論文 Evaluation of Temperature and Thermal Stress for Different Types of Cements Using Mock-up Test

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ABSTRACT : This experimental study aims at investigating a possibility of thermal cracks in mass concrete from applications of different cementitious materials. Four different types of cements were applied to the mock-up test and were evaluated in terms of temperature rises and thermal stresses by using thermocouples, strain gauges, non-stress gauges and effective stress gauges. This paper presents the comparison between experimental and theoretical results and shows how to utilize the data from strain gauges to obtain the stress values effectively.
KEYWORDS : mass concrete, cements, thermal cracks, temperature, gauges

1. INTRODUCTION

Controlling the hydration heat in mass concrete structure such as dam and pier can be achieved by applying larger size of aggregates and reducing the amount of cement. It is also expected that appling combination of low heat cement or the improvement of construction process such as the adjustment of block size and cooling systems can be more effective. In material point of view, thus, this study put an emphasis on the effect of cement types on the control of hydration heat. The magnitude of temperature rise and corresponding stresses were evaluated through the application of four different types of cement to mock-up specimens. The applied cements were Type V Portland cement for anti-sulphate, two blast furnace slag cements (45% and 65% of slag content) and a tertiary blended low heat cement. Thermocouples, strain gauges, non-stress gauges and effective stress gauges were embedded into each specimen for the measurement of internal temperatures and stresses. In addition, reliability of numerical results was evaluated by comparing measured values with theoretical ones for each age.

2. SIZE AND SHAPE OF SPECIMEN USED IN MOCK-UP TEST

2.1 DETERMINATION OF SPECIMEN SIZE

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Mixing was carried out according to Table 1 which follows the regulation of concrete specification to be below 50% of W/C when the structure is to be built around coastal area. Adiabatic temperature rise test was also carried out for each concrete to obtain maximum temperature rise(K) and exothermic reaction speed(α) which would be applied to the theoretical analysis later. The optimized block size of 6m×2.5m×1.5m(L×H×W) was determined from discriminable crack indices calculated for each cement. Since most significant crack occurrence in mass concrete structure is influenced mainly by the effect of outer restraints, a base concrete of 8.0m×3.2m×0.5m was placed below specimens and was connected with reinforcement bars. Heat shielder of 40cm thickness was wrapped along the specimen to minimize the influence of outside temperature. Fig. 1 shows the view of mock-up test.

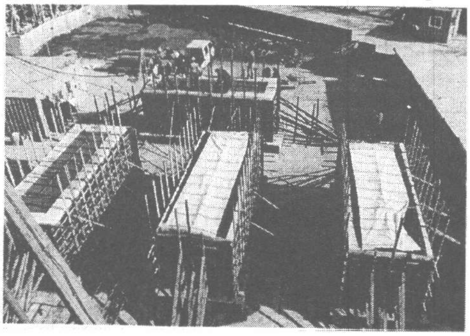

Fig. 1 Site view of mock-up test

Table 1 Material characteristics and mix design proportion

Physical Characteristics				W/C (%)	s/a (%)	Unit Content (kg/cm^2)					
Cement	Gravity	Blaine (cm^2/g)	Consistency (%)			W	C	S	G	S.P	A.E
Type V	3.22	3,277	22.7	47.6	48.5	162	340	858	929	2.55	0.204
Slag 45%	3.05	4,034	25.0	47.5	49	160	337	866	918	2.36	0.270
Slag 65%	2.97	4,294	27.0	47.5	46	166	349	791	947	2.44	0.332
Low heat	2.78	3,929	27.5	47.5	45	174	366	765	953	2.93	0.329

2.2 INSTALLATION OF GAUGES AND MEASURING METHODS

Major items of measurement in the experiment were temperature, thermal strains and/or stresses from each specimen. Gauges were installed only a half of specimen by using geometrically symmetric condition as shown in Fig. 2.

(1) Thermocouples

Since significant temperature difference between surface and inside of the specimen causes thermal cracks, which calls a crack due to internal restraints, total of 36 thermocouples were installed around the surface and the inside (Each specimen has 9 gauges) and were measured at every ages.

(2) Strain gauges

To measure the response of thermal strains according as time elapses, total of 36 strain gauges were installed. These data are converted to thermal stresses by multiplying elastic modulus measured at each age.

(3) Non-stress gauges

Non-stress gauge is not to measure the internal stress directly, but to measure

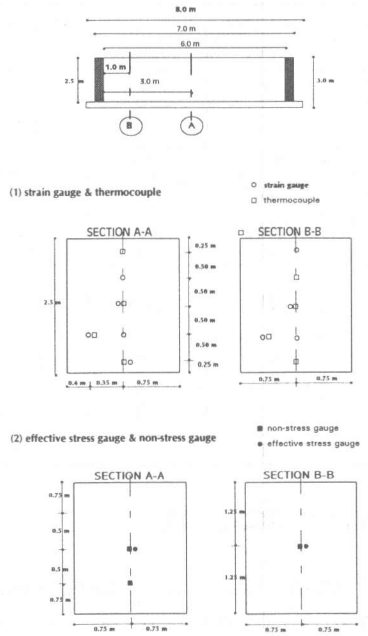

Fig. 2 Location of gauge installation

the strain values which are related to traction-free deformations not developing stresses. Non-stress gauge is usually fabricated by installing strain gauges inside the PVC cylindrical container of Φ10cm× 30cm, which has small holes for water to be able to penetrate free. This gauge can be also used to measure coefficients of thermal expansion. In this study, total of 12 were used, each specimen has two at center and one at side area.

(4) Effective stress gauge

Effective stress gauge is used to measure dry shrinkage, self deformation and creep value directly and then to convert to thermal stresses automatically through load cells. Therefore there is no need to perform converting work like strain gauges. Each specimen has 1 gauge at the center and corner, respectively.

(5) Data acquisition

Data were recorded every 30 minutes during 1 week which is known to be a period of highly active hydration, then every 1 hour during the second week. Data were measured every 2 hours from 3 weeks to 2 months period.

3. FINITE ELEMENT ANALYSIS

3.1 MATERIAL INPUT

Material data required for hydration analysis are maximum temperature rise(K), exothermic reaction speed(α), elastic modulus of concrete and strengths. The values of K and α were obtained from adiabatic temperature rise test, while elastic modulus, compressive and tensile strengths were calculated using maturity theory, since those values are not easy to obtain from experiment in early age concrete. Input data for analysis are shown in Table 2.

3.2 MODELLING

Size of a mesh for finite element analysis was 0.5m×0.25m×0.35 (length×height ×width). Bedrock was divided by 2.5m equally in all directions.

Table 2. Input data for theoretical analysis

Input Items		Type V	Slag 45%	Slag 65%	Low heat	Bedrock
Adiabatic temperature rise	K(℃)	43.9	51.7	41.91	36.7	-
	α	0.63	0.44	0.36	0.36	-
Thermal conductivity (kcal/m · hr · ℃)		2.3	2.3	2.3	2.3	2.5
Specific heat (kcal/kg · ℃)		0.25	0.25	0.25	0.25	0.18
Convection coefficient (kcal/m^2 · hr · ℃)		7(upper) 5(side)	7(upper) 5(side)	7(upper) 5(side)	7(upper) 5(side)	-
Initial temperature (℃)		10	10	10	10	20
Compressive strength f'_{28} (kg/cm^2)		240	240	240	240	-
Elastic modulus ($\times 10^5$ kg/cm^2)		2.3	2.3	2.3	2.3	3.0
Coefficient of thermal expansion ($\times 10^{-5}$/℃)		1.0	1.0	1.0	1.0	1.0
Poisson's ratio		0.17	0.17	0.17	0.17	0.17

4. DISCUSSION OF MEASURED AND ANALYZED RESULTS

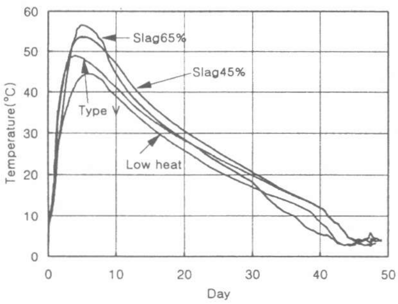

Fig. 3 Temperature measured from the center part of section A-A for each cement

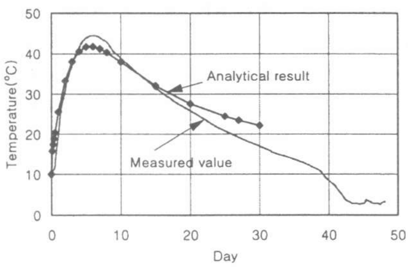

Fig. 4 Comparison between actual measurements and analytical results in low heat cement

Fig. 3 shows the temperatures measured at the center of each specimen. It can be observed that order of the magnitude is slag 65%, Type V, slag 45% and low heat cement. When a time arriving at the maximum temperature was compared, slag 45% was 4 days since concrete placement, Type V and slag 65% were 5 days and low heat cement was 6 days. This indicates that the cement with slag content of 45% hydrates most actively. Since the crack associated with internal restraints is directly related to the difference of temperature between inner and outer area as mentioned earlier, it can be inferred that low heat cement has the lowest possibility of crack occurrence in compare with other cements.

Fig. 4 shows the comparison between the measurements and analytical results at the center of specimen when low heat cement is applied. It is found that analytical results are similar to the measured values comparatively, especially maximum temperature and the arriving time, which are known to be important factors of controlling thermal cracks, are almost identical with each other. This indicates that theoretical analysis is applicable well to estimate problems relevant to temperature.

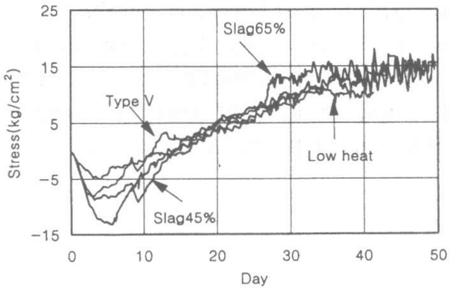

Fig. 5 Effective stresses measured at the center of section A-A

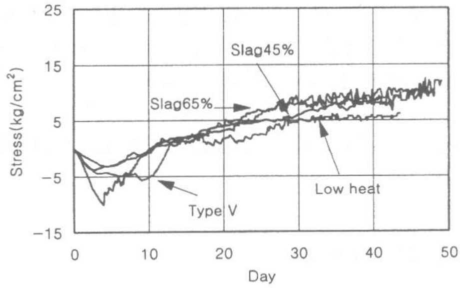

Fig. 6 Effective stresses measured at the center of section B-B

It is thought that in Figs. 3 and 4, rapid drop of temperature gradient in the rear of curves is due to the removal of heat shielder, accordingly effects of cold temperature in air.

Effective stresses measured at the center (section A-A) of specimen are shown in Fig. 5. All of cements had a shape of changing from compression to tension, although there are some differences on values. Noises were observed along the main line after 30 days, which may result from that by removing heat shielder, specimens were subject to expansion and contraction periodically depending on the temperature changes in air.

Fig. 6 shows thermal stresses of section B-B measured from effective stress gauges. It can be observed that shape of the curve is similar to that of Fig. 5, but values are different each other. It may be explained from that location of section A-A is more easily affected by outer restraints than that of section B-B

Values measured from effective stress gauges were plotted in Fig. 7 along with those obtained from strain gauges. It can be found that they are in a good agreement each other comparatively. In a case of using strain gauges, however, the measured data were multiplied by elastic moduli which are calculated on the basis of maturity concept at every age. The comparison indicates that to obtain stress values, strain gauges would be available instead, because the effective stress gauges are expensive.

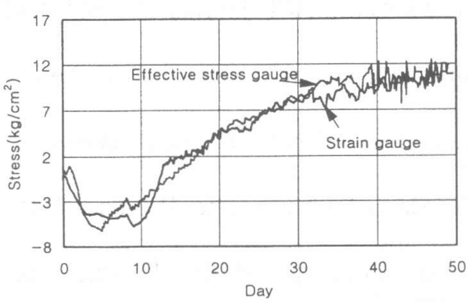

Fig. 7 Comparison of stress results from effective stress gauge and strain gauge

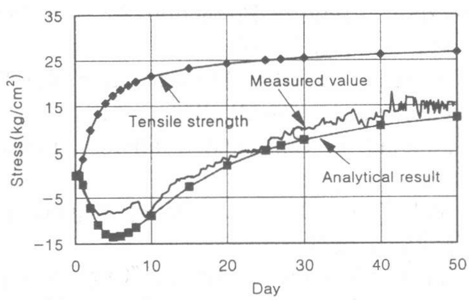

Fig. 8 Comparison of measured values and analytical ones in terms of effective stress

Comparison between the measurements and analytical results when using Type A cement is shown in Fig. 8. Even though there are some differences on the values, it can be noted that analytical results are very useful to comprehend the trend of stress occurrence. The differences are inferred to decrease considerably by performing additional experiments associated with thermal characteristics of concrete such as thermal conductivity, specific heat, the effect of reinforcement bars and so on.

5. CONCLUSIONS

(1) The concrete which has lower values of adiabatic temperature rise showed lower peak temperature and possibility of crack occurrence as a result of mock-up test. Since blended cements have a temperature dependences, mass concrete mixed with these cements often has a worse effect on the control of temperature than Portland cement.

(2) Stresses calculated from strain gauges had a good agreement with ones from effective stress gauges comparatively, which indicates that strain gauges can be used alternatively.

(3) There was a slight difference between actual measurement and theoretical values, but the trend of stresses was almost similar. It is expected that these differences can be reduced significantly only if additional tests associated with thermal characteristics of concrete are performed.

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