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Accuracy in Estimating the Mix Proportions of Hardened Concrete*

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Abstract

It is necessary to know and control inner factors which influence durability when structures are designed and constructed. The most important factor is mix the proportions, especially the water-cement ratio. Therefore, the accuracy of estimating the water-cement ratio is the most important point in evaluating durability and estimating life time. However, in the case of existing concrete structures, there is no documentation in most cases. Consequently, in many cases estimation of the water-cement ratio from a hardened concrete sample is necessary for existing structures. This method is shown in papers of CAJ and JSCE. But there are few experiments and little consideration about the accuracy of estimating the mix proportions of hardened concrete.

In this paper, accuracy in estimating mix proportions of hardened concrete is studied. And the following results were attained.

(1) In order to improve the accuracy of estimating mix proportions, the accuracy of quantifying CaO and measuring attached water must be improved.

(2) The test of attached water measurement must be conducted before strength tests on the specimen for estimating mix proportions, because large errors in estimating the amounts of attached water will influence the estimation of the water-cement ratio.

1. Introduction

It is necessary to know and control inner factors which influence durability when structures are designed and constructed. The most important factor is the mix proportions, especially the water-cement ratio. Therefore, the accuracy of estimating the water-cement ratio is the most important point in evaluating durability and estimating life time. However, in the case of existing concrete structures, there is no documentation in most cases. Consequently, in many cases estimation of the water-cement ratio from a hardened concerete sample is necessary for existing structures. This method is shown in papers of CAJ and JSCE. But there are few experiments and little consideration about the accuracy of estimating the mix proportions of hardened concrete.

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2. Procedure

2.1. Procedures of Different Methods

A typical method of estimating the proportion of hardened concrete is classified and shown in Fig. 1.

- Estimating mix proportions (Calculating) method
  - Method with ignition loss. (CAJ method)
  - Method without ignition loss
    - Balance method (CAJ method)
    - Method considering air content (JSCE method)
    - Method without considering air content (JSCE mtehod)

Fig. 1. Classification of estimating mix proportions.

2.2. Estimation Procedures of Mix Proportions Considering Accuracy

The CAJ [1] method by ignition loss was chosen to consider the accuracy of estimating mix proportions of concrete.

2.3. Flow of Measuring Procedure

A flow-chart of the outline of the measuring method for estimating mix proportions was given in reference [1] are shown in Fig. 2.

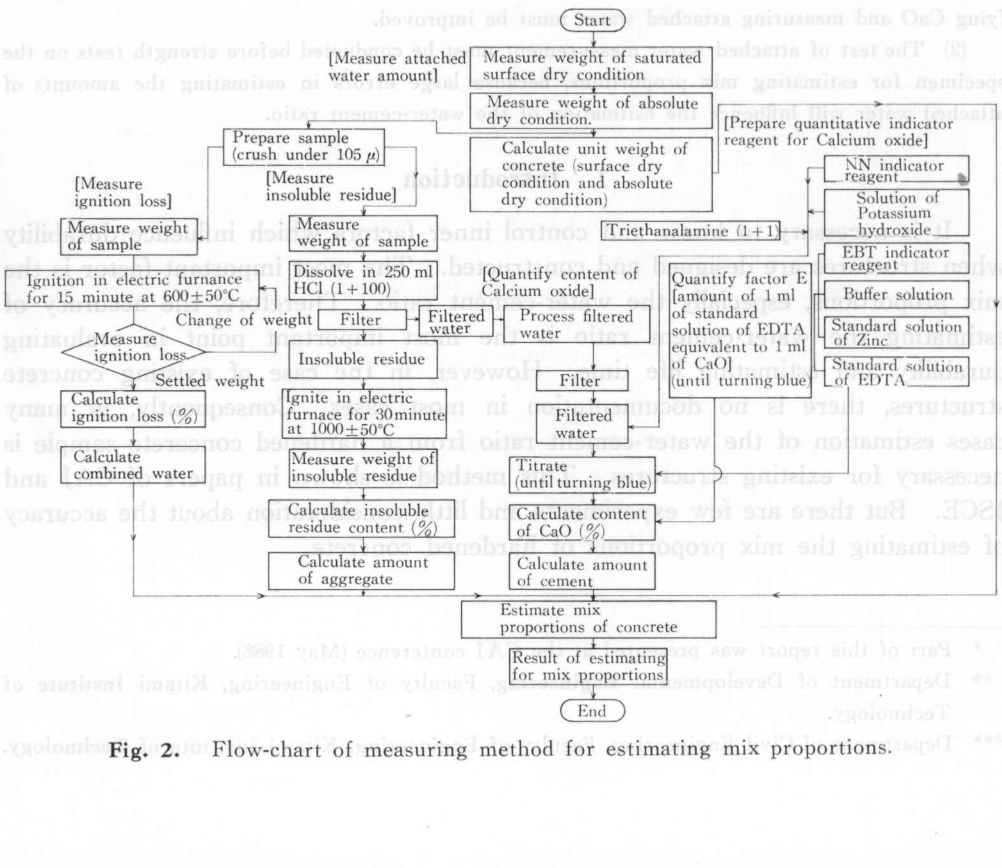

Fig. 2. Flow-chart of measuring method for estimating mix proportions.

2.4. Calculation of Estimating Mix Proportions

The calculation of estimating mix proportion was the method in which the water content of concrete was calculated from attached water and ignition loss of concrete given in reference [1].

2.5. Method of Consideration for Accuracy of Mix Proportions

The error in measuring and its influence on each item of analysis are clarified to study the reliability of measured estimation for mix proportion. The calculating expressions are readjusted and arranged into a single expression. The process of calculating mix proportions is the estimate of the water-cement ratio which is especially important for quantifying durability. Further more, the variables of measured data are processed by total differential calculus. It is the expression for the propagation of error of the water-cement ratio. Therefore, it expresses the formula of error of measured data, which is substituted in the estimation, and its weight. The process leading to the expression is indicated as follows.

(1) Estimating Euqation of Water Cement Ratio

The expression for the estimation of the water-cement ratio is shown in equation (1).

$$W/C=\frac{(1.541\times W_1-0.93)\times C_A+(1.031\times I_2+I_1)\times W_1+100\times I_1-1.2559\times I_2-1.0498\times I_2\times Q}{1.5504\times C_A-0.006512\times I_2} \quad (1)$$

where I_1: Ignition loss (%), I_2: Insoluble residue (%), C_A: Content of Calcium oxide (%), W_1: attached water (%), Q: percentage of water absorbed aggregate. Therefoɪe, the measured data of ignition loss and insoluble residue of cement and aggregate is referred to in the data of JIS and CAJ [1].

(2) The Equation of Water-cement Ratio

The equation (1) is treated with variables which are I_1, I_2, C_A, W_1 and Q by total differential calculus, in order to induce error propagation of the water-cement ratio. It is shown as follows:

$$dW/C=\frac{\partial W/C}{\partial I_1}dI_1+\frac{\partial W/C}{\partial I_2}dI_2+\frac{\partial W/C}{\partial C_A}dC_A+\frac{\partial W/C}{\partial W_1}dW_1+\frac{\partial W/C}{\partial Q}dQ \quad (2)$$

Then, it is developed as follows:

$$dW/C=\left[\frac{W_1+100}{1.5504\cdot C_A-0.006512\cdot I_2}\times dI_1\right]$$
$$+\left[\frac{(1.5984624\cdot W_1-1.947147-1.6276099\cdot Q)\cdot C_A+0.006512\cdot((1.541\cdot C_A+I_1)\cdot W_1+100\cdot I_1-0.93\cdot C_A)}{(-0.006512\cdot I_2+1.5504\cdot C_A)^2}\times dI_2\right]$$
$$+\left[\frac{0.00605616\cdot I_2-0.0100349\cdot W_1\cdot I_2-1.5504\cdot(1.031\cdot I_2\cdot W_1+I_1\cdot W_1+100\cdot I_1-1.2559\cdot I_2-1.0498\cdot I_2\cdot Q)}{(1.5504\cdot C_A-0.006512\cdot I_2)^2}\times dC_A\right]$$

$$+\left[\frac{1.541 \cdot C_A + 1.031 \cdot I_2 + I_1}{1.5504 \cdot C_A - 0.006512 \cdot I_2} \times dW_1\right] + \left[\frac{-1.0498 \cdot I_2}{1.5504 \cdot C_A - 0.006512 \cdot I_2} \times dQ\right] \quad (3)$$

The parts of partial differential calculus in this expression are the weight of each measured datum's error to the error of estimation for the water-cement ratio measured error. The product of error and the weight of each measured item indicate the range of error in estimation for the water-cement ratio. The mean square error (M) in estimating the water-cement ratio is shown as follows:

$$M = \pm\sqrt{\left(\frac{\partial W/C}{\partial I_1}\right)^2 \cdot dI_1^2 + \left(\frac{\partial W/C}{\partial I_2}\right)^2 \cdot dI_2^2 + \left(\frac{\partial W/C}{\partial C_A}\right)^2 \cdot dC_A^2 + \left(\frac{\partial W/C}{\partial W_1}\right)^2 \cdot dW_1^2 + \left(\frac{\partial W/C}{\partial Q}\right)^2 \cdot dQ^2} \quad (4)$$

2.6. Experimental specimens

Standard specimens (H1, H2, H3) whose mix proportion is already known are ϕ 10×20 cm as shown in Table 2. The mix time is 2 minutes. The fresh concrete was placed in 2 layers into form of a cylinder. Each layer was compacted by a vibrator. After 48 hours, the specimens were taken out from the form and cured in standard curing water.

On the other hand, the specimens (K1, K2) were taken from an existing concrete structure, and were extracted by a ϕ 120 mm diameter coring machine.

3. Results

3.1 Error in Estimating Water-Cement Ratio

The results of each specimen are shown in Table 1. The experiment results of standard specimens in which the mix proportions are already known are shown in Table 2. The result of error in estimating the mix proportions of the standard specimens is shown in Table 3. According to Table 3, it is considered as the following.

(1) The error of quantifying CaO is 4.67% in deviation and about 50% to error of estimation for the water-cement ratio.

(2) The error of attached water before strength tests in weight of measured datum error is 3.15%. After strength testing, that is 3.23% and the tendency to be larger than that before strength test.

(3) The percentage of water absorption of aggregate is small compared to the error of estimating the water-cement ratio because of the small weight of the error.

(4) The weight of error of the ignition loss is large at 8.15%, but the error of measured data is small and has little influence on the error of estimation for the water-cement ratio.

(5) About accuracy of estimation of mix the proportion of the specimen samples from an existing structure, the water-cement ratio in samples from on

Table 1. Experiment result

Item \ Number of Speimen			H 1			H 2			H 3			K 1			K 2		
Weight of saturated surface dry condition (g)		*1	3763.3			3727.4			3780.7			2418.3			2941.6		
		*2	3761.3			3727.1			3769.6			2219.4			2920.9		
Weight of absolute dry condition (g)		*1	3539.5			3517.6			3564.6			2267.6			2767.3		
		*2	3522.3			3502.9			3538.1			2061.8			2732.9		
Unit weight of concrete (surface dry condition) (kgf/m³)		*1	2405			2395			2407			2345			2334		
		*2	2412			2403			2416			2345			2358		
Unit weight of concrete (absolute dry condition) (kg/m³)		*1	2262			2260			2270			2199			2196		
		*2	2258			2258			2267			2179			2206		
Attached water amount (%)		*1	8.07			7.13			7.41			8.48			8.14		
		*2	8.54			7.57			7.89			9.49			8.73		
Measure ignition loss	Weight of sample (g)		1.0042	1.0007	0.9996	1.0014	1.0035	0.9952	1.0066	1.0059	1.0054	1.0014	0.9980	1.0104	0.9962	1.0127	0.9989
	Loss (g)		0.0343	0.0342	0.0327	0.0341	0.0343	0.0351	0.0345	0.0355	0.0362	0.0318	0.0373	0.0335	0.0358	0.0341	0.0370
	Ignition loss (%)		3.42	3.42	3.27	3.41	3.42	3.53	3.43	3.53	3.60	3.18	3.74	3.32	3.59	3.37	3.70
Weight of residue insoluble	Weight of sample (g)		1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
	Insoluble residue (g)		0.8401	0.8230	0.8204	0.8063	0.8401	0.8385	0.8290	0.7957	0.8341	0.8011	0.8119	0.8023	0.7721	0.7934	0.7915
	Insoluble residue content (%)		84.01	82.30	82.04	80.63	84.01	83.85	82.90	79.57	83.41	80.11	81.19	80.23	77.21	79.34	79.15
Quantify content of calcium oxide	Weight of zinc (g)		0.325			0.325			0.325			0.325			0.325		
	Content of zinc (%)								99.99								
	Standard solution of Zinc								0.994								
	Quantify factor E (ml)								16.9								
	Standard solution of EDTA(ml)		11.05	11.10	11.10	10.45	9.90	10.10	10.05	8.50	10.15	11.10	11.10	12.20	11.90	11.50	11.50
	Amount of 1ml of standard Solution of EDTA equi-Valent to 1 ml of CaO								0.000825								
	Calculate content of CaO (%)		9.12	9.16	9.16	8.62	8.17	8.33	8.29	7.01	8.37	9.16	9.16	10.07	9.82	9.49	9.49
Compressive strength (kgf/cm²)			—			199			204			268			274		
Youngs modulus (kgf/cm²)			—			164000			163000			123000			132000		

*1 Measuring before compressive test *2 Measuring after compressive test

Table 2. The results of estimating the mix proportions of standard specimens (H1, H2, H3)

Item		Water cement ratio (%)	Unit weight of cement (kg/m³)	Unit weight of water (kg/m³)	Unit weight of fine aggregate (kg/m³)	Unit weight of coase aggregate (kg/m³)	Air entrained ageant (cc)	Air content (%)
Mix proportion of origin		65.0	234	152	705	1221	38.2	4.9
Mix proportion of estimating	Ignition loss	66.3	277	183	1942		—	—
	Balance method	53.0	281	148	1974			

Table 3. Result of considering error of estimating the mix proportions of standard specimens (H1, H2, H3)

Item of analysis	Result of measurement (%)	Error of measurement (Standard deviation) (%)	Weight	(Error of measurement) ×(Weight) (%)
Ignition loss	3.45	0.09	8.54	0.77
Insoluble residue	82.52	1.48	0.39	0.58
CaO	8.47	0.64	7.30	4.67
Attached water before strength test	7.54	0.39	8.07	3.15
Attached water after strength test	(8.00)	(0.40)	(8.07)	(3.23)
Percentage of water absorption aggregate	1.91	0.03	6.88	0.21
Water cement ratio	66.3(70.0)	M (Mean error): 5.7(6.0)		

Note ; ( ): calculation with attached water after testing.

Table 4. Result of considering errors in estimating the mix proportions of sample specimen (K1, K2)

Item of analysis	Result of measurement (%)	Error of measurement (Standard deviation) (%)	Weight	(Error of measurement) ×(Weight) (%)
Ignition loss	3.48	0.21	7.64	1.60
Insoluble residue	79.54	1.23	0.42	0.52
CaO	9.53	0.33	6.24	2.06
Attached water before strength test	8.31	0.17	7.03	1.20
Attached water after strength test	(9.11)	(0.38)	(7.03)	(2.67)
Percentage of water absorption aggregate	1.73	0.92	5.86	5.39
Water cement ratio	65.1(70.7)	M (Mean error): 6.1(6.6)		

Note ; ( ): calculation with attached water after testing.

existing structure is 61.5%. When the error of measured data (standard deviation) are imputed, the Mean error is ±6.1%. These resuls are shown in Table 4.

3.2 Improvement of Accuracy of Estimation

(1) In order to improve the accuracy in estimating mix proportions, the accuracy of quantifying CaO and measuring attached water must be improved.

(2) The test of attached water measurement must be conducted before the strength test on the specimen for estimating mix proportions, because a large error in the amount of attached water will influence the estimation of the water-cement ratio.

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