High-volume fly ash (HVFA) concrete was developed by CANMET in the 1980's. In this high-performance concrete, 55-60% of the portland cement is replaced by Class F fly ash. The water-to-cementitious materials ratio (W/CM) is maintained at 0.32 ± 0.01 with portland cement and fly ash contents kept at about 150 and 225 kg/m³, respectively. The water content of the mixture is kept low at about 120 kg/m³, and acceptable workability is achieved by the use of large dosages of a superplasticizer (SP), typically 3 to 6 l/m³. This type of concrete has excellent long-term mechanical and durability properties, this is supported by voluminous research data and some field data (1-19). The early-age strength (6 to 8 MPa) at 1 day is ample enough for form work removal except in cold regions. The 28-day and 91-day compressive strengths of this type of concrete ranges from 35 to 50 MPa and from 45 to 70 MPa, respectively. The long-term strength of more than 110 MPa at 10 years has been achieved in demonstration blocks (20).

As mentioned above, this type of concrete requires a high dosage of superplasticizer for some types of fly ashes. This may in turn make this concrete more expensive than normal portland cement concrete with similar mechanical properties. Yet, this type of concrete would be more durable, and environmently friendly. Still, this concrete has not found acceptance among practicians for whom the importance of durability comes way behind the initial cost of the materials. Also, the early age strength development characteristics of such concrete is considered as a handicap in cold regions.

In order to extend the general concept of HVFA concrete and its applications to a wider range of construction, this research project was initiated, aimed at optimizing the fly ash content in concrete. Such fly ash concrete would develop an adequate 1-day compressive strength, and have economical advantages compared to conventional portland cement concrete with similar 28-day compressive strength.

The study was divided into three parts. The first part dealt with non-superplasticized and non-air entrained fly ash concrete. The second and the third parts investigated the effect of a superplasticizer and an air-entraining admixture on the conclusions drawn in Part I, respectively.

For Part I, the control concrete targeted was a non-air entrained concrete with a cement content of 330 kg/m³, a water-to-cement ratio of 0.50, and a 28-day compressive strength of 40 MPa. For the fly ash concretes, the fly ash replacement level investigated ranged from 30 to 50% of the total weight of the cementitious materials (CM), kept at 300 to 400 kg/m³. The water was adjusted to produce a fly ash concrete with a slump of 100 ± 20 mm.

In Part II, superplasticized concrete mixtures were added in order to compare, in terms of cost, two ways of enhancing the early age compressive strength of the fly ash concrete. One way is to
reduce the W/CM and adding the superplasticizer to the concrete mixture, and the other is to reduce the fly ash content, keeping the total weight of CM constant in the concrete mixture.

In part III of the study, the effect of air entrainment on the compressive strength of the fly ash concretes was investigated.

Two fly ashes from Point Tupper, Nova Scotia, and Sundance, Alberta were used in this study. Point Tupper fly ash, an ASTM Class F ash, contained 4.2% CaO and had a Blaine fineness of 2270 cm$^2$/g. Sundance fly ash met the general requirements of ASTM Class F ash, had relatively high CaO content of 13.4% and a Blaine fineness of 3060 cm$^2$/g.

Based on the present study, the following conclusions were drawn:

**Non-air entrained concrete made without SP**
- For concrete made with Sundance fly ash, it is possible to substitute a normal portland cement concrete, with w/c of 0.50 and a 28-day compressive strength of 40 Mpa, by a concrete incorporating 50% of fly ash with 1-day compressive strength of 10 MPa and similar 28-day compressive strength. This will result in about 17% cost saving. Such concrete would, however, develop significantly higher compressive strength in the long term than the control concrete.
- For concrete made with Point-Tupper fly ash, it is possible to substitute the above normal portland cement concrete with concrete incorporating 40% of fly ash with 1-day compressive strength of 10 MPa and similar 28-day compressive strength, resulting in a cost saving of 13%. Such concrete would also develop significantly higher long term compressive strength than the control concrete.

**Effect of superplasticizer (SP)**
- In order to enhance the early age compressive strength of the concretes, it was economical to reduce the W/CM by adding a SP than to reduce the fly ash content in the concrete mixtures with a CM content of approximately 400 kg/m$^3$ and a fly ash content ranging from 30 to 50%. This, however, was not true for concrete mixtures with low CM content (~300 kg/m$^3$).

**Effect of air entrainment**
- For fly ash concretes, each percent of entrained air reduces the compressive strength by about 4 to 5%.
- It was found possible to substitute a normal air-entrained concrete with W/C of 0.45 and 28-d compressive strength of ~40 MPa by a concrete incorporating 50% Sundance fly ash which could yield 1-d and 28-d strengths of about 10 and 40 MPa, respectively. This will result in a cost saving of 18%. The fly ash concrete would develop very low penetrability to chloride-ion compared to the moderate penetrability of the control concrete, and much higher long term compressive strength than the control concrete.
- In the case of Point-Tupper fly ash concrete, it is possible to substitute the above normal air-entrained concrete with concrete incorporating 30% of fly ash with 1-day compressive strength of ~9 MPa and similar 28-day compressive strength. This will result in a cost reduction of 10%. This fly ash concrete would develop low penetrability to chloride-ion
compared to the moderate penetrability of the control concrete, and much higher long term compressive strength than the control concrete.

It should be noted, however, that the above conclusions are valid for concrete mixtures with cementitious materials and fly ash contents ranging from 300 to 400 kg/m³ and from 30 to 50%, respectively. The conclusions related to the cost of concrete are valid for prices of $130/tonne of cement, $65/tonne of fly ash, and $3/litre of superplasticizer.

References


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