論文 Experimental Study and Application of Simple Electric Circuit Model to the Flowing Behaivior of High Flowing Concrete

Mostafa KHANZADI*1, Masaru SATO*2, and Osamu SENBU*3

ABSTRACT: This paper concern with part of the experimental and analytical studies of flowing behavior of high flowing concrete. In the experimental part of the study, among different workability tests, only the results of L flow and two point tests of two seies of high flowing concrete mixes are discussed. In the analytical part of the study a simple electrical model was set up to estimate the concrete flow, flow speed, and to assess the effect of material properties on the fluidity of mixes in term of resistance (R) in the electrical model.
Key words: Acryle, Condenser, Electrical model, Flowing resistance, High flowing concrete, L flow, Slag powder, Two point test, Viscosity, Viscosity agent, Yield value.

1. INTRODUCTION

The performance requirement of flowing concrete is that should have ability to fill every corner of the mold of congested reinforcement without using vibration. An experimental study was conducted to examine the effect of variables such as unit water content and dosage of superplasticizer on the rheological properties of two series of high flowing,. Many fundamental analytical studies regarding with flowing behavior of concrete have been reported. All of these studies are based on the mechanical model. There is very close mathematical similarity between the mechanical and electrical modeling. Electrical, Mechanical analyses of several different types can be developed. In many cases constructing an electrical model are essential simplification [1]. However in this study an attempt has been made to estimate L flow,, flowing time, flow speed, and the effect of material properties on the fluidity of the concrete mixes by applying electrical circuit theory.

2. EXPERIMENTAL PROGRAMS

2.1 MATERIALS AND MIXING PROPORTIONS

(a) Cementitious materials: The cementitious materials used included type I normal portland cement as specified in JIS 5210 with surface area of 3320 cm^2/g and specific gravity of 3.16 and highly fine graded granulated blast furnace slag powder of blain size of 5950 cm^2/g and specific gravity of 2.9.

---

*1 Department of Architecture, Hokkaido University , Graduate student, member of JCI.

*2 Department of Architecture, Hokkaido University, MS. C student.

*3 Department of Architecture, Hokkaido University, Ph.D., member of JCI.

(b) Aggregate: The coarse aggregate (C.A) used was crushed stone with specific gravity of 2.9 and nominal maximum size of 20 mm. The fine aggregate (F.A) was local natural sand with specific gravity of 2.75 and fineness modules of 2.69.
(d) Admixtures: The admixtures used in this study consisted of high range air entraining water reducing of aminosulfonate based (FP200H) in series 1 and polycarbon based superplasticizer (SP8SX2) in series 2 mixes.
(e) Viscosity controlling agent: Acryle type of viscosity controlling agent produced by Nihon cement was used in series two mixes.

2.2 MIX PROPORTIONS AND MIXING PROCEDURES

From trial mixes, two series of concrete mixes were selected. These series are defined by replacement of ordinary portland cement (opc) by slag powder as slag concrete (series 1) and by addition of acryle type of viscosity agent to opc as acryle concrete (series 2). In each series either the water content or dosage of superplasticizer varied from low to high contents, in order to achieve the desired levels of workability (i.e., stiff, high, and very high fluidity mixes). The mix proportions of concrete mixes are shown in Table 1.

Table. 1 The mix proportions of the concrete mixes

Mix name	W/C (%)	S/A (%)	Quantities (kg/m³)						SP (%)	AE (%)
			W	C	BFS	S	C.A	V.A		
SL1	33	55	150	205	251	101	803	---	2.5	---
SL2	35	55	161	205	251	100	790	---	2.5	---
SL3	36	55	164	205	251	998	787	---	2.5	---
SL4	35	55	161	205	251	100	790	---	2.0	---
SL5	35	55	161	205	251	100	790	---	2.5	---
SL6	35	55	161	205	251	100	790	---	2.7	---
AC1	34	52	175	512	---	912	812	4	1.7	0.6
AC2	35	52	180	514	---	904	804	4	1.7	0.6
AC3	37	52	190	509	---	892	794	4	1.7	0.6
AC4	35	52	180	514	---	904	804	4	1.4	0.6
AC5	35	52	180	514	---	904	804	4	1.7	0.6
AC6	35	52	180	514	---	904	804	4	2.1	0.6
OPC	55	48	200	364	---	871	909	4	---	---

S/A = sand - aggregate ratio, BFS = blast furnace slag
V.A = viscosity agent, SP = superplasticizer, S = sand,
AE = air entraining agent, SL= slag powder concrete,
AC = acryle concrete, Note: SL2 = SL5
AC2 = AC5

Concrete mixing was carried out in a 100 liter capacity vertical pan mixer. The mixing time was fixed to 6, 7, and 5 minutes for acryle, slag, and ordinary concrete mixes respectively.

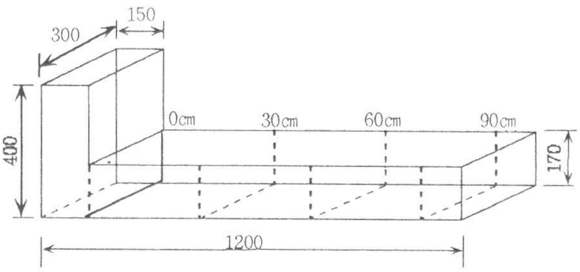

Fig. 1 L flow mold

2.3 TESTING PROCEDURES

(a) Two points test

The development and theory of the Tattersall [2] two point apparatus devised to assess the workability of concrete has been used. The testing is based on the Bingham model with relationship of $T = g + hN$. By measuring the torque (T) produced on the impeller rotating in the bowl of two point test apparatus filled with fresh concrete at various speed (N) settings, the yield value (g) and viscosity (h) can be obtained.

(b) L shape mold

The L shape mold as shown in Fig. 1 was made in order to study the flowing behavior of the concrete mixes. The testing procedure was as follows;
- First the vertical portion of the mold filled with concrete while the exit gate was closed,
- The exit gate pulled out and concrete started to move in the horizontal part of the mold, followed by measurement of flowing time at 30 cm intervals, and
- Then the final horizontal movement (L F) and drop or slump of concrete in the vertical portion (LFS) were recorded, these values and flowing time data were used to express the flowing behavior of fresh concrete and as input data in the electrical model analysis.

3 ANALYTICAL STUDY

3.1 ELECTRICAL MODEL

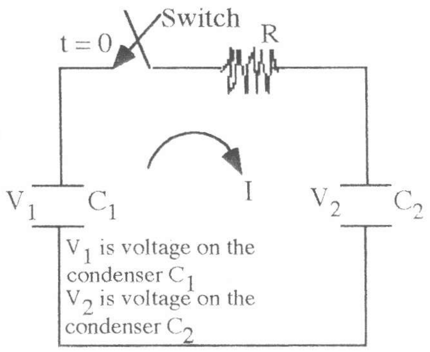

Fig. 2 Electrical circuit model

The simple electrical circuit shown in Fig. 2 was set up to estimate the flow characteristics of high flowing concrete, such as flow resistance, L flow, and flow speed in the L shape mold. For this circuit we can write

$$V_1 = IR + V_2 \quad (1) \qquad I = C_2 \frac{dv_2}{dt} \quad (2)$$

combining Eqs. 1 and 2 $\therefore$

$$V_1 = RC_2 \frac{dv_2}{dt} \quad (3)$$

Where ; R and τ are resistance and time constant respectively.

The current in condenser and in the circuit is the same because the circuit is in series, therefore

$$C_1 \frac{dv_1}{dt} = -C_2 \frac{dv_2}{dt} \quad (4)$$

Substituting for V_1 (from equation 1) and V_2 (from equation 2) in to equation. 4

$$C_1 \frac{d}{dt}(RC_2 \frac{dv_2}{dt} + V_2) + C_2 \frac{dv_2}{dt} = 0 \quad (5)$$

By solving equation 5 and after obtaining general and particular solutions and assuming that;

$$V_1 = V_0 \quad \text{and} \qquad R = \tau \frac{C_1 C_2}{C_1 + C_2} \quad (6)$$

Therefore equation of voltage V1 on the condenser C1 can be found.

$$V_{2(t)} = \frac{C_1}{C_1 + C_2} E(1 - \frac{1}{\exp(B)}) \quad (7)$$

Where; $B = \frac{-t}{\tau}$

E = Initial voltage

The flow speed at any time can be estimated easily by differentiating equation 7 with respect to t.

However, for the aim of this study it was assumed that the following similarities exist between electrical circuit shown in Fig. 2 and schematic of the L shape mold shown in Fig. 3.

As the proposed electrical section is compatible to the mold of U shape, it was first assumed that mold is in the form of U shape (dotted line in Fig. 3). The height and cross sectional area of vertical portion of the L shape mold is equal to the initial voltage E and condenser C_1 respectively, the area of right hand column of U shape mold is equivalent to condenser C_2, horizontal flow of concrete in the mold is equivalent to voltage V_2, and The concrete flowing resistance is identical to resistance R in the circuit (Eq. 6).

It was assumed that the concrete in the right hand column of the mold (shaded area) can have flow pattern in the L shape mold as shown in Fig. (3), and concrete flow in the horizontal portion of the L shape mold can be estimated by applying conversion factor K to equation (7).

Considering above similarity, and applying conversion factor K to Eq. 7, therefore the equation of the concrete flow in the L shape mold can be obtained (Eq. 8).

$$LF_t = K\left(\frac{C_1}{C_1 + C_2} E(1 - \frac{1}{\exp(B)}\right) \qquad (8)$$

In the above equation K is conversion factor and LF_t is the concrete flow in the L shape mold at time t.

But at (t = ∞)

$$LF_{t \to \infty} = K\left(\frac{C_1}{C_1 + C_2} E\right) \qquad (9)$$

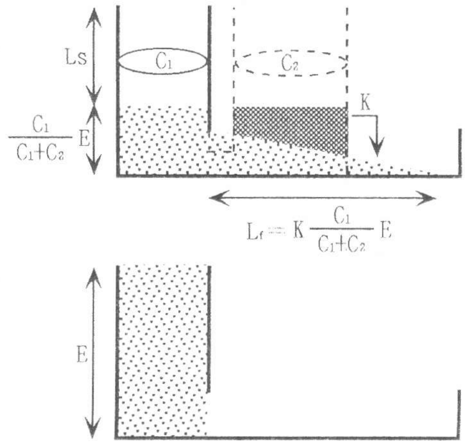

Fig. 3 Analogy between concrete flow in the L shape mold and electrical circuit model

4. DISCUSSION OF RESULTS

4.1 RHEOLOGICAL CONSTANTS (Yield value and Plastic viscosity)

The two point test apparatus was used to measure the rheological constants (yield value and plastic viscosity) of concrete mixes. Fig. 4 shows typical results of two point test associated with the effect of change in unit water content and dosage of superplasticizer on the flow properties of slag concrete. It is seen that the flow properties approximated closely to the Bingham model, and the relationship between torque and speed is linear. This figure indicates that the yield value and viscosity of mixes were decreased either by increase in water content or dosage of superplasticizer. In order to show the importance effect and beneficial use of mineral fine powders on the improvement of workability, the results of two point test of slag mixes compared with the results of two point test of ordinary portland cement concrete. Fig. 4 shows that the yield value of ordinary mix is considerably higher and its viscosity lower than mineral mixes.

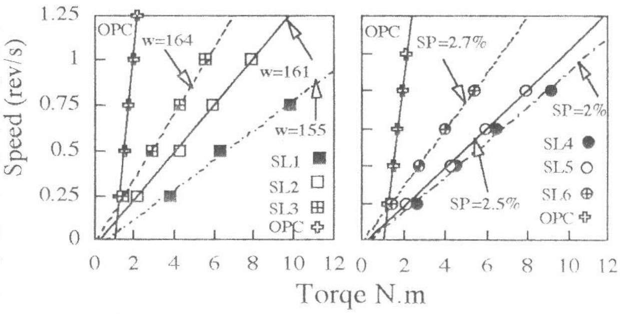

Fig. 4 Torque and speed relationship of slag concrete.

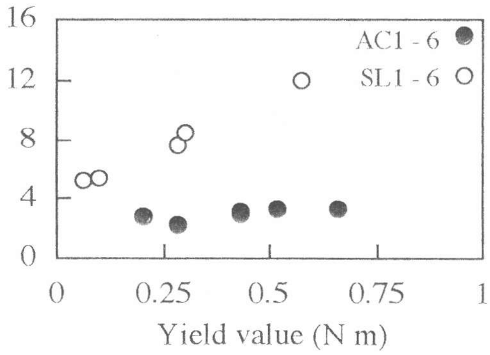

Fig. 5 Relationship between yield value and plastic viscosity.

By comparing the yield and viscosity of mineral and acryle mixes (given in Table. 2, and shown in Fig 5) it is seen that mineral mixes are more susceptible to change due to the variation of either water content or superplasticizer's dosage than acryle concrete mixes. The reason back to the beneficial use of viscosity agent which can control the viscosity of water in the concrete and also influence the deformability and segregation resistance. General speaking the use of viscosity agent in the concrete restrain the free water to move and control friction resistance between solid and therefore reduce shear resistance.

4.2 CONCRETE FLOW IN THE L SHAPE MOLD

The observed and estimated values of L flow of slag and acryle concrete mixes due to variation of water content and dosage of superplasticizer are shown in Fig. 6. This Figure indicates that there are very good agreement between observed and estimated values of L flow, where nearly all observed values are matched the estimated curve. It is seen that as the dosage of superplasticizer or unit water content increase the L flow also increases while the flowing time decreases. The full description of flow properties and segregation resistance of these concretes in the plain and reinforced L shape molds are given in reference [3]. Considering the L flow and flowing time of slag and acryle concrete mixes, it is seen that fluidity of acryle concrete is less susceptible to change due to variation of water content and dosage of superplasticizer than slag concrete. Parts (c) and (d) of Fig. 6 indicate that the L flow and flowing times of AC2, AC3, AC5, and AC6 mixes are nearly the same.

4.3 CONCRETE FLOW PARAMETERS

The flow of concrete is restricted by adhesion force between matrix and the aggregate particles and by viscosity. The resistance to deformation depends on the concrete constituent, mainly texture of aggregate, richness of the mixture, water-cement ratio, admixture, and type of cementitious materials. These are the parameters which mainly affect the viscosity and adhesion force, and therefore concrete flowing resistance. In this study only the effect of water and superplasticizer dosage are defined by flowing parameters obtained from electrical model (C_2, K, and R). The results of analysis are given in table. 2.

Table. 2 The results of slump flow, two point tests and estimated values of flow parameters from electrical model.

Mix name	Slump flow	Two point test g	Two point test h	Flow parameters C_2	Flow parameters K	Flow parameters R
AC1	55.8	0.66	3.3	1550.0	9.96	0.031
AC2	64.8	0.43	3.1	3150.0	19.47	0.024
AC3	66.5	0.28	2.4	2550.0	16.22	0.013
AC4	57.3	0.52	3.3	1405.7	7.88	0.027
AC5	64.8	0.43	3.1	3150.0	19.47	0.024
AC6	71.3	0.20	2.8	3150.0	19.52	0.017
SL1	58.5	0.57	12.0	1101.7	6.12	0.086
SL2	65.5	0.28	7.6	1745.1	11.55	0.034
SL3	70.8	0.10	5.5	2362.5	15.41	0.022
SL4	55.8	0.30	8.6	1444.7	9.34	0.033
SL5	65.5	0.28	7.6	1745.1	11.55	0.034
SL6	71.5	0.06	5.3	2121.4	14.78	0.031

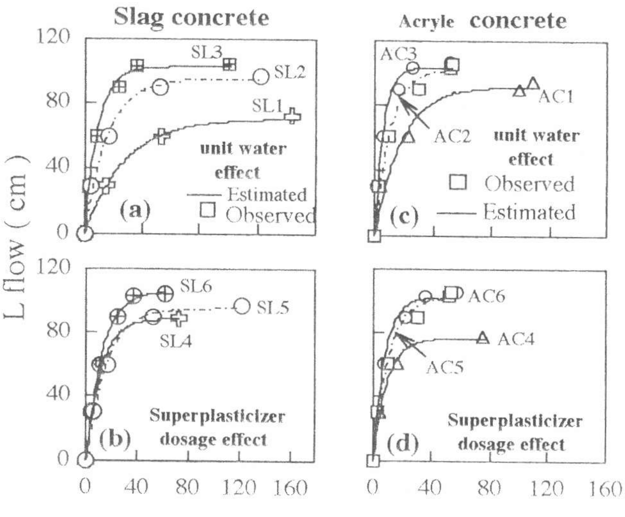

Fig. 6 Estimated and observed values of L flow versus flowing time.

SL1- 3= slag concrete with water content of 155, 161, and164 lit/m³
SL4 - 6= dosage of superplasticizer = 2.1, 2.5, 2.7 % respectively.
AC1- 3= acryle concrete with water content of 175,180, 190 lit/m³
AC4 - 6= dosage of superplasticizer = 1.4, 1.7, 2.1% respectively.
Note: SL2 = SL5
AC2 = AC5

1- Concrete flow resistance (Parameter R)

By comparing the relation between yield value and viscosity of mixes shown in Fig. 6 and yield value, viscosity and flow resistance (R) in Fig. 7, it can conclude that; a) there is very good correlation and meaningful relation between viscosity of mixes obtained from two point test and flow resistance R. In fact the higher the value of viscosity the higher resistance to the concrete flow; b) The relation between yield value and flow resistance R indicates that the resistance R is not yield value dependent.

2 - Condenser C_2 and conversion factor K

Diagrams (c) and (d) of Fig. 7 illustrate the relation between C_2 and rheological constants g and h. It can be seen from these diagrams that condenser C_2 varies significantly while viscosity of acryle mixes remain nearly unchanged, therefore C_2 seems to be independent of viscosity. Diagram (c) indicates that there is meaningful relation between yield value and condenser C_2. In fact C_2 is a function of yield value in other words the lower yield the higher the value of C_2.

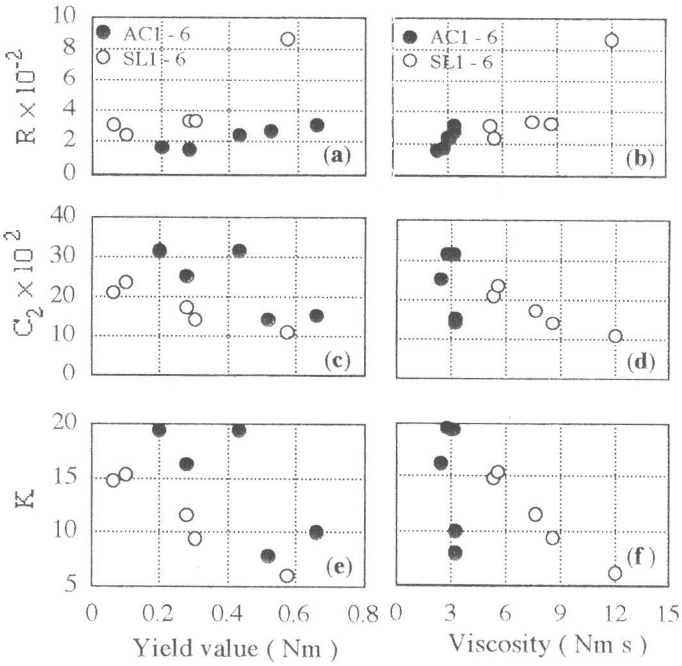

Fig. 7 Relation between yield value, viscosity and estimated values of flow parameters (R, C_2, andK).

The relationship between yield value, viscosity and parameter K are shown in Diagrams (e) and (f) of Fig. 7. The same discussion mentioned for C_2 is applicable to the parameter K and rheological constants relations. Considering the results of slump flow, yield value, viscosity, K, and C_2 parameters shown in Table 2, it is seen that in most of the mixes as the yield value decreases slump flow increases and flow parameters K and C_2 increase . Hence we can conclude that both K and C_2 are function of yield value.

5. CONCLUDING REMARKS

This study mainly focused on the applicability of proposed electrical model to describe the flowing behavior of high flowing concrete mixes in the L flow mold. From the results of this study it can be conclude that, there is good correlation and meaningful relation between viscosity and flowing resistance R. It was found that there is no correlation between viscosity and condenser C_2 and flow conversion factor K, both C_2 and K parameters seem to be function of yield value.

Based of the above findings the authorizes are optimistic to define the effect of mixture materials , reinforcement, mold surface and mold size by application of electrical circuit theory. An experimental and analytical study have under taken in the Department of Architecture, of Hokkaido university to define above effects.

REFERENCES

1. Wylie, C. R., " Advanced Engineering Mathematics," McGraw Hill Book Company, New York, 1960.
2. Tattersal, G. H. and BANFIL, P.F.G. "Rheology of Fresh Concrete," London, Pitman,
3. Khanzadi, M., "Flowing Properties of High Flowing Concrete," Internal Report., Department of Architecture., Hokkaido University.