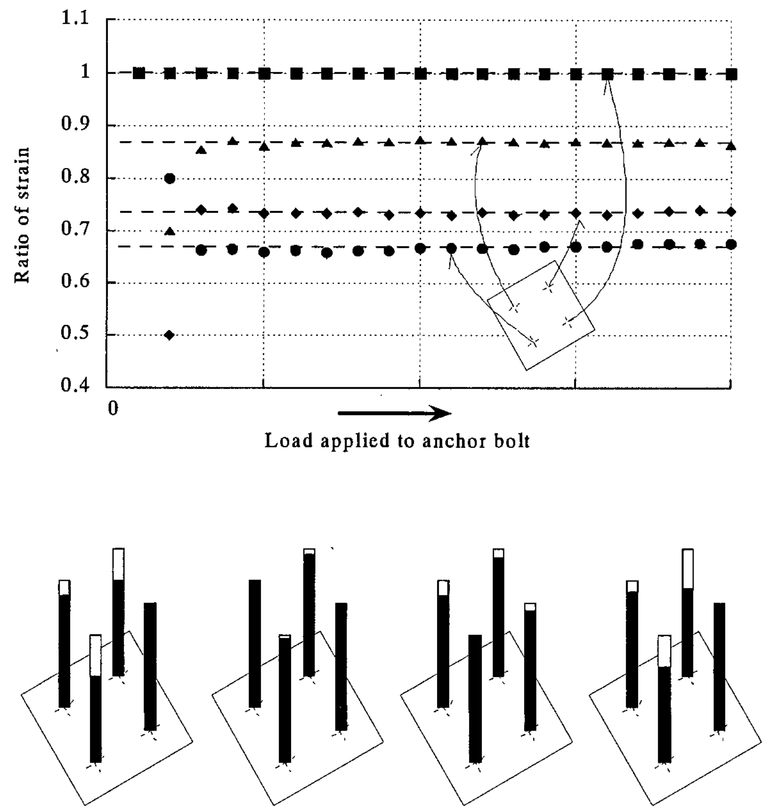


Fig.12 Ratio of strains of four bolts

3.2 RESULTS OF PULL-OUT TESTS

Fig.13 shows the history of the temperature and the load of the specimens of series No.2. In this figure, the temperature shows the value by the thermo-couple above the specimen to be measured the air temperature near the heating surface of specimen. The specimens No.2-e,f and the specimen No.2-g were cooled without and with the insulator, but the effect of difference cooling on the pull-out strength of them was not seen. Comparing the results of the specimenNo.2-k and No.2-n, the temperatures inside these specimens at the end of heating and the pull-out strength of them were almost the same. Therefore, the effect of the difference of process of heating between 500℃(Ⅰ) and 500℃(Ⅱ) on the pull-out strength was not also seen. The specimen No.2-d did not fracture under 0.935t of the tensile load even when the air temperature reached 500℃. However, the specimen No.2-h and i fractured under the same tensile load when the air temperature reached about 400℃.

Fig.14~17 show the results of temperature measurement of the specimens in series No.3. From Fig.14, which indicates measured temperature transient of the specimen No.3-c, it can be observed that there is little difference among the

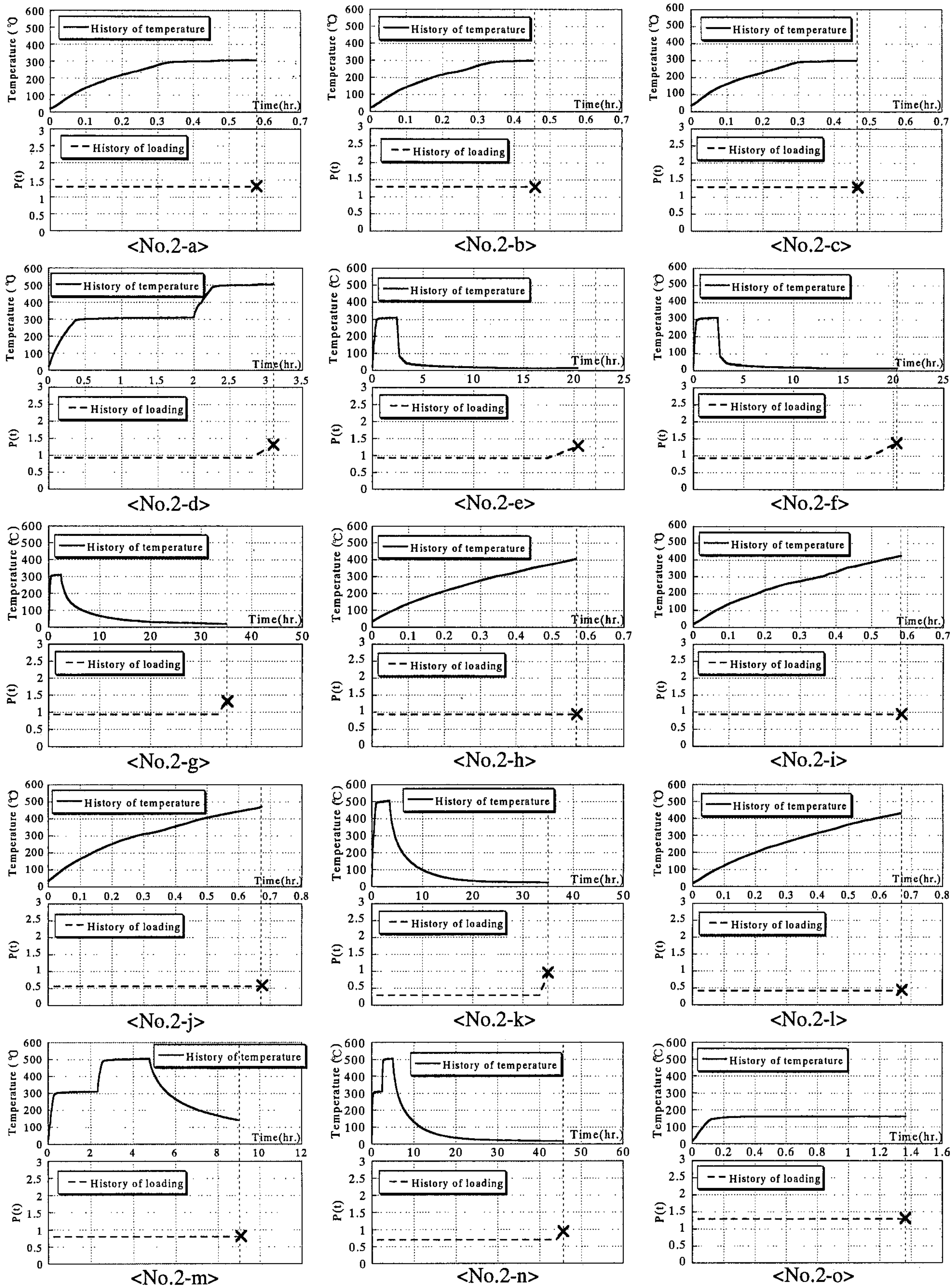


Fig.13 The history of temperature and loading

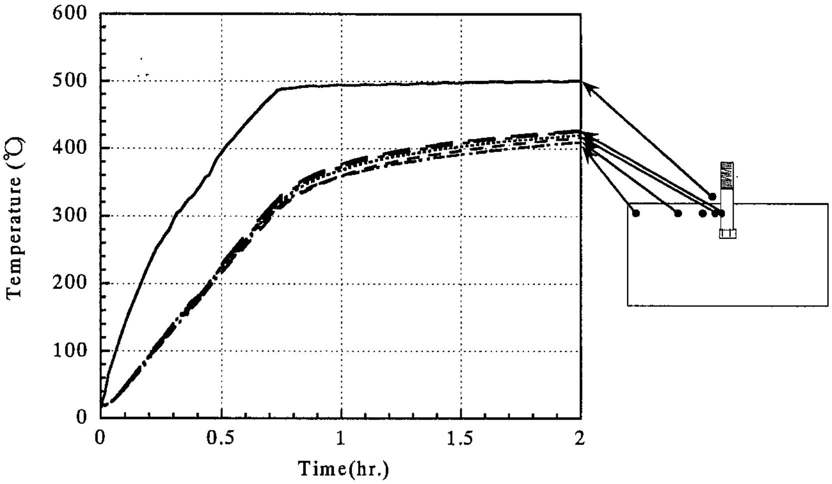


Fig.14 Temperature transient in horizontal line of specimen

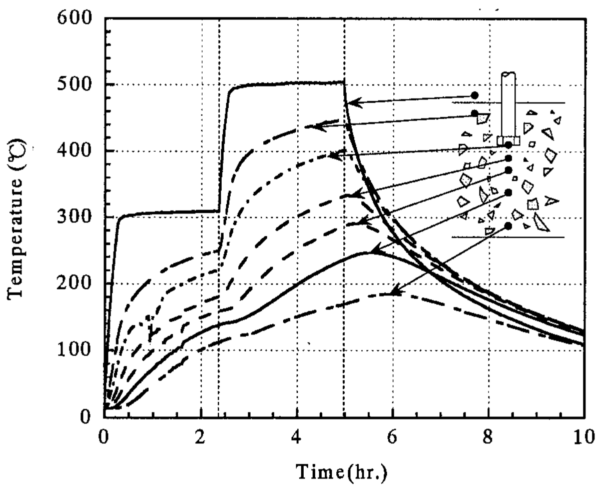


Fig.15 Temperature transient in vertical line of specimen

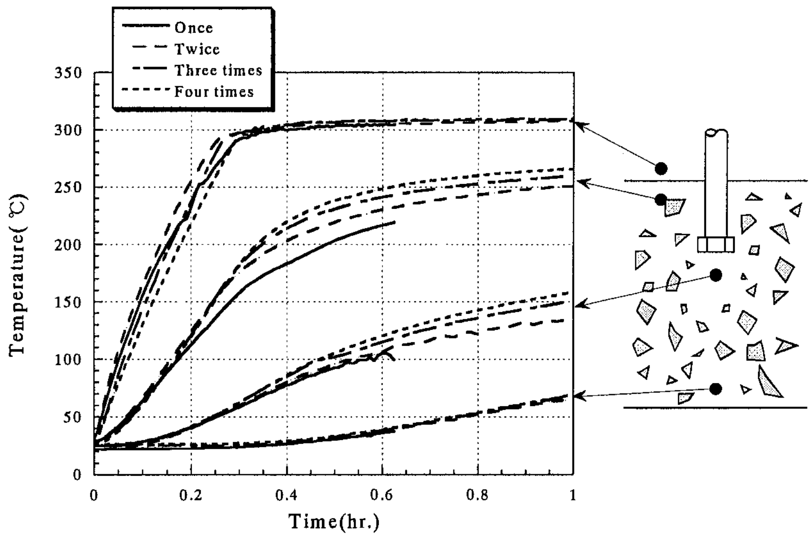


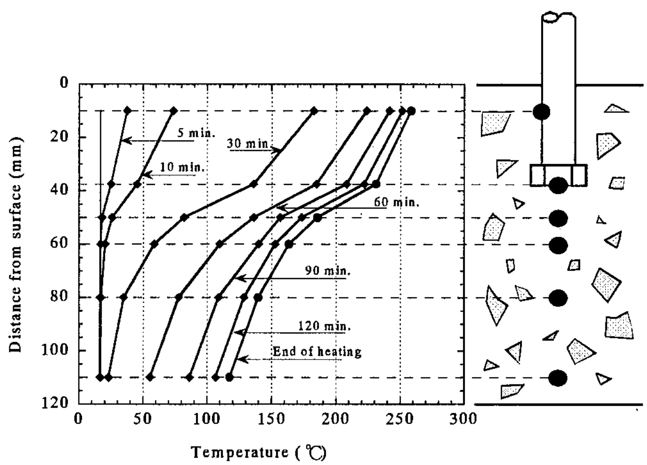
Fig.16 Temperature transient in specimen heated repeatedly

temperatures of the horizontal points in the specimen. Fig.15 shows the temperature transient of the specimen No.3-d during and after heating. It can be seen that the temperatures in the specimen went up for a short while after the end of heating.

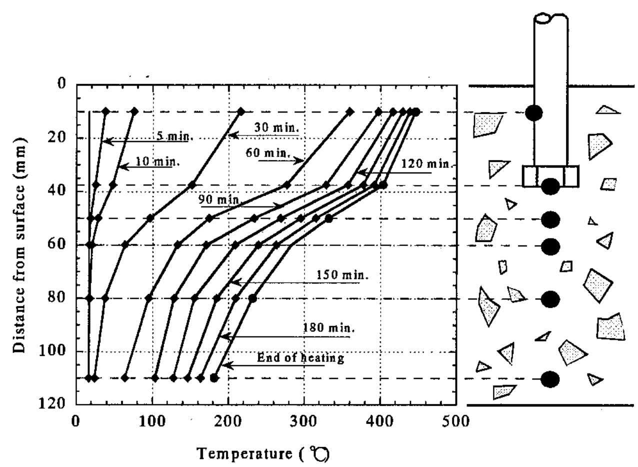
Fig.16 shows the temperature transient by repetitional heating in the specimen No.3-a. The first heating was lasted for 40 minutes. The temperature transient of the concrete part whose temperature was under 100℃ at the end of the first heating followed the same path as the first heating. However, the temperature of the part of concrete whose temperature was over 100℃ elevated faster than the previous heating. This result revealed that the thermal characteristic of concrete such as thermal conductivity changed by evaporation of water in concrete. However, there is little difference between the pull-out strength of No.3-a and of No.2-e-g, and the effect of repetition of heating on pull-out strength was not seen.

Fig.17 shows the temperature distribution in the specimen during heating with each process of heating. Note that S shaped of temperature distribution was due to the difference of thermal conductivity between the bolt and concrete.

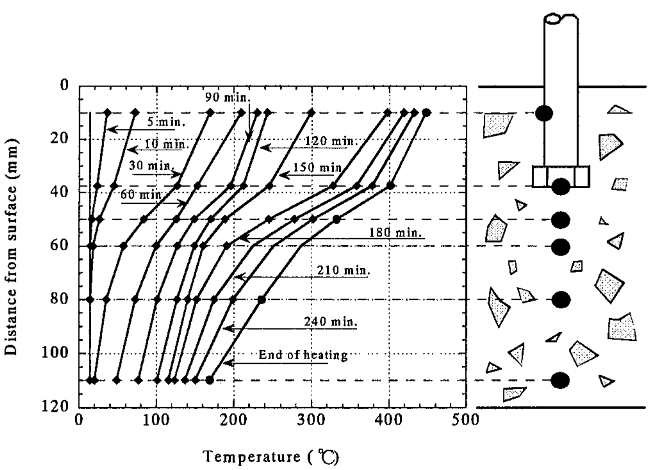
It was observed that there were two types of failure mode in all the specimens. Except No.2-d and o, the surface installed an anchor bolt of all the specimens which fractured during heating broke into pieces with a sound of explosion. (See Fig.18) Meanwhile, for the other specimens, an anchor bolt was pulled out due to radial cracks around the anchor bolt. (See Fig.19)



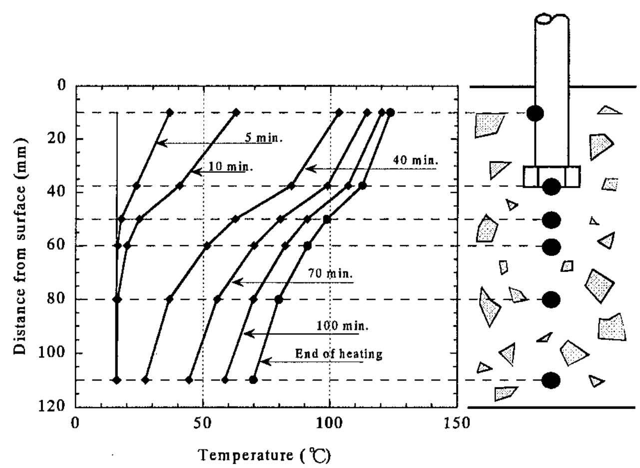
<No.3-b>



<No.3-c>

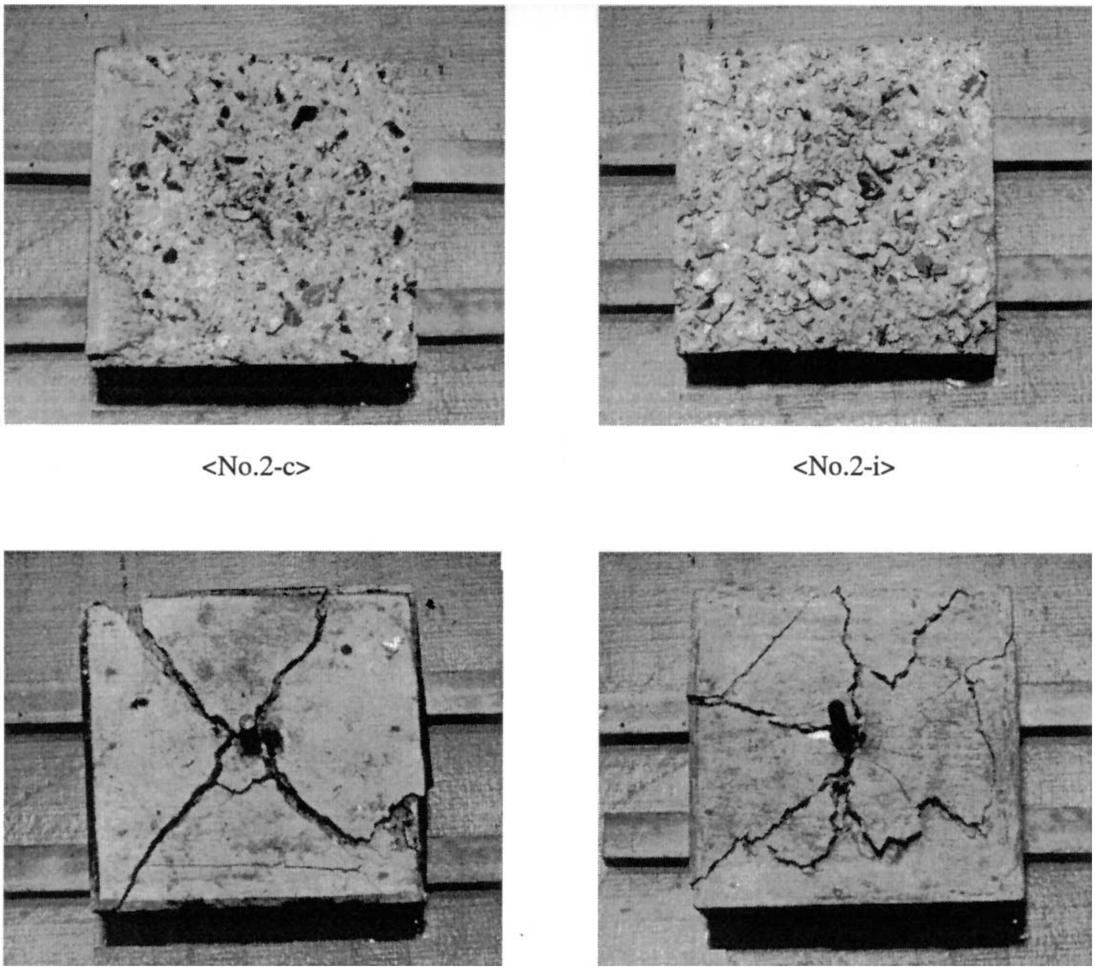


<No.3-d>



<No.3-e>

Fig.17 Measured temperature distribution in specimens



<No.2-c> <No.2-i>

<No.1-b> <No.2-m>

Fig.19 Failure mode of the specimen with crack

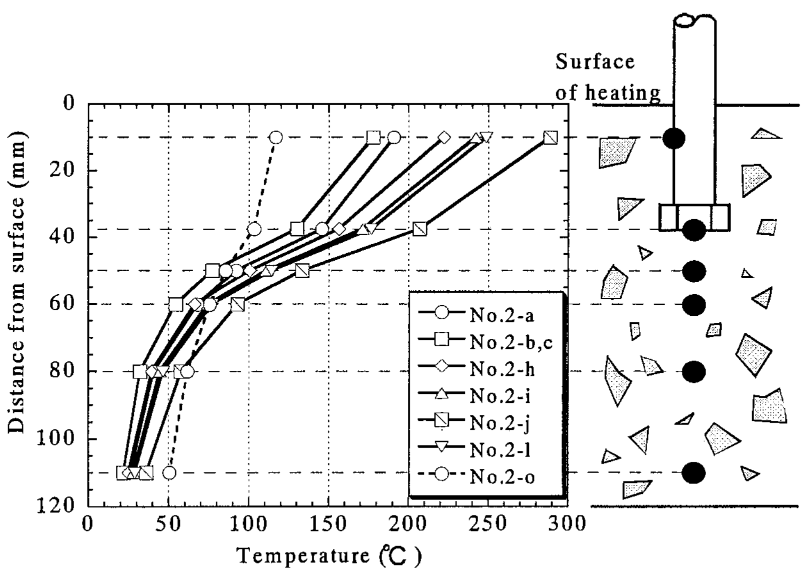


Fig.20 Temperature distribution in the specimens at the breaking point

About the specimens which fractured during heating, the temperature distribution in the specimens when they fractured are indicated in Fig.20. From this figure, it can be observed that the difference of temperatures inside No.2-o is much smaller than the others, and the effect of thermal stress would be little. This probably caused the difference of failure mode. With the specimens except No.2-o, the explosion probably happened because both the thermal stress and steam pressure occurred inside concrete and they are added to the stress conveyed by concrete by the tensile load applied to an anchor bolt.

The relation of pull-out strength and temperature during heating are plotted in Fig.21 and after heating in Fig.22. In these figures, the test results of specimens series No.1 are also indicated and the vertical axis stands for the pull-out strength normalized by the average of the test results of specimens series No.1. The average of tested pull-out strength under normal temperature was higher than the one calculated by Eq.(2), and almost the same as the one calculated by Eq.(3). From these figures, the pull-out strength during heating up to 500℃ decreases to about 20% of it under normal temperature, while the pull-out strength after heating decreases to about 50% of it under normal temperature. Based on these results, a linear relationship between pull-out strength and temperature is empirically formulated as shown in Fig.21 and Fig.22. The linear relationship between pull-out strength and temperature during heating is presented by the formula as follows;

$$P/P_0 = -1.49\times10^{-3}T + 1.04 \tag{5}$$

The following formula is the relationship between pull-out strength and temperature after heating;

$$P/P_0 = -9.94\times10^{-4}T + 1.02 \tag{6}$$

where, P_0: pull-out strength under normal temperature(kg), and T: temperature (℃).

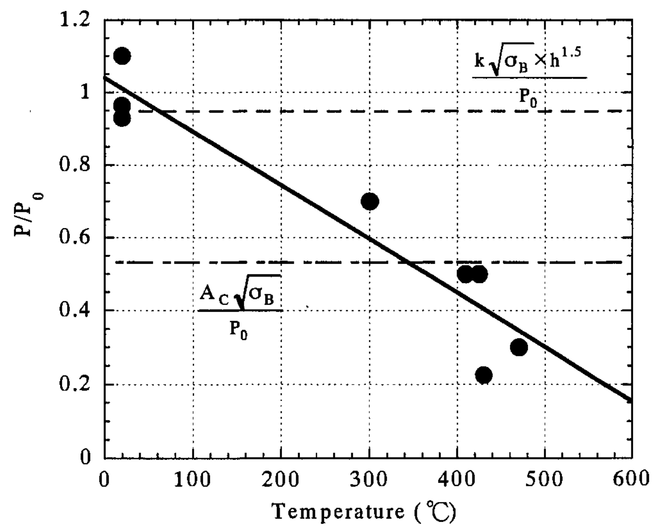


Fig.21 Relation between pull-out strength and temperature during heating

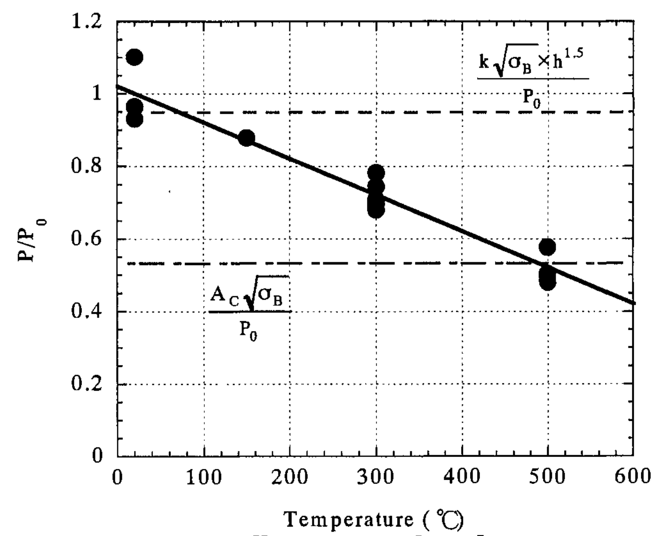


Fig.22 Relation between pull-out strength and temperature after heating

4. CONCLUSIONS

In this research, the pull-out testing of a cast-in place anchor bolt in concrete under high temperature was carried out. The results shows that pull out strength of a cast-in-place anchor bolt decrease greatly both during heating and after heating. From this experimental investigation with maximum temperature 500℃, it is concluded

1) Pull-out strength of a cast-in-place anchor bolt decrease to 20% while a cast-in-place anchor bolt in concrete was heated.

2) In the case of a cast-in-place anchor bolt which is tested after being cooled to normal temperature, pull-out strength of a cast-in-place anchor bolt decrease to 50%.

Based on the results of the test, a linear relationship between pull-out strength and temperature is empirically formulated during heating and after heating.

With this experimental research, the basic date of the pull-out strength of a cast-in-place anchor bolt in concrete under high temperature could be obtained and the outline of the relationship between temperature and pull-out strength could be observed. Based on the results of the experiment that were obtained this time, is should be pointed out that future studies are needed with the same specimens reported in this paper to obtain more date on pull-out strength of a cast-in-place anchor bolt under high temperatures.

From the results of failure mode in this test, the specimens were too small with cone failure. Research is also underway to use bigger size specimens to obtain cone failure type of fracture. Furthermore, the pull-out tests of a cast-in-place under high temperature will be carried out by using the specimens with the different embedment depth of an anchor bolt. To examine the effect of the rate of temperature increase on the pull-out strength of an anchor bolt, a comprehensive test program is planed to be carried out in near future.

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