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ABSTRACT

This research was carried out to evaluate performance of concrete produced, placed and cured under weather conditions normally followed in this country as well as several other countries. Mechanical properties of concrete containing low-calcium fly ash were determined under simulated hot and dry weather conditions. Compressive strength, tensile strength, and secant modulus of elasticity were measured. A concrete designed to have 28-day compressive strength of 2500 psi (17 MPa) was used in this investigation. Mechanical properties were measured at three levels of temperature 73, 95 and 120'F (23, 35 and 49*C) and four levels of cement replacement by Class F fly ash (0, 10, 20 and 30%) on an equal weight basis. Results show that for hot weather the optimum quantity of this low-calcium fly ash varied between 10-20% by weight of cement used with respect to compressive strength, tensile strength, and secant modulus depending upon test temperature and age.

INTRODLJCTION

Researchers have shown that mechanical properties of concrete are adversely affected when curing temperatures deviate from the normal curing conditions [1]. High-temperature and low-relative humidity result in reduction in concrete strength and modulus of elasticity, resistance to abrasion, and resistance to weathering. Presence of high-temperature, variable humidity, wind velocity and intense solar radiation in hot climate conditions pose great problems in production and quality control of concrete in the field. Addition of fly ash to concrete should help alleviate some of the problems arising from hot weather concreting, as the presence of Class F fly ash in concrete mixtures leads to decrease in water demand, and reduced rate and amount of heat of hydration.

Various international authorities including ACI have recommended hot weather concreting practices to minimize the adverse affects of hot weather conditions on concrete properties. However, in majority of normal housing construction work in this country as well as abroad, these practices are seldom followed. As a result, concrete strength properties are adversely influenced by hot weather conditions. Little data exist concerning actual performance of fly ash concrete manufactured, placed, and cured under conditions followed in housing construction work. Therefore, a need exists to obtain design data on concrete manufactured under hot weather conditions, especially the conditions in normal home building practices.

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Some correlation exists between chemical composition and performance of fly ash in concrete. Performance of fly ash in concrete is strongly influenced by its physical and mineralogical properties. Two different fly ashes having similar chemical composition may have entirely different performance in concrete depending upon their physical and mineralogical properties. Therefore, in order to evaluate the effects of any desired parameters on performance fly ash concrete, it is highly essential to have uniform properties of a given fly ash, especially physical and mineralogical properties.

OBJECTIVES

This research work was primarily undertaken to determine performance of concrete produced, place, cured, and tested under hot and dry weather conditions prevalent in majority of current housing construction practices in the U.S.A. as well as abroad. In this work, the influence of low-calcium fly ash (ASTM Class F) addition and temperature conditions on mechanical properties of concrete was determined under hot and dry weather conditions. Results of this investigation would be useful in determining optimum mixture proportion of fly ash concrete for use under hot weather conditions.

LITERATURE REVIEW

Numerous studies have been conducted to evaluate mechanical properties of fly ash concrete [1-12]. Based on the results from past studies, Berry and Malhotra (3) reported that inclusion of fly ash in concrete results in improved workability, pumpability, cohesiveness, finish ability, ultimate strength, and durability. Lane and Best [6] indicated that fly ash properties influenced the compressive strength of concrete to a greater degree compared to its influence on modulus of elasticity. They reported that modulus of elasticity and compressive strength were lower at early ages and higher at later ages compared to reference concrete without fly ash. Lohtia et al. [4] indicated that replacement of 15% Class F fly ash was optimum with respect to strength, modulus of elasticity, and creep. Ghosh and Tikalsky (5] compared fly ash concrete with reference concrete. Their results indicated that concrete containing fly ash of good quality had equivalent modulus of elasticity values and significantly lower creep values than the reference concrete.

Al-Ani and Al-Zaiwary [8] investigated the influence of curing period and curing delay on concrete properties in hot weather conditions. Their results revealed that a maximum of three days of curing was sufficient for rich mixes, whereas a longer period was required for lean mixes (at least 7 days). The delay in curing resulted in considerable reduction in compressive strength. Abbasi and Al-Tayyb [9]studied the influence of hot weather conditions on modulus of rupture and splitting tensile strength of concrete. They reported that the required compressive strength was obtained in hot climate conditions, but the respective modulus of rupture and the splitting strength of concrete were lower by about 20 and 10 percent compared to the reference concrete cured at normal laboratory temperature. Cebeci [10] investigated the effect of simultaneous changes in the curing temperatures (17 and 37*C) and the relative humidity of the curing medium (100%, 75%, and 33%) on strength development of concrete up to a period of one year. Their results revealed that the decrease in the humidity had a greater effect than the curing temperature on the resulting strength development of concrete. The compressive strength of concrete kept in low-humidity was found to be 30 to 46% lower compared to those cured in water. Ravindrarajah and Tam [11] studied performance of fly ash concrete under hot climates with a temperature of 28 $\pm$ 2'C and relative humidity of 75 $\pm$ 15%. The results exhibited that the rapid rate of hydration of the reference concrete under hot and humid environments could be altered by the additions of fly ash to the rates similar to those of the reference concrete under normal temperature conditions.

EXPERIMENTAL PROGRAM

Substantial variation in temperature and relative humidity values is observed in hot and dry weather conditions. In this investigation, typical values of temperatures and relative humidity encountered in hot weather conditions were selected to simulate hot weather condition. In hot weather conditions, higher temperature is generally accompanied with lower humidity. Attempts were made to simulate actual concreting conditions normally followed by house builders.

Portland cement concrete for this research was proportioned to have a 28-day compressive strength of 2500 psi (17 MPa). This is a typical concrete used for home building, indoor concreting having lower performance requirements. A low- calcium fly ash of uniform properties obtained a single source was selected for this study. Fly ash concretes were designed to incorporate low-calcium (Class F) fly ash at cement replacements of 10, 20, and 30% by weight of cement used. Test temperature was maintained to simulate hot weather conditions at three different temperature levels of 73, 95 and 120 ^{o}F + 3^{o}F (23, 35 and 49^{o}C). Experiments were designed to evaluate compressive strength, secant modulus of elasticity, and tensile strength of concrete as a function of fly ash inclusion, temperature, and relative humidity conditions in which the concretes were manufactured and cured.

MATERIALS

ASTM Type I Portland cement (C-150) was used. ASTM Class F fly (C-618) ash was used in this study. The physical properties and chemical analysis of the cement were determined using appropriate ASTM standards (Table 1). Physical and chemical properties of the fly ash determined in accordance with applicable ASTM test methods are shown in Table 2. The coarse and fine aggregates were air- dried, 3/4 in. (19 mm) maximum size Madison gravel, and Janesville sand, respectively, meeting ASTM C-33 requirements. The coarse aggregate was a combination of two different size fractions; two parts of 3/8 to 3/4 in. (9.5 to 19 mm) and one part of No. 4 to 3/8 inch (9.5 mm) by weight.

MIXTURE DESIGN

A trial batch method of mixture proportioning was utilized in this investigation. Four trial batches were proportioned and mixed, and compressive strength specimens were made and tested at various ages, see Table 3. From the results, mix proportioning curves were plotted.

From these curves, a concrete mixture proportion was selected to have the 28-day compressive strength of 2500 psi (17 MPa). The mixture consisted of 362 lbs. cement, 1330 lbs. S.S.D. sand, 2052 lbs. S.S.D. 3/4" maximum size aggregates, and 275 lbs. water per cu. yd. concrete. Besides this reference concrete, fly ash concrete mixtures were proportioned to have fly ash at cement replacements of 10, 20 and 30% by weight. The proportions of other ingredients were kept constant.

PREPARATION, CASTING, AND CURING OF TEST SPECIMENS

All the concrete ingredients were kept in rooms maintained at the three temperature levels of 73, 95 and 120^{o}F + 3 ^{o}F (23, 35 and 49 ^{o}C) for at least 24 hours prior to mixing the materials. All the associated equipments were also kept at these temperatures. The aggregates were mixed dry for two minutes and then half of the required water was added. Wet mixing was carried out for 45 seconds and then fly ash, cement, and the remaining water were added and mixing was continued for two minutes and 15 seconds. The resulting mixture was used to cast samples for the given test conditions. Properties of the fresh and hardened concretes are shown in Table 4. Weight of hardened concrete was measured at an age of 24 hours. Cylindrical specimens of 6xl2 in. (152 x 305 mm) were made in cast iron molds for compressive strength, tensile strength, and secant modulus of elasticity from all the concrete mixtures. Test specimens were kept in mold for 24 hours at their respective casting temperatures. All specimens were stripped after 24 hours of casting. The specimens for 95OF (35'C) and 120OF (490C) then were transferred to a water bath maintained at their casting temperatures for a week. The 73' F (23'C) specimens were kept in moist closet for 7 days.

Beyond 7 days, the 6xl2 in. (152 x 305 mm) cylinders for the 73 ^{o}F (23 ^{o}C) designation were kept at 73 ^{o}F (23 ^{o}C) and 55% +5 % relative humidity (R.H.) for three weeks. Afterwards the storage room was maintained at 73^{o}F (23^{o}C) and 20% R.H. until all testing was completed. The test specimens for the 95 ^{o}F (,3 S^{o}C) designation were kept in a hot room at 95 ^{o}F (35 ^{o}C) and 70 + 5% relative humidity for the first two weeks. Later, the room was kept at 95 ^{o}F (35 ^{o}C) and 50 + 5% R.H. until the time of their testing. For the 120 ^{o}F (49 ^{o}C) designation, the specimens were kept in an "oven" maintained at 120OF (49"C) and 55% +5% R.H. for the first two weeks, and later at 120OF (490C) and 25% R.H. until the time of testing.

TESTING OF SPECIMENS

Prior to testing, the top and bottom surface of each cylinder was capped with plaster of paris for compressive strength and modulus of elasticity measurements. All test specimens were tested for compressive and tensile strength, and secant modulus of elasticity in accordance with ASTM test methods. Three cylinders were tested for each test condition.

RESULTS AND DISCUSSION

The test data obtained in this investigation were substantially influenced by temperature and relative humidity maintained during mixing, casting, and curing operations. It is well established that the concrete properties are adversely affected when it is cured under high-temperature and low-humidity conditions. The damaging effects of low-humidity are much greater than that of the high- temperature. Investigations have revealed that the rate of hydration reaction becomes low below 80% relative humidity, and the reaction becomes negligible below 30% relative humidity. However rate of moisture loss, which affects hydration reaction, is substantially influenced by several other factors including size of concrete member, internal structure of concrete, etc. The negative effects of relative humidity will be lower in the case of large members compared to small members.

COMPRESSIVIE STRENGTH

Compressive strength data are shown in Table 5. The relation between compressive strength and age is demonstrated in Figures 1 through 3. The relation between compressive strength and fly ash content is shown in Figures 4 through 6.

As expected, compressive strength increased with increasing age. The rate of increase was found to be largely dependent upon the curing conditions. Generally, the rate of increase was higher for specimens manufactured and cured at 95 ^{o}F (35 ^{o}C), and 120 ^{o}F (49 ^{o}C) than the specimens at 73 ^{o}F (23 ^{o}C) (Figures I through 3).

In general performance of concrete improved with addition of fly ash up to certain level and beyond which it deteriorated. Addition of Class F fly ash caused reduction in porosity of concrete in both hydrated cement phase (HCP) and transition zone between HCP and aggregate phase. Additionally, inclusion of Class F fly ash causes reduction in thermally induced cracks caused by rapid rate of hydration reaction resulting from high temperatures- Consequently, strength of concrete is improved due to addition of fly ash in concrete mixes. Interparticle friction may further contribute to the strengthening of this composite material. it is also likely that beyond a certain point when particle to particle interactions become significant there could be a reduction in compressive strength and other strength properties understandably due to increased stress concentrations effects.

The concrete attained the maximum 28-day compressive strength at a fly ash addition of 10% at 73 ^{o}F (23 ^{o}C) and 95 ^{o}F (35 ^{o}C); and, 20% at 120 ^{o}F (49 ^{o}C). At 7 days, the compressive strength generally decreased with an increase in fly ash at all the test temperatures (Figures 4 through 6). At the 90-day age, the optimum fly ash level was also found to be 10% at a temperature of 73 ^{o}F (23 ^{o}C).

Secant Modulus of Elasticity

The secant modulus was determined at a compressive stress level of 0.33 times the compressive strength. The secant modulus data is presented in Table 5. The secant modulus as a function of age is shown in Figures 7 through 9. The relationship between fly ash and secant modulus is presented in Figures 10 through 12. The secant modulus values increased with age, within the range of the experimental error. In general, the secant modulus for the concrete at both 7 and 28 days decreased very slightly with increase in fly ash at temperature levels of 73 ^{o}F (23 ^{o}C) and 95

^{o}F (35 ^{o}C). When the temperature was increased to 120 ^{o}F (49 ^{o}C), the secant modulus appeared to be optimum at all ages for the 10% fly ash content concrete mixture.

Tensile Strength

The splitting tension tests were carried out at four levels of fly ash addition (0,10,20 and 30 percent) and three levels of temperature of 73, 95 and 120 ^{o}F (23, 35 and 49 ^{o}C), at the 28-day age only (Table 5). The relationship between tensile strength and percent inclusion of fly ash is presented in Figure 13. The tensile strength of the fly ash concrete decreased slightly (though not significantly) with increasing fly ash content. The tensile strength of the fly ash concrete appeared to be optimum in the range of 0-10% fly ash content at the temperature of 73 ^{o}F (23 ^{o}C) and 10% fly ash content at 95 ^{o}F (35 ^{o}C). At the temperature of 120 ^{o}F (49 ^{o}C) the mixture with 20% fly ash content showed the best results. In fact, for all practical purposes, the splitting tensile strength did not change significantly with increasing fly ash content or with increasing temperature.

CONCLUSIONS

This research was primarily carried out to evaluate mechanical behavior of concrete as a function of fly ash inclusion and temperature under hot and dry weather conditions. The results obtained in this investigation are valid only for concrete made with low-calcium fly ash, meeting ASTM Class F fly ash requirements. Fly ash replaced an equal weight of cement used in the reference concrete. Analysis of the test results led to the following main conclusions.

(1) The optimum level of fly ash for the concrete with respect to 28-day compressive strength was 10% at a temperature of 73 ^{o}F (23 ^{o}C) and 95 ^{o}F (35 ^{o}C); and, 20% at a temperature of 120 ^{o}F (49 ^{o}C).
(2) The optimum fly ash content in the concrete was found to be 10% with respect to modulus of elasticity under hot and dry weather conditions.
(3) The optimum amount of fly ash for the tensile strength was 10 to 20% within the experimental range, for all the test temperatures.

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Table 1: Physical Properties and Chemical Composition of Cement

Physical tests	
Blaine fineness, cm^2/gm	3,345
Normal Consistency, %	24.5
Setting time, hrs.	
- Initial	3.0
- Final	6.25
Autoclave expansion, %	0.094
Tensile strength, psi	
- 3 day	310
- 7 day	400
- 28 day	525
- 90 day	475
Compressive strength, psi	
- 3 day	1,900
- 7 day	2,955
- 28 day	4,965
- 90 day	6,365
Chemical composition, %	
Silicon dioxide (SiO_2)	21.30
Calcium oxide (CaO)	63.71
Aluminum oxide (Al_2O_3)	4.79
Ferric oxide (Fe_2O_3)	2.35
Sulphur trioxide (SO_3)	2.40
Loss on ignition (LOI)	0.90
Insoluble residue	0.20
Compounds, %	
C_3S	55.17
C_2S	19.47
C_3A	8.72
C_4AF	7.15

Note: 1 psi = 0.0069 MPa

Table 2: Physical Properties and Chemical Composition of the Low-Calcium Fly Ash

Physical tests	
Fineness	
- Mean particle diameter, microns	6.87
Specific gravity	2.47
Autoclave expansion, %	0.01
Drying shrinkage of mortar bars	
Mix data	
- Portland cement, gm	500
- Fly ash, gm	125
- Graded Ottawa sand, gm	1,250
- Water, gm	270
- Flow (consistency), %	112.5
Change of drying shrinkage of mortar bars at 28 days, %	-0.02
Pozzolanic activity index with lime	
Mix data	
- Fly ash, gm	350
- Lime, gm	175
- Ottawa sand, gm	1,575
- Water, gm	350
- Flow (consistency), %	112.5
Activity Index	925 psi
Chemical Analysis, %	
Silicon dioxide (SiO_2)	41.5
Aluminum oxide (Al_2O_3)	27.0
Ferric oxide (Fe_2O_3)	24.2
Calcium oxide (CaO)	2.2
Magnesium oxide (MgO)	0.9
Sulphur trioxide (SO_3)	1.0
Available alkalies as N_2O	0.44
Loss on ignition (LOI)	2.5
Moisture Content	0.3

Note: 1 psi = 0.0069 MPa

Table 3: Trial Batch Concrete Mix

Batch No.	Net w/c Ratio by wt.	Weight of Material; lbs. per cu. yd.			28-Day Compressive strength psi
		Cement	s.s.d. sand	s.s.d. Gravel	
1	0.434	722	888	2220	5400
2	0.478	575	1085	2200	5200
3	0.600	444	1211	2150	4250
4	0.750	365	1330	2060	2600

Note: 1 lb. per cu. yd. = 0.593 kg/m^3

Table 4: Properties of Fresh and Hardened Concrete

Temp. °F(°C)	Fly Ash, %	Air Content, %	Kelly Ball, in.	Wt. of fresh concrete, lb./cu. ft.	Wt. of hardened concrete, lb./cu. ft
73(23)	0	1.3	1	150.0	-
	10	1.0	1	151.6	-
	20	0.8	1-1/2	150.0	-
	30	1.3	1-1/2	150.8	-
95(35)	0	1.4	1	148.4	147.1
	10	1.0	1	149.6	147.5
	20	0.8	1-1/2	149.6	147.0
	30	0.8	1-3/4	149.6	147.2
120(49)	0	1.8	1	149.6	147.7
	10	1.4	1	148.4	146.5
	20	1.3	1-1/4	149.6	146.3
	30	2.0	1-3/4	149.6	146.5

Note: 1 inch = 25.4 mm; 1 lb per cu. ft. = 16.02 kg/m^3

Table 5: Mechanical Properties of the Concrete

Temp. °F(°C)	Fly Ash, %	Compressive Strength, psi 7-day	Compressive Strength, psi 28-day	Compressive Strength, psi 90-day	Secant Modulus, psi x 10^{-6} 7-day	Secant Modulus, psi x 10^{-6} 28-day	Secant Modulus, psi x 10^{-6} 90-day	Tensile Strength, psi 28-day
73(23)	0	1805	2309	3450	2.70	3.30	3.97	331
	10	1460	2580	2970	2.56	3.26	3.82	322
	20	1180	2000	2665	2.60	2.54	3.38	295
	30	1170	2285	2745	2.24	3.40	3.60	285
95(35)	0	1680	2400	-	2.90	4.00	-	323
	10	1660	2460	-	2.90	3.51	-	329
	20	1490	2315	-	2.80	3.50	-	295
	30	1315	2405	-	2.62	3.69	-	291
120(49)	0	1860	2420	2795	3.00	3.00	3.46	308
	10	1830	2530	2785	3.39	3.58	3.62	297
	20	1470	2630	2450	2.92	2.74	3.20	314
	30	1615	2500	2620	3.00	3.59	3.14	290

Note: 1 psi = 0.0069 MPa