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# ENHANCEMENT IN MECHANICAL PROPERTIES OF CONCRETE DUE TO BLENDED ASH

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## ABSTRACT

This study was carried out to evaluate the effects of blended ash mixture on mechanical properties of concrete. In this study two reference mixtures were used. One of the mixtures was a no-fly ash mixture, and the other mixture contained 35% unblended Class C fly ash. Additional mixtures were composed of three blends of Class C and Class F fly ash while maintaining a total fly ash content of 40% of the total cementitious materials. Mechanical properties such as compressive strength, tensile strength, flexural strength, and modulus of elasticity were determined as a function of age ranging from 1 to 91 days. The results showed that blending of Class F fly ash with Class C fly ash showed either comparable or better results compared to either the reference mixture without fly ash or the unblended Class C fly ash concrete mixture at a fly ash concentration of 40% of total cementitious materials.

## Introduction

Concrete microstructure, which governs its mechanical performance, depends upon a large numbers of parameters. These parameters include type, amount, and structure of constituent materials; curing environment; etc.(1-3). Concrete is composed of fine as well as coarse aggregates as fillers, and hydrated cement paste (HCP) as a binder resulting from reaction of cementitious materials with water. The structure of cement hydration products is greatly influenced by the rate of hydration reaction, type of hydration products formed, and their distribution in the HCP. The rate of hydration reaction and the resulting hydration products can be substantially modified by addition of mineral and chemical admixtures.

It has been well established that in cement-rich mixtures, the rate of hydration reaction is high enough to cause plastic shrinkage cracks as well as non-homogeneity in microstructure of concrete. The accelerated hydration results significantly from evolution of high level of heat due to hydration reaction in the mixture. Consequently, long and thin cementing C-S-H crystals are formed during the hydration process under such a condition. Such crystals occupy less space compared to that formed during normal hydration process, leading to a less dense concrete microstructure. As a result, concrete strength and durability properties are adversely affected.

To avoid these, low-heat cement as well as mineral and chemical admixtures are added. Class F fly ash can be added to concrete to control rate of hydration reaction and to improve its microstructure. The improvement in microstructure occurs due to grain as well as pore refinements, especially in the interface region between the aggregates and HCP. Inclusion of a Class C fly ash, up to a certain level, can exhibit hydration reaction similar to that of concrete made with portland cement alone. Therefore, a blend of Class C and Class F ashes should produce an improved rate of hydration reaction with a favorable microstructure compared to a concrete mixture with or without the addition of Class C fly ash. Considering this, it was postulated that a blend of Class F and Class C fly ashes will result in improved concrete structure due to modification of rate of hydration reaction as well as other benefits that are derived when Class C and/or Class F fly ash is added to concrete. This, in turn, will help enhance mechanical and durability properties of the concrete. This research was undertaken primarily to verify this hypothesis in improving concrete mechanical properties.

## Materials

A Lafarge Corporation cement meeting ASTM C 150 requirements for Type I cement was used in this work. Two fly ashes, a Class C and a Class F, were used for preparing blended ash products. Both the fly ashes conformed to the ASTM C 618 requirements. Three different blends of these fly ashes were prepared and used in this investigation. The coarse aggregate was crushed to a nominal maximum size of 19 mm. The fine aggregate was natural sand (6 mm max. size). The respective values of bulk specific gravity and absorption were 2.6 and 0.5% for the coarse aggregate and 2.7 and 1.4% for the fine aggregate. Both the aggregates met other requirements of ASTM C 33. A commercially available melamine-based superplasticizer and a synthetic resin type air-entraining agent were used in all the mixtures.

## Mixture Proportions

Two reference mixtures designated as C1 and C2 were proportioned for the 28-day design strength of 35 MPa. Mixture C1 contained no fly ash and mixture C2 contained 35% Class C fly ash of the total cementitious materials. The reference mixture without fly ash (C1) was composed of 356 kg/m$^3$ cement, 107 kg/m$^3$ water, 836 kg/m$^3$ sand, 5.4 L/m$^3$ superplasticizer, and 460 ml/m$^3$ air entraining admixture. Mixture C2 differed from C1 only in respect of fly ash content as it has 35% of Class C fly ash of the total cementitious materials used. All other mixtures had essentially the same mixture proportion, but they contained blended fly ash mixtures. The blended fly ash mixtures, designated as B1, B2, and B3 were prepared in the concrete laboratory of the Center for By-Products Utilization, University of Wisconsin-Milwaukee. The proportions of the fly ash blends were 75% Class C : 25% Class F for mixture B1, 50% Class C : 50% Class F for mixture B2, and 25% Class C : 75% Class F for mixture B3. In all the blended ash mixtures a total fly ash content of 40% of total cementitious materials was used. The water to cementitious materials ratio was kept at about 0.30 ± 0.02 for all the mixtures. The amount of superplasticizer was varied to obtain desired level of workability (190 ± 25 mm). Air content was kept at 6 ± 1% for all the mixtures by using the air entraining admixture. Each mixture was mixed in accordance with ASTM C 192 using a batch size of 0.15m$^3$. Soon after mixing, fresh concrete properties such as slump, unit weight, temperature, and air content were measured for each mixture using applicable ASTM standards. The unit weight of the mixtures varied between 2350 ± 50 kg/m$^3$.

## Preparation and Casting of Test Specimens

Cylinders (150 × 300 mm) were cast for determinations of compressive strength, splitting tensile strength, and modulus of elasticity of all the test mixtures. Prism specimens (75 × 100 × 300 mm) were made for flexural strength measurements. All the specimens (75 × 100 × 300 mm) were prepared in accordance with ASTM C 192. After casting, test specimens were covered with plastic sheets, and left in the casting room for 24 hours at a temperature of about 21 °C. They were then demolded and put into a 100% Relative Humidity moist curing room at 23 °C until the time of testing.

## Test Results and Discussions

Compressive Strength. The compressive strength data observed at various ages (1, 7, 28, and 91 days) are shown in Fig. 1. At the one-day age, Blend B1 (75% Class C and 25% Class F) showed the highest value of compressive of the mixtures tested. Also, the reference mixture without fly ash (Mix C1) showed better results than the reference mixture having unblended Class C fly ash alone at 35% fly ash content. Blend B3 (25% Class C and 75% Class F) showed the lowest value of compressive strength at the one-day age. The poorest performance of this mixture is due to its high Class F content which did not contribute sufficiently to the strength at this very early age because of its relatively low reactivity. At the age of 7 days, a dramatic improvement in the performance of the fly ash mixtures was noticed. All the fly ash mixtures except Blend B3 outperformed the reference mixture without fly ash. The highest compressive strength was observed for Blend B1 (75% Class C and 25% Class F). When curing was extended to 28 days, the blended ash results showed continuing improvement. The observed compressive values at 28 days were about 34, 47, 60, 51, and 37 MPa for Mix C1, C2, B1, B2, and B3, respectively. The test data at 91 days exhibited the same trend as that recorded at 28 days (Fig. 1). Improvement in properties of concrete due to pozzolanic contributions is well established (1,2,3). The grain and pore structure refinements that occur due to inclusion of blends of different fly ashes is not yet fully understood. It is apparent that structure of this concrete is improved by modifying the rate of hydration reaction due to Class C fly ash replacement with Class F fly ash.

In this work, however, a decrease in compressive strength was observed, especially at early ages, beyond 50% Class C fly ash replacement with Class F fly ash.

Tensile Strength. The splitting tensile results are shown in Fig. 2. At one-day age, the reference mixture without fly ash (Mix C1) showed higher splitting tensile strength than the values exhibited by the mixtures containing the Class C ash alone as well as blended ash mixtures. This is primarily due to the fact that at this early age fly ashes generally do not contribute sufficiently toward formation of pozzolanic C-S-H crystals (1). In fact, the hollow, spherical ash particles present in the mixtures may behave like flaws or notches at very early ages due to poor bond between the matrix and the particles. This, in turn, would affect the splitting tensile strength of concrete adversely more than it does compressive strength. A similar trend was also observed at the age of 7 days.

At 28 days, a similar general trend as the 7-day strength data was observed. But differences between the reference mixture without fly ash and the fly ash mixtures decreased to a very significant extent. This was probably due to much improved formation of pozzolanic C-S-H

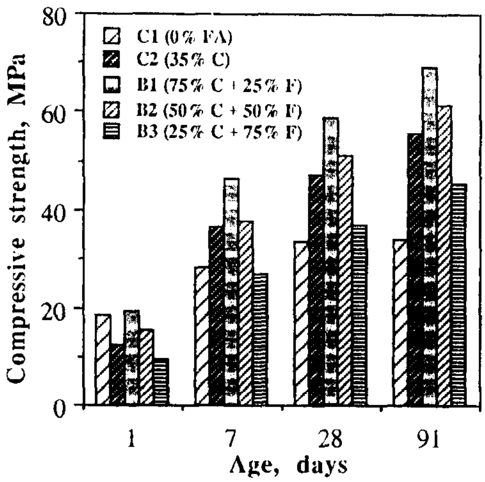


FIG. 1.
Effect of blended fly ash on compressive strength of concrete.

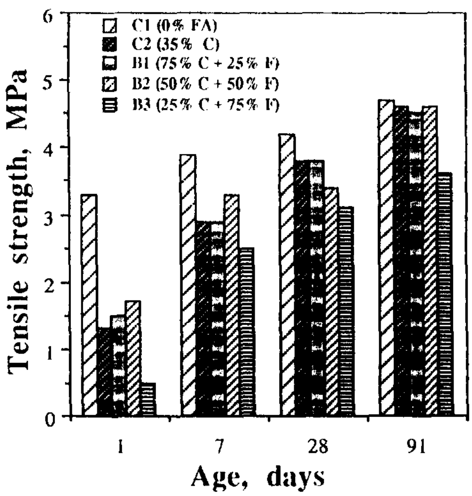


FIG. 2.
Effect of blended fly ash compressive strength of concrete on tensile strength of concrete.

crystals at this age. Blended fly ash Mix B1 and unblended fly ash Mix C2 showed tensile strength values quite close to that of the reference mixture without fly ash (Mix C1).

A dramatic improvement in performance of the fly ash mixtures occurred at the age of 91 days. This was certainly due to large pozzolanic contributions of the fly ash mixtures (1). All the fly ash mixtures except Mix B3 showed tensile strength values equivalent to that of the no-fly ash reference mixture (Mix C1).

Flexural Strength. The flexural strength data are demonstrated in Fig. 3. Blended fly ash concrete Mix B2 showed the highest value of flexural strength amongst all the mixtures tested at 7 days. At 28 days, all the concrete mixtures containing fly ash produced higher flexural strengths than the control mixture without fly ash. Blended fly ash concrete Mix B2 showed the best result followed by blended fly ash concrete Mix B1 and unblended fly ash concrete Mix C2. At the age of 91 days, the results followed the same trend as that observed at 28 days. Blended Mix B2 exhibited the highest flexural strength value, but the result was comparable to that obtained for blended fly ash Mix B1 and unblended fly ash Mix C2.

Modulus of Elasticity. The static modulus of elasticity test data are plotted in Fig. 4. At the age of one day, the control mixture showed the best result. As curing progressed, the difference between the fly ash mixtures and the no-fly ash mixture decreased to a significant extent. This was due to the increased contributions of fly ash in the formation of cementing crystal in the mixtures incorporating fly ash. At the 7-day age, the performance of the control mixture was equivalent to that shown by blended fly ash concrete Mix B1. Other mixtures showed slightly lower modulus values relative to the control incorporating no fly ash (Mix C1). At 28 days, the trend of the results was analogous to that of the 7-day results; however, the difference between mixes was dramatically decreased. At 91 days, the best result was observed for concrete Mix

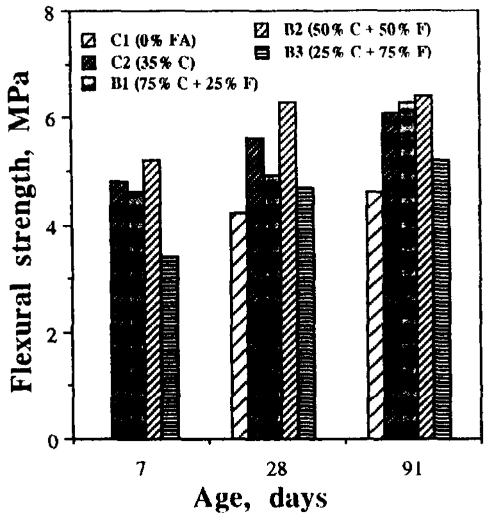


FIG. 3.
Effect of blended fly ash on flexural strength of concrete.

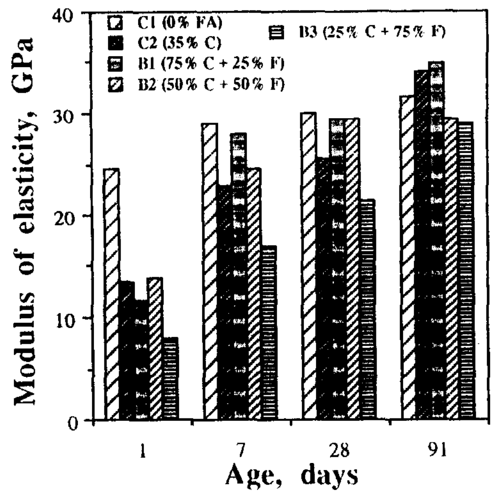


FIG. 4.
Effect of blended fly ash on modulus of elasticity of concrete.

B1. However, all other mixtures (Mix C1, C2, B2 and B3) exhibited equivalent results at the age of 91 days.

## Conclusions

The following are the major conclusions based upon the present investigation.

1. The effect of blending of Class C and Class F was significant on mechanical properties of concrete mixtures tested. Up to a certain level of replacement of the Class C fly ash with the Class F fly ash, mechanical properties of concrete were greatly improved.
2. At the one-day age, all other fly ash mixtures, except blended fly ash concrete Mix B1, showed lower compressive strength than the control mixture without fly ash. The best compressive strength was observed for blended fly ash Mix B1 followed by blended fly ash Mix B2 at 7-day age and beyond.
3. At early ages up to 7 days, the no-fly concrete showed better tensile strength results than the mixtures containing either blended fly ash mixtures or unblended ash. All the fly ash mixtures except blended ash Mix B3 exhibited tensile strength equivalent to that shown by the reference mixture without fly ash at the age of 91 days.
4. In general, the mixtures containing either unblended fly ash mixture or blended fly ash mixtures showed higher flexural strength than the reference mixture containing no fly ash, except Mix B3 at the 7-day age.
5. At early ages, the no-fly ash mixture showed higher modulus of elasticity than the fly ash mixtures. The difference between these mixtures became significantly small as curing was extended beyond 7 days. At 91 days, blended fly ash Mix B1 showed the best result, but all the other mixtures exhibited comparable results.

6. The results revealed that up to 50% of Class C fly ash can be replaced with Class F in order to prepare blended ash mixtures for use in concrete for improving concrete mechanical properties.

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