# Sulphate Resisting Cement 389

# Table 1

## Mixture Proportions

### of Concrete Containing Fly Ash

	1b/yd <sup>3</sup>	kg/m <sup>3</sup>
Cement	340	200
Fly Ash	85	50
Cement & Fly Ash	425	250
Water	255	150
Fine Aggregate	1470	875
Coarse Aggregate	1730	1030
Water-Reducing Admixture	2110 cc	2790 cc
Air-Entraining Admixture	125 cc	165 cc

W/(C + FA) = 0.6A/C + FA) = 7.49 Slump = 3.5 in. (90 mm) Air Content = 5.2%

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# Table 2

Physical Properties of Saskatchewan Fly Ash

1.	Specific Gravity	2.30
2.	Blaine Fineness, cm <sup>2</sup> /gm	2253
3.	Pozzolanic Activity Index (a) With Portland Cement at 28 days, percent of control (b) With lime at 7 days, psi (MPa)	145% 882 (6.1)
4.	Water Requirement, Percent of Control	94.41%
5.	Soundness, Autoclave expansion or Contraction, percent	0.081
6.	Compressive Strength of Mortar Cubes - % of control at 7 days - at 28 days	113 145
7.	Drying Shrinkage of Mortar Bars at 28 days, percent	0.089

Chemical Composition of Saskatchewan Fly Ash

		Property	Average of 3 Samples
СНІ	EMIC	AL COMPOSITION, PERCENT	
1	-	Silica (siO <sub>2</sub> )	43.03
2	-	Alumina (Al <sub>2</sub> 0 <sub>3</sub> ) plus Iron (Fe <sub>2</sub> 0 <sub>3</sub> )	27.93
3	-	Mangnesium Oxide (MgO)	3.67
4	-	Sulphur Trioxide (SO <sub>3</sub> )	0.59
5	-	Ignition Loss	0.55
6	-	Available Alkali (Na <sub>2</sub> O)	2.56

# TABLE 3

Physical Properties of Sulphate Resisting Cement (Type V)

1.	Blaine fineness	3690	sq.cm/gm
2.	Autoclave expansion, per cent	0.2	
3.	Compressive strength, 3 days 7 days 28 days	15.0 24.9 37.4	MPa MPa MPa
4.	Percent passing, #200 sieve #325 sieve	99.5 94.8	

Chemical Composition of Sulphate Resisting Cement (Type V)

1.	Silica (SiO <sub>2</sub> ), per cent	22.20
2.	Alumina $(Al_20_3)$ , per cent	3.27
3.	Iron $(Fe_20_3)$ , per cent	4.57
4.	Lime (CaO), per cent	62.69
5.	Magnesium Oxide (MgO), per cent	3.95
6.	Sulfur Trioxide (SO <sub>3</sub> ), per cent	2.13
7.	Loss on ignition, per cent	0.66



Fig. 1--Relationship of compressive strength to temperature after an exposure of 200 days



Fig. 2--Relationship of modulus of elasticity to temperature after an exposure of 200 days



Fig. 3--Stress-Strain diagram for concrete exposed 200 days to a temperature of 250°F (121°C)



Fig. 4--Relationship of creep of sealed concrete to time at indicated temperature and applied stress of 1500 psi (10.35 MPa)



Fig. 5--Relationship of creep of unsealed concrete to time indicated temperature and applied street of 1500 psi (10.35 MPa)



Fig. 6--Relationship of creep to temperature at the age of 200 days and a stress-strain ratio of 0.4



Fig. 7--Relationship of creep recovery to time at a temperature of  $250^{\rm O}F$  (121 $^{\rm O}C)$ 

# Microstructures and Properties of Granulated Slag-Portland Cement Blends at Normal and Elevated Temperatures

By D.M. Roy and K.M. Parker

<u>Synopsis:</u> Blends of separately ground (fine) granulated blast furnace slag with portland cement generally possess properties equivalent to or in ways superior to typical portland cements. Heats of hydration, apparent activation energies for reaction, and structure development are modified in high slag content mixtures. By three days the strength development of blends is equivalent to that of pure portland cement at normal temperatures but this stage is achieved more rapidly at elevated temperatures, while a very fine pore structure is developed with longer time. Phase changes, microstructural and property development including permeability development as a function of time are discussed.

Keywords: blast furnace slag; compressive strength; heat of hydration; microstructure; permeability; porosity; portland slag cements; temperature.

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#### INTRODUCTION

Our interest in the properties of granulated blast furnace slag originated with their potential for generating durable concrete based upon a cement paste matrix having very low permea-The properties of blast furnace slag cements have been bility. reviewed recently (1-4), wherein it has been shown that after a usually initial delay in strength development, the later stage properties of cements containing large proportions of granualted slag develop equivalent later stage properties. Recent studies (4,5) suggest that there need not be much delay in strength development, and that in many ways with respect to those properties relating to durability (4,6), the properties may be superior. They further showed the beneficial effects of heat upon the hydration characteristics (4,7). In current studies we have been concerned both with reaction mechanisms (4,7) and in the development of microstructure and consequent property development (8).

In the present work, therefore, it was the objective to determine the microstructures of pastes and mortars of portlandgranulated blast furnace slag (separately ground) blends with different water/cement ratios and as a function of curing temperature. The porosity, pore size distribution and surface area were determined by mercury porosimetry, and the pore structures related to the microstructures as determined by scanning electron microscopy. Permeabilities to water were determined for some of the materials, and related to the other measurements. Further, the properties were investigated as a function of curing temperature.

### EXPERIMENTAL

Cements (type K/II ASTM) and finely ground granulated slag (Table 1) were used for the studies, as pure cement and 60:40 blends of slag with cement. In earlier studies several different proportions of cement to slag were used (4,9). Samples had w/c (water/cementitious solid) ratios of 0.30, 0.40, 0.50 and 0.60 and were cured in saturated calcium hydroxide solution at 27, 45, 60 and 90°C for periods from 14 to 28 days. The microstructures of fracture surfaces were studied under scanning electron microscopes: ISI DS-130 and Super III. Phase development and changes were

followed by x-ray diffraction with a Philips APD -3600/01 diffractometer. Water permeabilities were determined with pressure differentials up to 600 psi, measured on apparatus described elsewhere (10).

### Specimens

Cylindrical samples 2.54-cm diameter x 2.54 cm height were epoxied into a steel ring and sealed into a permeability cell. A gas pressure driven piston pressurized water at the required pressure which was held constant for the required period, up to several days. A Quantachrome autoscan mercury intrusion porosimeter was used with intrusion pressures up to 60,000 psi. The Washburn equation:

$$P = -\frac{2\gamma\cos\theta}{r}$$

was used to calculate pore volumes, V and dV/dP as a function of radius [this function is equivalent to dV/d(1/r) where r = radius of pores, P is pressure, and S = surface area],  $\theta$  = wetting angle for mercury, assuming  $\theta$  = 140°, and  $\gamma$  = surface tension. Samples for mercury porosimetry were freeze-dried; later measurements were made on samples vacuum dried at 80°C for 2 hours; and an additional set dried with acetone followed by room temperature vacuum drying. Samples from the three methods showed little difference in pore structures. A Seebeck-type calorimeter was used for isothermal measurement of heats of hydration, while volumetric and linear dimensional changes were measured by techniques reported elsewhere (13,14).

### RESULTS

### Early Stage Properties

Heat of hydration--Isothermal hydration calorimetric measurements were made of the early heat of hydration of blends of cement and slag in different proportions. The results have been discussed in more detail elsewhere (4,7); however, Fig. 1 illustrates the typical differential calorimetric curves obtained at 27°C of the pure cement and blends of up to 65% slag. At 15°C the peaks are smaller and delayed in time, while at 45 and 60°C the effects are The blends had two peaks (the second peak corresaccelerated. ponding to the slag component) which came closer together with increasing temperature, until at 60°C a single peak is observed. The slag cements have a higher activation energy for hydration (4,12) than pure portland cements, which is clear from the sequential temperature isothermal calorimetry studies. The slag cement hydration may be distinguished by more stages of hydration than pure portland cement (7), but the highest single activation energy for any stage is clearly higher than in portland cement. This helps explain the beneficial effect of thermal activation on slag cement hydration.