CONCRETO CON ALTO CONTENIDO DE CENIZA VOLANTE: PROPIEDADES MECÁNICAS Y ASPECTOS SOBRE LA DURABILIDAD

por

V.M. Malhotra

Sinopsis: El Centro Canadience para la Tecnología de Minerales y Energía (CANMET) posee un programa de investigación continua que está enfocado el uso de materiales cementantes suplementarios en el concreto. Como parte de este programa CANMET ha desarrollado concretos en los cuales se incorporan altos volúmenes de ceniza volante con bajo contenido de calcio y se obtienen revenimientos mayores de 150 mm utilizando grandes dósis de superfluidificantes. Comunmente, en concretos con alto contenido de ceniza volante, el contenido de cemento se mantiene en cerca de 150 Kg/m³, la relación agua-materiales cementantes es de aproximadamente 0.30 y el contenido de ceniza volante es de entre 56 y 60 por ciento en peso del total del material cementante.

Este trabajo discute las propiedades, aplicaciones y limitaciones de los concretos con alto contenido de ceniza volante. Las propiedades discutidas incluyen los proporcionamientos de las mezclas, propiedades mecánicas, diversos aspectos de la durabilidad y la permeabilidad. Se concluye que, en general, el concreto con alto contenido de ceniza volante posee un excelente desarrollo de resistencia y características de durabilidad, y exhibe muy poco aumento de temperatura. Estas propiedades lo hacen ideal para usarlo en grandes losas de cimentación, elementos estructurales gruesos y otras aplicaciones similares.

Palabras Clave: Concreto, durabilidad, ceniza volante, calor de hidratación, mecanismos de hidratación, permeabilidad, resistencia, superfluidificantes, propiedades térmicas.

HIGH-VOLUME FLY ASH CONCRETE: MECHANICAL PROPERTIES AND DURABILITY ASPECTS

by

V.M. Malhotra

Synopsis: The Canada Centre for Mineral and Energy Technology (CANMET) has an ongoing research program dealing with the use of supplementary cementing materials in concrete. As a part of this program, CANMET has developed concretes in which high volumes of low-calcium fly ash are incorporated and slumps in excess of 150 mm are obtained by the use of large dosages of superplasticizers. Typically, in high-volume fly ash concrete, cement content is kept at about 150 kg/m³, the water-to-cementitious materials ratio is about 0.30, and fly ash content is between 56 and 60 per cent by weight of the total cementitious material.

This paper discusses the properties, applications and limitations of the high-volume fly ash concrete. The properties discussed include mixture proportions, mechanical properties, various aspects of durability, and permeability. It is concluded that, in general, high-volume fly ash concrete has excellent strength development and durability characteristics, and exhibits very low temperature rise. These properties make it ideal for use in large mat foundations, thick-structural elements and other similar applications.

Keywords: Concrete, Durability, Fly ash, Heat of hydration, Mechanism of hydration, Permeability, Strength, Superplasticizers, Thermal properties.

ACI Honorary Member **V.M. Malhotra** is the Program Principal for the Advanced Concrete Technology Program, Canada Centre for Mineral and Energy Technology (CANMET), Dept. of Natural Resources, Ottawa, Canada. He is a prolific author, editor, and researcher, and has received many awards and honours from ACI and other institutions throughout the world.

INTRODUCTION

Low-calcium fly ash (ASTM Class F) has been incorporated into concrete as replacement for portland cement for the construction of mass gravity dams since 1935 (1). The primary aim in the use of fly ash was, and has been to reduce the heat of hydration. The low early-age strengths obtained by the use of fly ash were not critical as the compressive strength requirements were generally of the order of 20 MPa at 90 days or one year. In earlier years, the percentage of fly ash used was limited to about 30 per cent. In 1965, Mather (2) reported an investigation in which he studied the effects of 60% solid volume replacement of cement with fly ash. For water-to-(cement + fly ash) ratio (W/C+F) of 0.50 and 0.80, he reported three-day strengths of 4 and 1.5 MPa respectively. In recent years, large volumes of fly ash have been incorporated into the construction of roller-compacted concretes but, once again, the low-early age strengths are not of concern (3).

In 1985, CANMET initiated studies on structural concrete incorporating high volumes (>50%) of low-calcium fly ash. The purpose of this research was to develop concrete with adequate early-age strength and workability, low temperature rise and high later-age strength. This was successfully achieved (4-19).

This paper discusses the mechanical properties and durability aspects of high-volume fly ash concrete and outlines its limitations.

MIXTURE PROPORTIONS

Like normal portland cement concrete, the mixture proportions of high-volume fly ash concrete will depend upon the strength level required. In general, the cement content varies from 100 to 180 kg/m³ with W/C+F ranging from about 0.30 to 0.40. The water and fly ash contents are kept at about 115 and 220 kg/m³, respectively, and slumps in excess of 150 mm are achieved with high dosages of superplasticizers. In studies at CANMET, the maximum size of coarse aggregate has been kept at 19 mm, but high-volume fly ash concretes have been made using 25 and 39 mm maximum size aggregates. The high percentage of fly ash in the concrete mixture does not pose any serious problem for the entrainment of 5 to 6 per cent air in concrete except that large dosages of the air-entraining admixtures are required. However, this has no adverse effect on the properties

of fresh and hardened concrete (6). Nevertheless, exploratory investigations should be performed to ensure that air-entraining admixtures used are compatible with the type of cement and fly ash incorporated into the concrete mixture. Typical mixture proportions for the high-volume fly ash concrete are shown below:

	Batch Quantities
ASTM Type I Cement:	150 kg/m³
ASTM Class F fly ash:	210 kg/m³
Water:	115 kg/m³
Coarse aggregate (19-mm max):	1275 kg/m³
Fine aggregate:	620 kg/m³
Air-entraining admixture:	720 mL/m³
Superplasticizer:	4.0 L/m³

The physical properties and chemical analysis of the various fly ashes used are given in Table 1.

PROPERTIES OF FRESH CONCRETE

Bleeding

Bleeding tests performed on high-volume fly ash concrete have shown that this concrete does not bleed (Table 2). This is due to the very low water content (≈115 kg/m³) used in this type of concrete (11). This would necessitate additional curing in hot weather to avoid plastic shrinkage cracks.

Entrainment of Air in Fresh Concrete

No difficulty has been encountered in the entrainment of air in high-volume fly ash concrete, though the dosage required is considerably more than that for portland cement concrete without fly ash. However, it should be pointed out that the fly ashes used in the high-volume fly ash concrete systems have relatively low carbon content. It may be difficult to entrain high percentages of air in the above system if the fly ash has carbon content >6%, but the judicious selection of an air-entraining admixture can overcome this problem (14).

Density of Fresh Concrete

Investigations at CANMET have shown that the density of high-volume fly ash concrete is of the order of 2400 kg/m³, and is comparable with the density of portland cement concrete without fly ash. Considering that the specific gravity of fly ash is generally lower than that of portland cement (2.6 versus 3.1), the density of high-volume fly ash concrete is considered high, and this is due to the reduced water content due to the use of superplasticizers.

Dosage Requirement of Superplasticizer

Because of the very low water-to-cementitious materials ratio (≈0.30) of the high-volume fly ash concrete, the use of superplasticizers becomes mandatory. The dosage required will depend upon the slump to be achieved; for flow concrete, the dosage is of the order of 1.5 per cent of the total cementitious material (≈5 kg/m³). There is also a question of compatibility between superplasticizers and portland cements in the presence of fly ashes. Exploratory investigations should always be performed to ensure that there is no undue delay in the setting time of concrete when using the high-volume fly ash concrete system (11,14).

PROPERTIES OF HARDENED CONCRETE

Temperature Rise

Because of the very low cement content, the temperature rise in the high-volume fly ash concrete during the first few days after placement is very low. For example, the peak temperature measured at mid-depth of a high volume fly ash concrete block (1.5 x 1.5 x 1.5 m) at 2 days was 31.3°C when the ambient and placing temperatures were 24° and 12°C, respectively (12).

Strength Properties

The high-volume fly ash concrete exhibits adequate strength development characteristics both at early and later ages. For example, the one-day compressive strength of high-volume fly ash concrete can vary from 5 to 9 MPa depending upon the type of cement. These strength values are more than adequate for formwork removal at normal temperatures, and are comparable to the strength developed by portland cement concrete with about 250 kg/m³ of cement. The later-age compressive strength in some instances have been shown to reach about 60 MPa at one year. The 28-day flexural and splitting-tensile strengths of the high-volume fly ash concrete are about 15 and 10 per cent of the corresponding 28-day compressive strength, and these are, once again, comparable to the values for the normal portland cement concrete. Fig. 1 shows typical compressive strength development data for high-volume fly ash concrete.

The compressive strength development of air-cured high-volume fly ash concrete preceded by 7 days of initial moist curing as compared with the continuously moist-cured specimens follows the same trends as the control concrete i.e. the strength of the former concrete (air cured) is somewhat lower than the latter concrete (moist cured) (Fig. 2).

Young's Modulus of Elasticity

The Young's modulus of elasticity of high-volume fly ash concrete made with limestone aggregate generally exceeds 30 GPa, and is thus somewhat higher than the modulus for comparable strengths of portland cement concrete. The higher modulus is probably due to large percentage of aggregates, and in addition, due to the unhydrated fly ash particles acting as a fine filler material in the concrete.

Creep Characteristics

The creep characteristics of high-volume fly ash concrete are shown in Fig. 3. The creep strain at one year ranges from 150 to 400 x 10⁻⁶ which is comparable to or lower than that of the portland cement concrete of comparable strength.

Drying Shrinkage

The drying shrinkage strains of high-volume fly ash concrete and normal portland cement concrete, determined in accordance with ASTM C 157, are comparable (11). Fig. 4 shows such data on drying shrinkage strains on fly ash and control concrete prisms which had been cured in lime-saturated water for either 7 or 91 days and then air dried at 23 ± 1.7° and 50 ± 4 per cent relative humidity for periods up to about 500 days.

Water Permeability

Water permeability tests using a CANMET uniaxial flow apparatus were performed on the fly ash concrete incorporating 150 kg/m³ of ASTM Type I cement and 190 kg/m³ of fly ash. Briefly, the test method consists of measuring the uniaxial water flow through concrete cylinders, 125 mm high with a diameter of 150 mm, under a pressure of 3.5 MPa. The test specimens were maintained in the permeability cells for more than 6 months, and it was found that no water had passed through the specimens during this period. Based upon data previously published by CANMET, this indicates that the concrete tested has extremely low permeability, although no numerical values can be assigned (20).

DURABILITY ASPECTS OF HIGH-VOLUME FLY ASH CONCRETE

Resistance to the Penetration of Chloride Ions

Several investigations at CANMET have indicated that high-volume fly ash concrete has very high resistance to the penetration of chloride ions (6,7). The AASHTO T277-83 test method, "Rapid Determination of the Chloride Permeability of Concrete" is the most commonly accepted test in North America, and was therefore, adopted as the preferred