The Effects of Fly Ash and Portland Cement on Long Term Excavatability of Flowable Fill

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ABSTRACT

Specifying agencies low confidence in the excavatability of flowable fill has restricted the growth of this market for coal combustion byproducts. The Ready Mixed Concrete Associations of Kentucky and Tennessee sponsored a preliminary study at Tennessee Technological University (TTU) to increase confidence in excavatable flowable fill (EFF). Further, the associations and TTU applied for and received Combustion Byproducts Recycling Consortium (CBRC) funding to conduct a two-year field study of EFF. The results of the preliminary study are presented as well as the plan for the CBRC two-year field study.

The preliminary study was conducted in the laboratory using nine EFF mixtures. The impact of paste components on engineering properties of EFF was evaluated using Type I Portland cement contents of 30, 45, and 60 lbs/yd^3 and Class F fly ash contents of 300, 370, and 440 lbs/yd^3. Engineering properties evaluated included flow (ASTM D 6103), compressive strength (ASTM D 4832), and bleed time. The results of the study indicate very strong correlations between rate of early compressive strength gain (R^2 = 0.957) and 182-day compressive strength (R^2 = 0.9409) with Portland cement and Class F fly ash contents.

The CBRC study will make use of twenty-three 3x3x16 foot trenches and 4x8 inch cylinders to determine the relationship between compressive strength and excavatability. The product of the study will be a CD-ROM containing project results and a model specification for EFF containing coal combustion byproducts. The CD will be provided to municipal officials and engineers at four free seminars at the conclusion of the project.

OBJECTIVE

The objective of the preliminary study was to increase specifying agency confidence by quantitatively determining the effect of Class F fly ash content on EFF compressive strength development. This preliminary study was limited to a six-month duration. Longer-term information will be provided from the Combustion Byproducts Recycling Consortium (CBRC) study.

RESEARCH METHODOLOGY

Nine EFF mixtures were used to assess the impact of ASTM C 618 Class F Fly Ash and Portland cement content. Proportions for the EFF mixtures were chosen using Kentucky Transportation Cabinet (1) and Tennessee Ready Mixed Concrete Association (TRMCA) recommendations as well as a previous Tennessee Technological University capping research mixture (2). Trial batches were performed with set amounts of fly ash and Portland cement. Aggregate and water were adjusted until a flow of greater than 8.75 inches was measured. The mixtures selected are shown in Table 1 and the testing protocol followed is shown in Table 2. The schedule for compressive strength determination is shown in Table 3. An experimental wet-suit neoprene in rigid retainers was used as the capping method. Prior research performed has proven the experimental capping method statistically superior or equal to the ASTM D 4832-95 approved capping methods (2).

Table 1. Non Air Entrained Mix Designs in lbs/CY

	Mix 1	Mix 2	Mix 3
Type I PC	30	30	30
Class F Fly Ash	300	370	440
Ohio River Sand	3000	2560	2508
Water	550	501	491
	Mix 4	Mix 5	Mix 6
Type I PC	45	45	45
Class F Fly Ash	300	370	440
Ohio River Sand	2603	2552	2499
Water	510	499	490
	Mix 7	Mix 8	Mix 9
Type I PC	60	60	60
Class F Fly Ash	300	370	440
Ohio River Sand	2595	2538	2513
Water	508	500	500

Table 2. Testing Protocol for Plastic and Hardened Properties

Parameters	Number of Frequency
Batches per mixture	1
No. of cylinders per batch	30
Batch Size	Approximately 1.8 cubic feet
Flow	1 per batch
Compressive Strength	3 per batch per break day

Table 3. Compressive Strength Cylinder Break Schedule

Day	7	28	63	98	140	182
Week	1	4	9	14	20	26

RESULTS

Mixtures 1 and 7 sheared rather than flowed, all other mixtures had flows in excess of 8-inches. All nine mixtures bled in less than 7 seconds. The average compressive strength values for each mixture design are shown in Table 4. Figures 1 through 3 show the early compressive strength development of mixtures with 30, 45, or 60 lbs/yd^3 of Type I Portland cement respectively.

Table 4. Average Compressive Strength

Mix	7-Day (psi)	28-Day (psi)	63-Day (psi)	98-Day (psi)	140-Day (psi)	182-Day (psi)
1	2	5	4	6	5	N/A
2	4	12	20	24	20	22
3	11	19	25	31	32	26
4	7	14	23	25	29	36
5	10	21	37	41	34	36
6	25	42	52	64	64	78
7	20	32	54	83	63	81
8	25	44	74	93	89	116
9	39	64	100	125	144	156

ANALYSIS OF RESULTS

Mixture 1 (30 lbs PC/300 lbs FA) and Mixture 7 (60 lbs PC/300 lbs FA) failed the flow requirement by shearing. All mixtures with 30 lbs/yd^3 of Portland Cement and two of three EFF mixtures with 45 lbs/yd^{3}of Portland Cement violated the 30-psi minimum compressive strength at 28-days. Mixture 9 (60 lbs PC/440 lbs FA) had a 182-day compressive strength of 156 psi just above the 150 psi maximum compressive strength at 2 years. These facts suggest that the paste component of an EFF mixture is the most important component of the mixture. There appears to be a minimum cementitious materials content for adequate performance. Mixtures with insufficient cementitious materials contents are non-homogenous, exhibit inadequate flow and very low compressive strength results.

Values of the coefficients of determination (R^2) for the fit of the logarithmic trend lines to compressive strength development of each of the nine EFF mixtures indicate an excellent fit. The maximum R^2 value was 0.986 while the minimum value was 0.8987. The coefficient of ln(x) of each trend line indicates the rate of early compressive strength development of the mixture. Figure 4 is a plot of the coefficient of ln(x) versus the square of the PC weight multiplied by the weight of Class F fly ash. The excellent fit (R^2 = 0.957) of the linear trend line shows mathematically what the industry personnel have intuitively known for some time – EFF strength is directly proportional to cementitious materials content. Further, PC content influences early compressive strength development more than Class F fly ash content.

Figure 5. shows 182-day compressive strength of EFF versus PC weight cubed times Class F fly ash content. Again, the excellent fit (R^2 = 0.9409) of the linear trend indicates a strong relationship between compressive strength and amount of cementitious materials in the EFF paste.

The strong correlations shown in Figures 4 and 5 indicate that it may be possible to develop a mechanistic design procedure for EFF based on rate of strength development required and allowable ultimate strength. This possibility will be further explored in the CBRC field study.

CBRC STUDY

Twenty-five different EFF mixture trenches (3 x 3 x 16 feet) simulating utility cuts were planned for the study. However, foundry sand aggregates were not available at the planned time of placement, therefore only twenty-three trenches were placed. Twenty EFF mixtures contain coal combustion byproducts and three comparison mixtures contain chemical air generators. Further, five different aggregates were used to attempt to access the impact of aggregate type on EFF properties. After approximately two years, an attempt will be made to determine the excavatability of each simulated utility cut trench with a backhoe. The qualitative excavatability will be correlated with compressive strength development of the EFF over the two-year period.

Compressive strength development will be determined in the same manner as in the preliminary study, but will continue until the time of trench excavation (approximately two years).

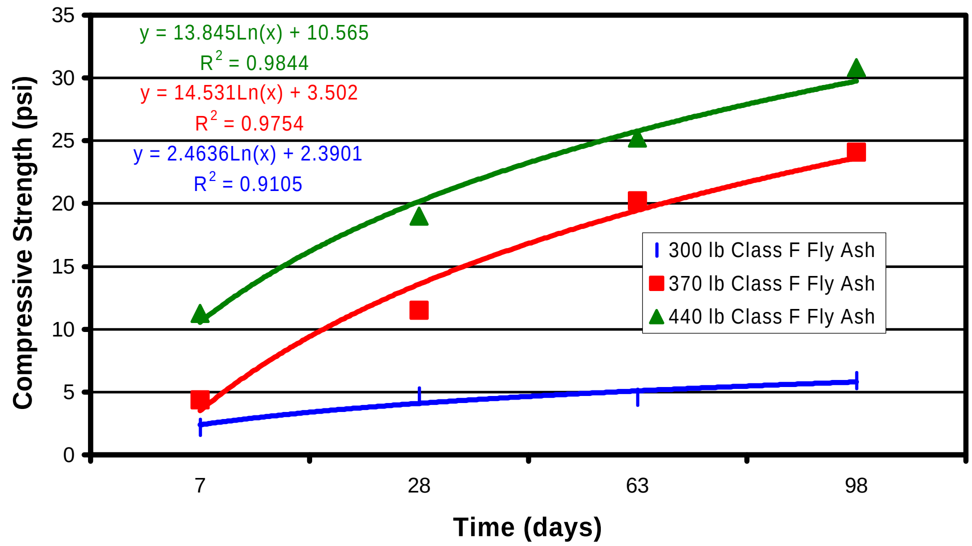

Figure 1. Early Compressive Strength Development of Mixtures Containing 30 lbs/CY of Type I Portland Cement

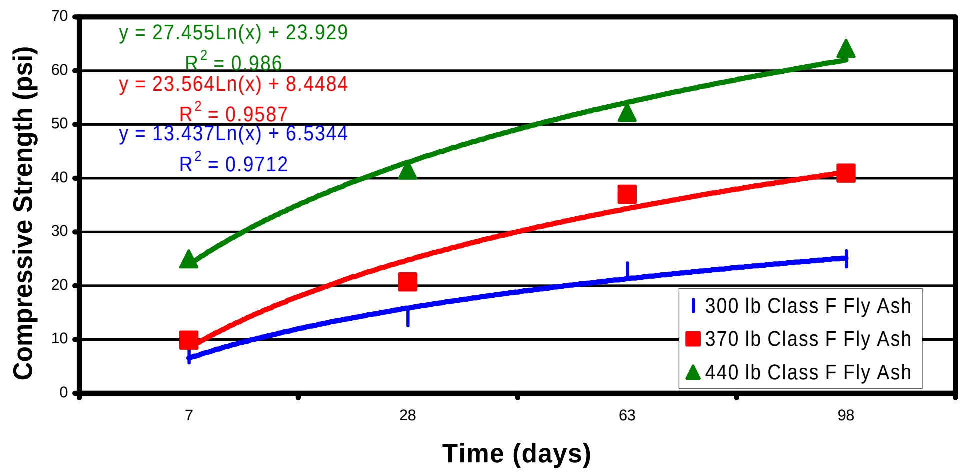

Figure 2. Early Compressive Strength Development of Mixtures Containing 45 lbs/CY of Type I Portland Cement

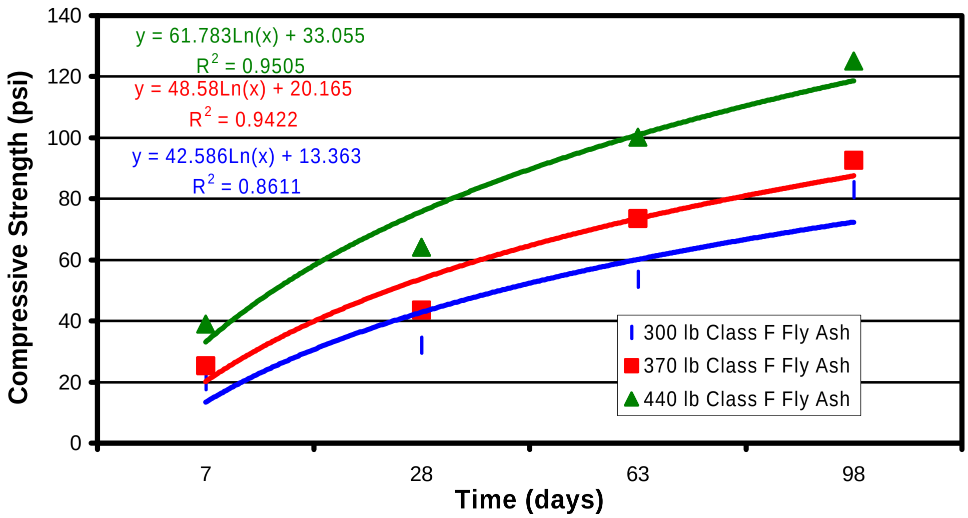

Figure 3. Early Compressive Strength Development of Mixtures Containing 60 lbs/CY of Type I Portland Cement

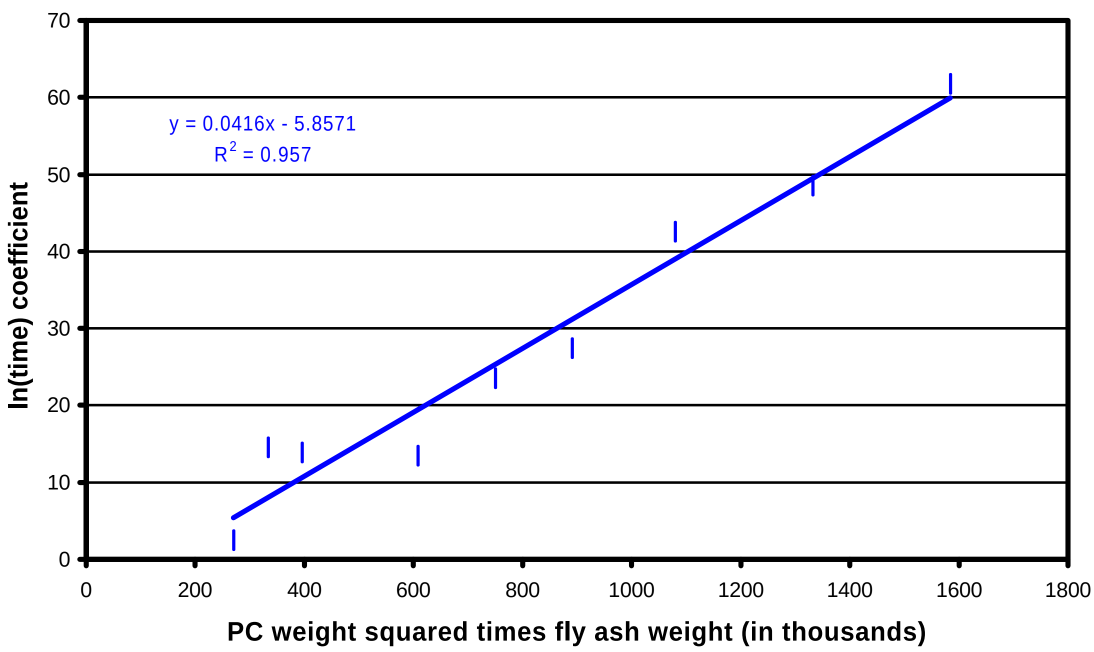

Figure 4. Comparison of rate of early compressive strength development with cementitious materials content

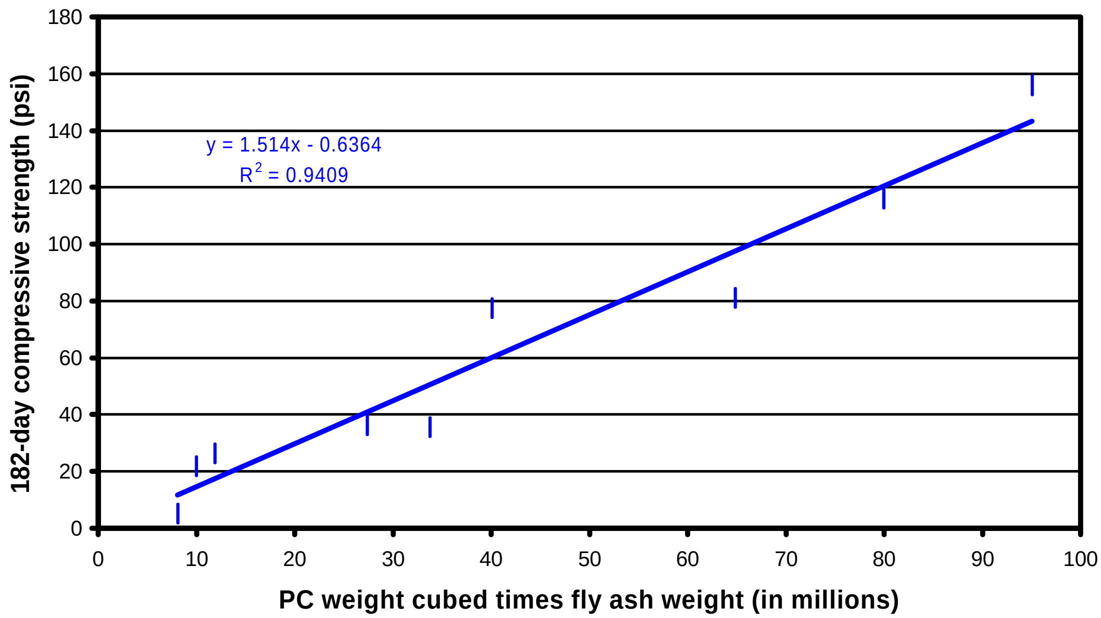

Figure 5. Comparison of 182-day compressive strength development with cementitious materials content

The product of the CBRC study will be a CD-ROM containing project results and a model specification for EFF containing coal combustion byproducts. The CD will be provided at no cost to municipal officials and engineers at four free seminars in 2003. The seminars are planned for Nashville and Knoxville in Tennessee and Lexington and Elizabethtown in Kentucky. Further, free CD-ROMs will be available through TRMCA and KRMCA. Hopefully, the wealth of information obtained will increase specifying agency confidence in EFF containing coal combustion byproducts.

CONCLUSIONS

The following conclusions can be drawn from the preliminary study:

1. Cementitious materials content appears to be the critical element in EFF mixtures. It controls the rate of strength development, the ultimate strength of EFF and the mixture plastic properties. There appears to be a minimum cementitious materials content since it was shown in this research that too little paste leads to a non-homogenous mixture with inadequate flow and very low compressive strength results.
2. The strong correlations between early strength development and 182-day compressive strength indicate the possibility of developing a mechanistic design procedure for EFF containing coal combustion byproducts.

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DISCLAIMER

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