

# **Center for By-Products Utilization**

## **THE USE OF FLY ASH IN PUMPABLE MASS CONCRETE**

**By Tarun R. Naik, Lihua Wei and Dean M. Golden**

Report No. CBU-1991-07  
June 1991

Presented and published at the 84<sup>th</sup> Annual Meeting & Exhibition, Vancouver,  
British Columbia, June 16-21, 1991

Reference: Naik, T.R., Lihua Wei and Dean M. Golden, "The Use of Fly Ash in  
Pumpable Mass Concrete

Department of Civil Engineering and Mechanics College of  
Engineering and Applied Science  
**THE UNIVERSITY OF WISCONSIN – MILWAUKEE**

The Use of Fly Ash in Pumpable Mass Concrete

By

Lihua Wei  
Research Assistant  
Center for By-Products Utilization  
Department of Civil Engineering and Mechanics  
College of Engineering and Applied Science  
The University of Wisconsin- Milwaukee  
P.O. Box 784, Milwaukee, WI 53201

Dean M. Golden  
Sr. Project Manager, Waste and Water Management Program  
Environmental Control Systems  
Electric Power Research Institute  
P.O. Box 10412  
3412 Hillview Avenue  
Palo Alto, California 94303

and

Tarun R. Naik  
Director, Center for By-Products Utilization  
Department of Civil Engineering and Mechanics  
College of Engineering and Applied Science  
The University of Wisconsin- Milwaukee  
P.O. Box 784, Milwaukee, WI 53201

## INTRODUCTION

Engineers seeking to improve the workability of concrete can either increase the amount of water per unit volume, which will also reduce the concrete strength and increase shrinkage, or increase the amount of cement in the mix, which also increases strength and the heat of hydration, which causes cracks in mass concrete applications. Fly ash has been used as a partial substitute for cement to improve the workability of concrete without sacrificing the strength, or causing additional shrinkage or cracking. This study evaluated several combinations of ash and water reducing admixtures to optimize concrete pumpability, To achieve this, two steps were taken: (1) addition of water-reducing admixtures; and (2) addition of fine fly ash.

In this research study water-reducing admixtures were employed for the purpose of reducing the water content while maintaining the desired workability, and fly ash was used primarily as a partial replacement for cement to reduce the heat of hydration. The mix proportions were carefully chosen for the concrete. The properties of both fresh and hardened concrete, hydration heat of cement paste, and temperature rise of concrete were tested.

## MATERIALS

Cement: 42.5 MPa (6000 Psi) Portland- slag cement

Sand: medium sand, fineness modulus 2.8

Crushed stone: maximum grain size 25 mm (1 in)

Water-reducing admixture: W.R.----- normal water-reducer

S.P.----superplasticizer

R.W.R.---retarding water-reducer

Fly ash: its chemical compositions and physical properties are shown in Table 1. This is a typical ASTM Class F fly ash.

Table 1 Chemical Composition and Physical Properties of Fly Ash

| Chemical Composition (%)                          |                 |       | Physical Properties (%)          |                  |
|---|-----------------|-------|----------------------------------|------------------|
| SiO <sub>2</sub> + Al <sub>2</sub> O <sub>3</sub> | SO <sub>3</sub> | L.O.I | Fineness 4900 Mesh Sieve Residue | Water-Rquirement |
| 85.1  | 0.4             | 5.66  | 4.98                             | 101              |

## EXPERIMENT RESULTS AND ANALYSIS

### *Slump Loss*

Slump loss is a normal phenomenon in all concrete because it results from gradual stiffening and setting of hydrating cement paste. For pumpable concrete, the test results showing the slump loss generally means difficulty in pumping. Therefore, slump loss is an important factor for evaluating quality of pumpable concrete.

Table 2 Fresh Concrete Slump Variation

| Cement Content (kg/m <sup>3</sup> ) | Fly Ash Content (%) | Type of Water-Reducer | Initial Slump (cm) | Final Slump (cm) |       |         |       |
|-------------------------------------|---------------------|-----------------------|--------------------|------------------|-------|---------|-------|
|                                     |                     |                       |                    | 0.5 Hr.          | 1 Hr. | 1.5 Hr. | 2 Hr. |
| 340                                 | 0                   | W.R.                  | 18                 | 12.2             | 10.4  | 7.1     | 6.2   |
| 309                                 | 15                  | W.R.                  | 17.5               | 11.9             | 10.3  | 8.6     | 7.0   |
| 320                                 | 0                   | S.P.                  | 18.1               | 15.3             | 10.1  | 8.4     | 6.7   |
| 289                                 | 15                  | S.P.                  | 20.1               | 18.0             | 13.3  | 12.0    | 8.8   |
| 340                                 | 0                   | R.W.R.                | 18.8               | 16.1             | 12.8  | 9.0     | 7.7   |
| 306                                 | 15                  | R.W.R.                | 18.3               | 16.3             | 12.8  | 9.3     | 8.4   |

Note: 100 kg/m<sup>3</sup> = 0.23 lbs /cu.yd.  
2.54 cm = 1 in

Tests showed that slump loss for concrete mixtures with fly ash were smaller than that for the mixtures without fly ash (shown in Table 2 and Fig. I The final slump values after I hour of hydration were maintained at minimum 10 cm (4 in), which indicated mixtures still had good pumpability.

### *Setting Time*

The penetration resistance method was employed to determine setting time of concrete, and comparisons similar to that described in the ASTM method were made between the mixtures with and without fly ash. Test results are shown in Fig. 2.

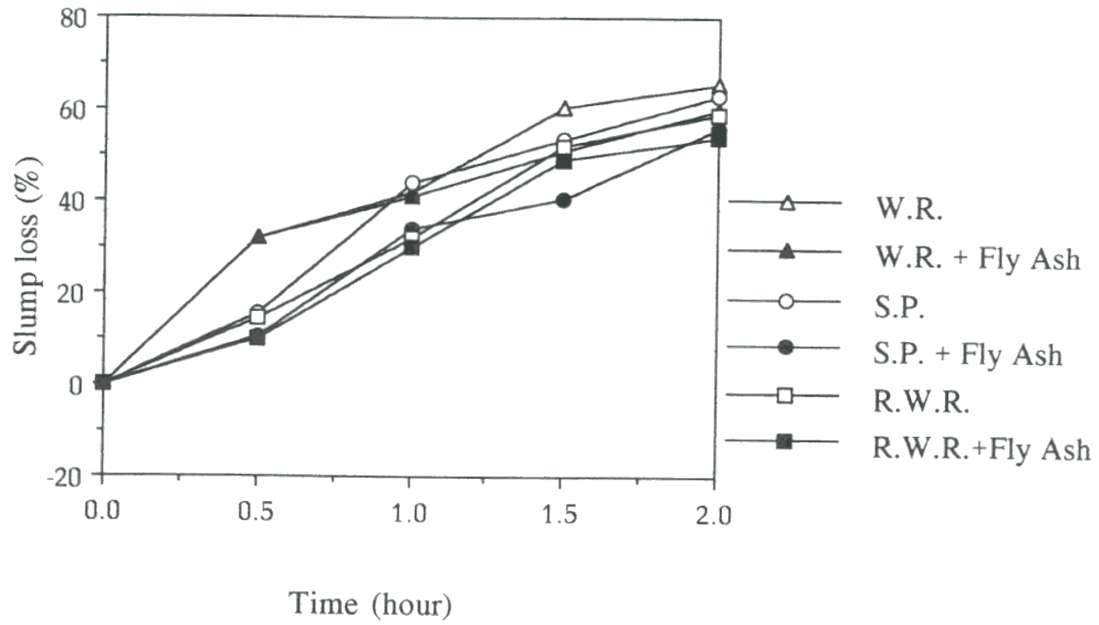


Fig. 1 Concrete Slump vs. Time

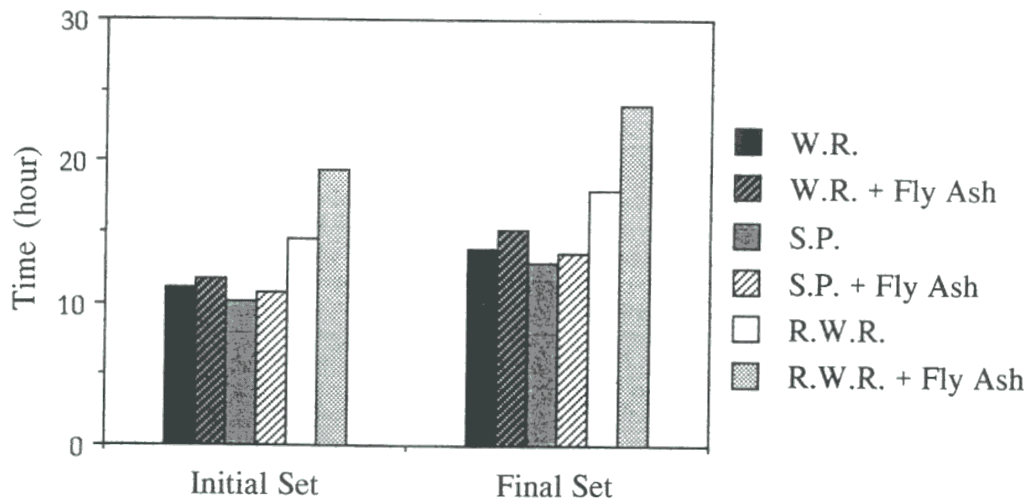


Fig. 2 Concrete Setting Time

The tests proved that fly ash generally slowed the setting of concrete. The observed retarding effect was affected by the combined influence of fly ash and water-reducing admixtures. When compared to no fly ash concrete, the fly ash concrete with W.R.--normal water-reducer, the setting time was retarded by 0.5 hour for the initial set and 1.5 hour for the final set. With S.P.--superplasticizer, setting time was retarded by 0.5 hour for initial and final set, and with R.W.R.--retarding water-reducer, setting time was retarded by 5 to 6 hour. The retardation of set time using fly ash enables mass concrete placement that avoids cold joints between fresh concrete and hardened concrete.

### *Strength Development*

The strength development of pumpable mass concrete with and without fly ash were examined. The data is shown in Table 3.

**Table 3 Compressive Strength of Concrete at Different Curing Ages**

| Cement Content (kg/m <sup>3</sup> ) | Fly Ash Content (%) | Type of Water-Reducer | Slump (cm) | Compressive Strength (MPa) |         |         |
|-------------------------------------|---------------------|-----------------------|------------|----------------------------|---------|---------|
|                                     |                     |                       |            | 7 Days                     | 28 Days | 60 Days |
| 370                                 | 0                   | W.R.                  | 19.0       | 17.6                       | 31.4    | 37.2    |
| 333                                 | 15                  | W.R.                  | 17.5       | 16.9                       | 33.4    | 38.7    |
| 360                                 | 0                   | S.P.                  | 18.9       | 23.6                       | 34.2    | 40.9    |
| 324                                 | 15                  | S.P.                  | 19.8       | 24.0                       | 32.8    | 41.2    |
| 336                                 | 0                   | R.W.R.                | 20.0       | 17.0                       | 30.6    | 34.3    |
| 298                                 | 15                  | R.W.R.                | 19.5       | 15.9                       | 26.3    | 35.3    |

Note: 100 kg/m<sup>3</sup> = 0.23 lbs /cu.yd.

2.54 cm = 1 in

6.9 Mpa = 1000 Psi

The test results indicated that concrete made with 10% cement replacement by 15% fly ash, resulted in its 28-day compressive strength basically close to that of the concrete without fly ash. The 60-day strength were a little higher for fly ash concrete, although their 7-day strength were a little lower, with compared to no fly ash concrete.

*Physical and Mechanical Properties*

Physical and Mechanical properties of hardened concrete results are shown in Table 4.

**Table 4 Physical and Mechanical Properties**

|  |         |       |       |       |       |       |       |
|--|---------|-------|-------|-------|-------|-------|-------|
| Cement Content (kg/m <sup>3</sup> )          |         | 309   | 328   | 351   | 314   | 345   | 309   |
| Fly Ash Content (%)                          |         | 0     | 15    | 0     | 15    | 0     | 15    |
| Cement Replacing (%)                         |         | 0     | 10    | 0     | 10    | 0     | 10    |
| Type of Water-Reducer                        |         | W.R.  | W.R.  | S.P.  | S.P.  | RWR   | RWR   |
| Slump (cm)                                   |         | 19.8  | 19.2  | 20.1  | 20.8  | 18.2  | 18.0  |
| Compressive Strength R28 (MPa)               |         | 31.4  | 32.3  | 34.0  | 35.0  | 38.7  | 34.4  |
| Tensile Strength (MPa)                       |         | 2.6   | 3.3   | 3.2   | 2.9   | 3.0   | 2.9   |
| Flexural Strength (MPa)                      |         | 5.1   | 5.6   | 5.3   | 4.7   | 5.9   | 6.1   |
| Prismatic Strength (MPa)                     |         | 24.1  | 28.3  | 26.0  | 24.7  | 32.9  | 34.2  |
| Bond Strength (MPa)                          |         | 4.3   | 4.5   | 4.5   | 4.0   | 4.7   | 4.3   |
| Modulus of Elasticity *10 <sup>4</sup> (MPa) |         | 3.3   | 2.7   | 4.3   | 3.3   | 3.5   | 3.5   |
| Permeability Resistance (mark B)             |         | >12   | >12   | >12   | >12   | >12   | >12   |
| Shrinkage Value mm/M                         | 28-days | 0.324 | 0.303 | 0.313 | 0.290 | 0.423 | 0.333 |
|  | 90-days | 0.466 | 0.443 | 0.444 | 0.417 | 0.541 | 0.487 |

Note: 100 kg/m<sup>3</sup> = 0.23 lbs /cu.yd.

2.54 cm = 1 in

6.9 Mpa = 1000 Psi

The mechanical properties of pumpable mass concrete, such as compressive strength, tensile strength, flexural strength, and bond strength, containing both fly ash and water-reducing admixture are similar to those expected with water-reducing admixtures alone (for concrete without fly ash).

The modulus of elasticity of pumpable mass concrete containing fly ash was found to be slightly lower. All of the mix proportioning tested showed better permeability resistance. The shrinkage value of concrete with fly ash was determined to be lower than that of the concrete without fly ash.

## Hydration Heat

In order to prevent temperature and shrinkage cracks from occurring in the mass concrete, determinations were first made on the total amount of heat released and the rates of heat released from hydration of the cement pastes. This was done to characterize the setting and hardening behavior, and to predict the temperature rise of concrete.

By using a conduction calorimeter, the rate of heat evolution from cement pastes during the setting and early hardening period were recorded. Table 5 shows the mixtures of cement paste used and its corresponding test results of cement heat of hydration. A typical plot of hydration heat curve is shown in Fig. 3.

Table 5 Measured Results of Hydration Heat

| Cement Content (kg/cm <sup>3</sup> )    |           | 355   | 319   | 345   | 311   | 340   | 306   |
|---|-----------|-------|-------|-------|-------|-------|-------|
| Fly ash Content (kg/cm <sup>3</sup> )   |           | 0     | 56.4  | 0     | 54.8  | 0     | 54.0  |
| Type of Water-Reducer                   |           | W.R.  | W.R.  | S.P.  | S.P.  | RWR   | RWR   |
| Mixture of Cement Paste for Testing (g) | Cement    | 14.2  | 12.7  | 13.8  | 12.4  | 13.6  | 12.2  |
|   | Fly Ash   | 0     | 2.3   | 0     | 2.2   | 0     | 2.2   |
|   | Fine Sand | 0.8   | 0     | 1.2   | 0.4   | 1.4   | 0.6   |
|   | Water     | 7.8   | 7.8   | 7.8   | 7.8   | 7.8   | 7.8   |
| Hydration Heat (cal/g)                  | 24-hours  | 28.81 | 18.11 | 24.73 | 23.64 | 7.77  | 7.37  |
|   | 48-hours  | 5.92  | 43.73 | 46.02 | 49.29 | 38.55 | 31.19 |
|   | 72-hours  | 61.23 | 54.44 | 51.52 | 57.40 | 49.52 | 46.00 |
| Peak Appearing Time (h)                 |           | 19.5  | 27.0  | 21.0  | 23.0  | 34.0  | 41.5  |

Note: 100 kg/m<sup>3</sup> = 0.23 lbs /cu.yd.  
1000 g = 2.205 lbs

The cement and fly ash content used in these tests were as required for the concrete mix. The total cementitious content was 15 g. For the purpose of keeping the same W/C ratio, in the condition of same water content, fine silica sand was added when the mix total cementitious content was not enough to 15 g.

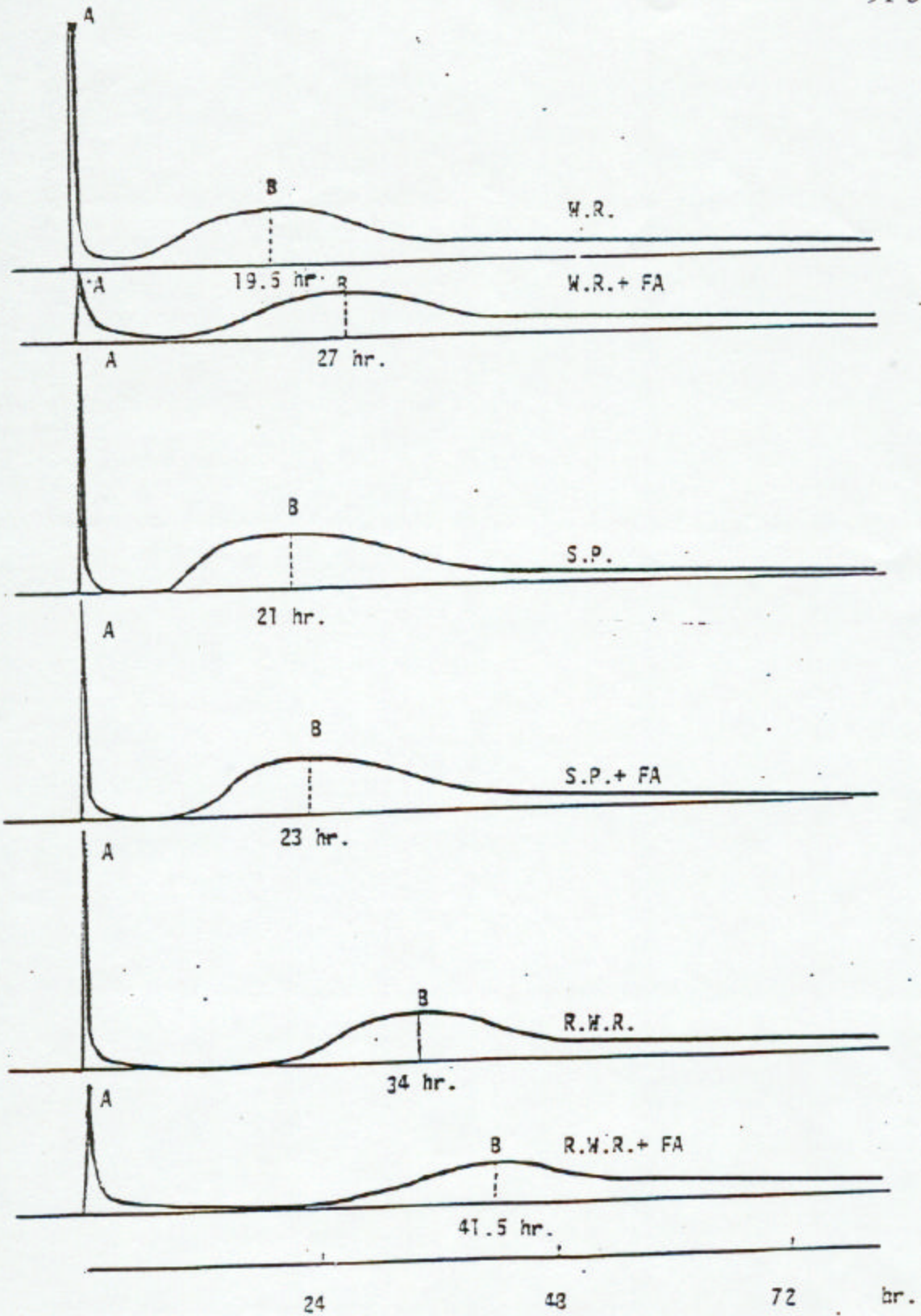


Fig.3 Hydration heat curves of cement pastes

The plots in Fig.3 show that on mixing the cement with water, a rapid heat evolution (peak A) occurs. This probably represents the heat of solution of aluminates (C3A and C4AF) and sulfates (C3A and C2S). This initial heat evolution ceases quickly when the solubility of aluminates is depressed in the presence of sulfate in the solution. The next heat evolution cycle, culminating in the second peak, represents the heat of formation of ettringite (peak B). The heat evolution period includes some heat of solution due to C3S and heat of formation of C-S-H (Calcium-Silicate-Hydrate).

The test results indicate that replacement of partial cement by fly ash exerted a distinct effect on the reduction in the heat of hydration. The hydration heat liberated was lower and slower than that without fly ash paste. The second peak of hydration heat liberation occurred at about one day after mixing for the paste containing W.R.--normal water-reducer and S.P.--superplasticizer, and at about one and a half days for the paste containing R.W.R.--retarding water-reducer. The rate of hydration heat liberation for the paste containing different water-reducing admixtures corresponded to the retarding tendency of setting time. The paste retained much of its plasticity before the commencement of heat cycle and stiffing and slowed the initial set before reaching the peak at B, which corresponds to the final set.

### *Temperature Rise*

For the sake of knowing the actual temperature variation of mass concrete, a measurement was taken of the temperature rise in mass concrete containing fly ash together with W.R.--normal water-reducer. The test results are shown in Fig. 4.

In concrete containing 315 kg/m<sup>3</sup> cement and 55.6 kg/m<sup>3</sup> fly ash, the temperature rise was 43 °C in 28 days. The rate of temperature rise was quick at the early age, rising to 80% of its total in 3 days and 98% in 7 days. Therefore it is of particular importance in mass concrete construction to control the temperature rise during the early age of curing.

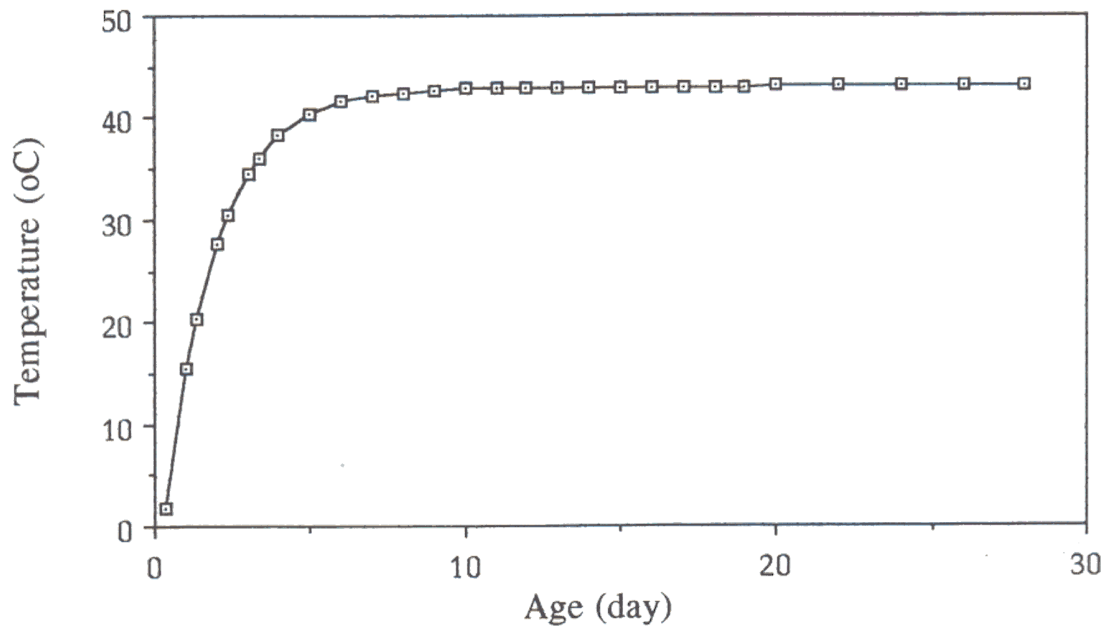


Fig. 4 Temperature Rise Curve for Concrete

## CONCLUSION

Pumpable mass concrete incorporating water-reducing admixtures and fine fly ash can have good workability, pumpability and water retention. Its slump can be controlled at  $18 \pm 2$  cm. Even after 1 hour of hydration, the slump values were higher than 10 cm, which means the mix can satisfy the needs of the pump' process.

The rate of strength development in fly ash concrete tends to be longer than that without fly ash. Replacement of 10% cement by 15% fly ash resulted in 28-day compressive strength, tensile strength, flexural strength, and bond strength that were basically similar to that of the concrete not incorporated with fine fly ash, but the modulus of elasticity values were slightly lower.

Addition of fly ash in mix proportions retard setting time of fresh concrete, decrease cement hydration heat and slow down the heat release speed due to reduction in cement, and decrease the shrinkage of hardened concrete thus ensuring good quality for mass concrete.

## REFERENCES

1. L. J. Lu, and T. Y. Qin, "Pumpable Ready Mixed Concrete for Use in Large Foundation Work" European Ready-mixed Concrete Organization 6th Congress, 1982, London, England.
2. L. H. Wei, "Research on Pumpable Fly Ash Concrete" Project Report, Shanghai Research Institute of Building Science, 1989, (in Chinese), Shanghai, China.
3. P. K. Mehta, Concrete Structure, Properties, and Materials, PRENTICE-HALL, INC., 1987, Englewood Cliffs, New Jersey.
4. V. M. Malhotra, Supplementary Cementing Materials for Concrete, Canadian Government Publishing Centre, 1988, Ottawa, Ontario.