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INVESTIGATION OF POTENTIAL USES OF ELECTRIC-ARC FURNACE DUST (EAFD) IN CONCRETE

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ABSTRACT

This paper presents the results of an investigation for the possible uses of electric-arc furnace dust (EAFD) by-product in concrete manufacturing. The effects of EAFD on the properties of fresh and hardened concrete are investigated. The results of standard tests on fresh concrete indicate that EAFD can be used as an effective set retarder. In addition, other standard tests appear to indicate that EAFD will enhance engineering properties of hardened concrete without any side-effects. © *1997 Elsevier Science Ltd*

Introduction

By-products are materials which are produced in the course of making other materials. In industrial countries, many by-products result and cause problems of storage, handling, and environmental pollution. Consequently, a lot of research work has been done to find possible uses of these materials.

One of the most popular uses of industrial by-products is in the construction industry, particularly in concrete manufacturing. In many countries these materials have been used successfully as a replacement for cement to reduce the cost of concrete materials. In addition, some by-products have proved to enhance the properties of concrete thus becoming more valuable.

Steelmaking industry generates a substantial quantity of dust. These include open hearth dust, basic oxygen process dust and electric arc furnace dust (EAFD). In the USA, the annual rate of production of EAFD was estimated recently at 650,000 tons. Its cost of disposal was estimated at about $200 million per year for the entire US steel industry (1).

Many of the recent attempts to treat EAFD were focused on chemical fixation of the dust to reduce its leachability. This was done to obtain delisting from the land ban restriction prior to land disposal (1). The method involves solidifying the dust using proprietary processes, which may require the addition of ordinary portland cement (OPC) and pozzolanic materials such as Pulverized Fuel Ash (PFA) (2,3). The solidified product should prevent or significantly reduce metal release into the environment.

One such process is described by Chappell (2). In this process, hazardous materials including EAFD can be encapsulated by treating the materials with an aluminum silicate or aluminosilicate and with a portland cement in the presence of water. The resulting slurry is allowed to set into rock. The rock has a permeability of less than 0.0001 cm/sec. and a 28-day compressive strength of 0.7 to 7 Mpa (100 to 1000 psi). This rock can be used for landfill, manufacture of construction materials, in the preparation of grout and in the encapsulation of other materials such as domestic refuse (2).

Lynn et al. (3,4) reported a process for the chemical stabilization of EAFD and similar dusts to render hazardous constituents, such as cadmium and lead, virtually immobile. The process is reportedly based on the pozzolanic reactions of fly ash which, in the presence of lime, water and chemicals adsorb and/or physically entrap the heavy metals present in EAFD into a calcium-alumino-silicate matrix.

More recently, Smith (5) reported a method and mixture for stabilizing EAFD which was claimed to be more economical than those disclosed previously. The method relies on the pozzolanic characteristics of the EAFD to form a cementitious hardened product entrapping the metals inherent in EAFD. The hardened product is reported to have acceptable leachate concentration, permeability characteristics and unconfined compressive strength.

The chemical composition of the EAFD varies considerably depending on its sources. A survey conducted by the Center for Metals Production (CMP) reported the range of zinc content of US EAFD to be from 5 to 50% by mass, with a median value of 19% (6). The emphasis on zinc content arises from the fact that recycling of the EAFD is done mainly to extract the zinc from it. A low zinc content renders it uneconomical to recycle the dust for zinc extraction.

Most of the EAFD is disposed to landfill. In 1985, EAFD disposal to landfill accounted for 73% of the total dust disposed. Recycling to recover zinc accounted for 14.5% and fertilizer manufacturing accounted for 8.9% (6).

In view of the previous work on utilizing EAFD, it is envisioned that it may be used in concrete for several reasons. First, concrete provides encapsulation of the EAFD which is an important goal, and second, its properties may be enhanced due to the zinc and pozzolanic compounds present in the dust.

In this paper, the EAFD will sometimes be referred to as baghouse dust (BHD), or simply as "dust".

The main goal of this work is to investigate the possible uses of EAFD in concrete. The effects of the dust on the properties of fresh and hardened concrete were investigated. A comprehensive test program was designed to arrive at specific recommendations for possible usage of EAFD in concrete.

Properties of Tested EAFD

The chemical composition of EAFD varies from one plant to another and from one melt to the next. The type and amount of scrap material used in the electric arc furnace have a pronounced effect on the chemical composition. Table 1 presents the contents of the tested EAFD as obtained from 4 different samples as well as the average contents. It can be observed that the variation in sample composition is quite small. This is due to the steelmaking materials and process being almost stable. The elements in the table are all present as oxides in the dust, hence the numbers in Table 1 do not add up to 100%. The three main constituents are iron, zinc and calcium oxides. This is also true for EAFD from steel mills in the US (1).

The unit weight of the tested EAFD is 764.8 kg/m^3 and its sieve analysis shows it to be a very fine material.

TABLE 1

Chemical Composition of Tested EAFD

	Analysis, % by mass				
Element	**A**	**B**	**C**	**D**	**Average**
Aluminum (Al)	0.71	0.66	0.69	0.74	0.70
Calcium (Ca)	9.41	9.28	9.30	9.56	9.39
Cadmium (Cd)	0.0004	0.0004	0.0004	0.0004	0.0004
Copper (Cu)	0.06	0.06	0.06	0.06	0.06
Iron (Fe)	33.5	33.3	33.7	33.9	33.6
Potassium (K)	1.73	1.60	1.68	1.77	1.70
Magnesium (Mg)	2.28	2.27	2.29	2.35	2.30
Manganese (Mn)	1.80	1.79	1.80	1.82	1.80
Sodium (Na)	2.48	2.63	2.62	2.54	2.57
Nickel (Ni)	0.01	0.01	0.01	0.01	0.01
Lead (Pb)	1.30	1.32	1.30	1.30	1.31
Phosphorus (P)	0.13	0.14	0.10	0.14	0.13
Silicon (Si)	2.43	2.34	2.32	2.41	2.38
Tin (Sn)	0.03	0.03	0.03	0.03	0.03
Sulfur (S)	0.59	0.58	0.56	0.56	0.57
Titanium (Ti)	0.09	0.08	0.08	0.09	0.09
Zinc (Zn)	10.7	10.8	10.7	10.7	10.7

Trial Mixes

The main objective of trial mix casting was to arrive at percentages of dust which are of practical use as replacement for cement. To achieve this, one control mix without dust and seven others with different percentages of dust (0.5, 1, 2, 2.5, 3, 4, 5) were cast and two main properties of fresh concrete were observed; namely, workability and setting time.

A mix proportion for plain concrete with type I ordinary portland cement was selected to be used for the various castings. The chemical composition of the cement is presented in Table 2. A water cement ratio of 0.62 which gave true slump between 8 to 10 cm was selected. The mix proportions per cubic meter of concrete for all mixes are shown in Table 3.

The following tests were conducted:

1. Slump test in accordance with ASTM C143 (7).
2. Time of setting test in accordance with ASTM C403 (7).

For each mix, four mortar specimens were prepared using 150 mm cube molds. Three specimens from each mix were used to determine rate of hardening. A record of elapsed time and penetration resistance was obtained. The initial and final setting times for each mix were computed as averages of three specimens and plotted in Fig. 1. The figure shows that increasing the percentage of dust replacement increases the initial and final setting times.

TABLE 2

Chemical Composition of Type I Portland Cement

		Result, % by mass	**Remarks**
Silicon dioxide	SiO_2	20.67	
Aluminium oxide	Al_2O_3	6.21	
Ferric oxide	Fe_2O_3	3.64	
Calcium oxide	CaO	64.54	
Magnesium oxide	MgO	0.80	Max. 4.0%
Sulfur trioxide	SO_3	2.61	Max. 3.0%
Loss on ignition	L.O.I	0.80	Max. 4.0%
Insoluble residue	I.R	0.26	Max. 1.5%
Alkalies		0.22	

The results from both tests provide the following observations:

1. The slump of fresh concrete is slightly increased with increase in dust content.
2. Setting times are not affected by baghouse dust with replacements up to 1%.
3. There is consistent increase in setting times for dust replacement greater than 1%.

The trend shows an increase in rate of hardening between initial and final setting with the increase in dust percentage replacement. This can be seen from the difference between the two curves in Fig. 1 becoming less with increasing dust content.

The effects of the dust on the concrete can be attributed to its physical properties and chemical composition. The dust fineness can cause the increase in slump as is well known.

TABLE 3

Mix Proportions in Kilograms per Cubic Meter for Trial Mixes

Mix Designation	Cement	Water (Free)	Coarse Aggregate		Sand	EAFD	
			10 mm	20 mm		(kg)	(%)
TMIXD1	350.00	217	390	730	715	0	0
TMIXD2	348.25	217	390	730	715	1.75	0.5
TMIXD3	346.50	217	390	730	715	3.50	1.0
TMIXD4	343.00	217	390	730	715	7.00	2.0
TMIXD5	341.25	217	390	730	715	8.75	2.5
TMIXD6	339.50	217	390	730	715	10.50	3.0
TMIXD7	336.00	217	390	730	715	14.00	4.0
TMIXD8	332.50	217	390	730	715	17.50	5.0

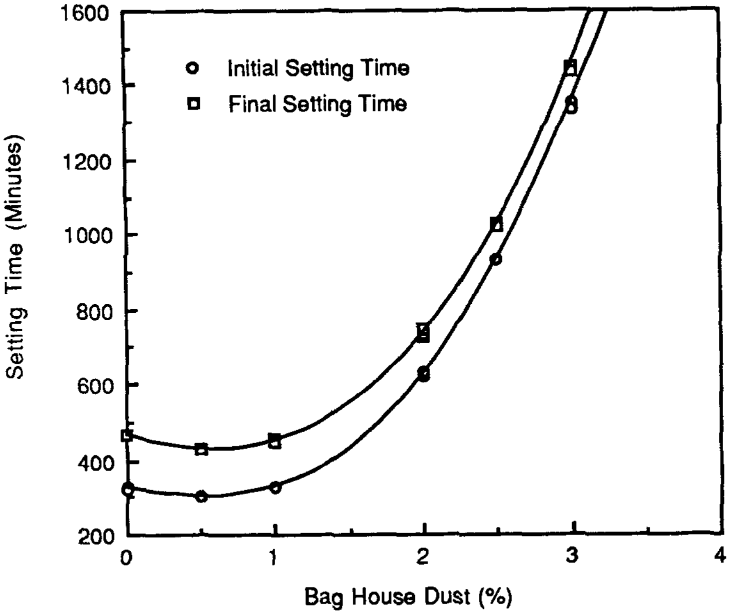

FIG. 1.

Effect of increase in dust percentage on setting time.

In addition, the zinc content of the dust can be the cause of set retardation since zinc oxide is known to have that effect on concrete (8).

Experimental Program

The preliminary testing of the dust has proved that it can be used as a set retarder in amounts ranging between 2-3% replacement of cement. Therefore, the following mixes were utilized:

Mix A: a control mix with 0% dust
Mix B: a mix with 2% dust replacement of cement
Mix C: a mix with 3% dust replacement of cement

The mix proportions in kgs per 1 cubic meter of concrete are as those for trial mixes with 0, 2 and 3% dust replacement presented in Table 3. The following tests were made on concrete specimens:

1. Initial and final setting times (ASTM C403)
2. Compressive strength (ASTM C39)
3. Splitting tensile strength (ASTM C496)
4. Abrasion resistance (ASTM C944)
5. Drying shrinkage measurement (ASTM C157)
6. Heat of Hydration

TABLE 4

Initial and Final Setting Times of Mixes with Various Percentages of EAFD

Mix Designation	Initial Setting Time Hrs : Min				Final Setting Time Hrs : Min			
	Specimen 1	Specimen 2	Specimen 3	Average	Specimen 1	Specimen 2	Specimen 3	Average
Mix A	3 : 54	3 : 52	3 : 52	3 : 53	5 : 45	5 : 41	5 : 43	5 : 43
Mix B	12 : 56	13 : 11	12 : 59	13 : 02	14 : 27	14 : 35	14 : 26	14 : 30
Mix C	32 : 17	32 : 12	32 : 11	32 : 13	33 : 57	33 : 48	33 : 53	33 : 53

A standard mixing procedure including the wetting of the mixer, the mixing of the dust with the mixing water, and the mixing time, was strictly adhered to. In this matter ASTM C192 procedures were followed as close as possible (7).

Testing Procedures and Results

Setting time. For the setting time test, 3 cubes 150 x 150 x150 mm were cast. The results for the setting times are given in Table 4. A comparison of these results and the results obtained during the preliminary testing phase is given in Table 5. It is evident that the setting times exhibit a large variability even for Mix A with no dust. This is a result of the setting time being sensitive to any changes in moisture content or environmental conditions.

Compressive strength. To study the effect of EAFD on compressive strength of concrete, 48 standard 152 x 305 mm cylinders were cast in two batches. Mix A and Mix B specimens were moist cured using wet burlap and polyethylene covers for 24 hours after casting, whereas Mix C specimens, due to its slow setting, were cured in a similar way for 48 hours. After initial moist curing, fifteen specimens were exposed to each of the following three conditions:

1. Moist curing (C1).
2. Average temperature and humidity (C2). (30°C and 50% relative humidity).
3. High temperature/Low humidity (C3) (55°C and 5% relative humidity).

TABLE 5

Comparison of Setting Times from Preliminary and Fullscale Testing of EAFD

Mix Designation	Dust (%)	Setting Times, Hrs : Min			
		Preliminary Testing		Full Scale Testing	
		Initial	Final	Initial	Final
Mix A	0	5 : 26	7 : 47	3 : 53	5 : 43
Mix B	2	10 : 25	12 : 14	13 : 02	14 : 30
Mix C	3	22 : 26	24 : 03	32 : 13	33 : 53

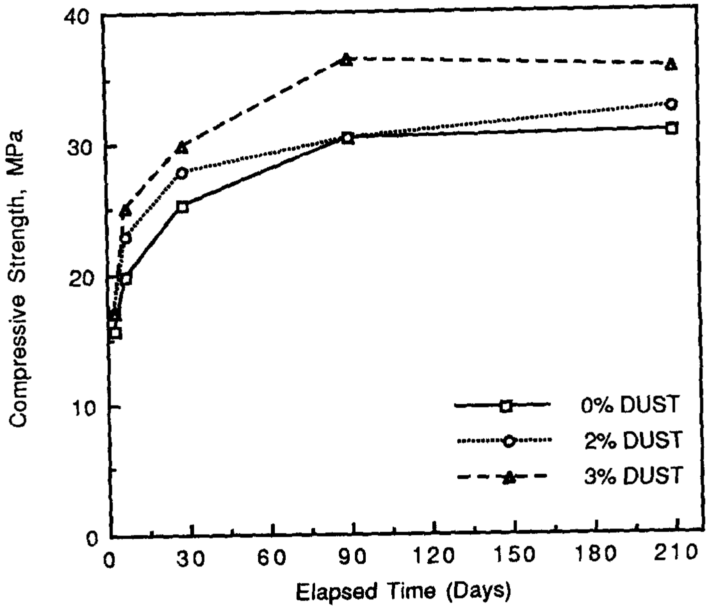

FIG. 2.
Compressive strengths for specimens exposed to curing condition C1.

The remaining three specimens were used to check the batch-to-batch variability.

Three identical cylinders from each mix and for each curing condition were tested in compression at 3, 7, 28, 90 and 210 days. Comparisons of compressive strengths of Mix A, Mix B and Mix C at various ages and for each curing condition are presented in Figs. 2, 3 and 4. From these figures, it is evident that there is an increase in compressive strength with the increase in percent of EAFD replacement from 0 to 3%. This increase is noticed at all ages of curing and for all curing conditions under study. It is also noticed that, for 3 days of curing the increase in strength obtained in case of Mix B (2% replacement) is greater than that obtained in case of Mix C (3% replacement).This is attributed to the difference in setting times between the two mixes. For Mix C the increase in strength obtained at 28 days of curing is more than 20% for curing conditions C1 and C2.

The increase in compressive strength of concrete containing dust can be attributed to its pozzolanic characteristics.

Splitting strength. For the splitting tensile strength test, 9 standard 152 x 305 mm cylinders were cast from each mix. After casting, the cylinders were cured using wet burlap and polyethylene covers for 24 hours, except in the case of Mix C, where the specimens were cured for 48 hours due to its slow setting.

Three specimens from each mix were exposed to the three curing conditions C1, C2 and C3 for 28 days. At the end of curing period, splitting tensile strength test was carried out in accordance with ASTM C496 (7). The results are presented in Table 6 which shows an increase in splitting tensile strength with the increase in percent of dust replacement from 0 to 3%. This increase is consistent for all the three curing methods used. For 2% dust re-

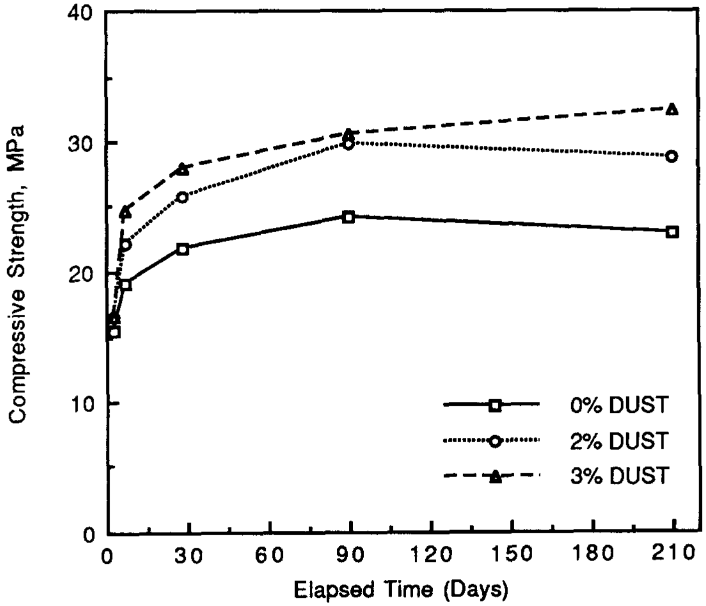

FIG. 3.
Compressive strengths for specimens exposed to curing condition C2.

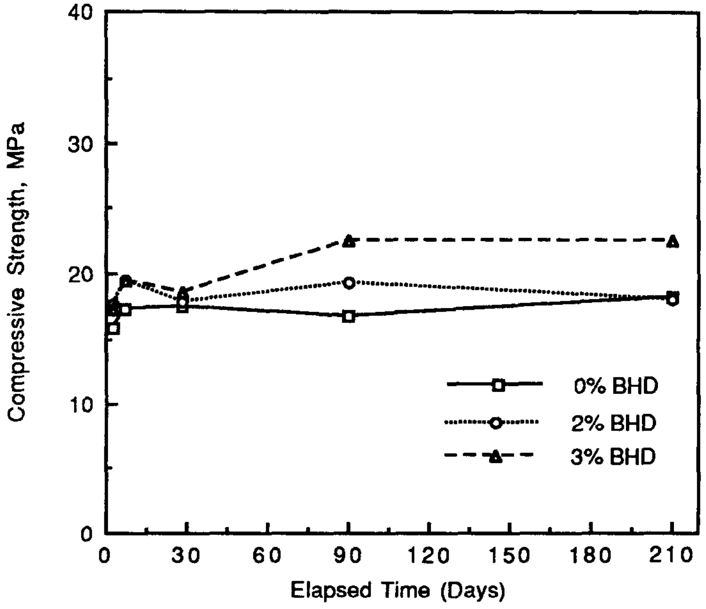

FIG. 4.
Compressive strengths for specimens exposed to curing condition C3.

TABLE 6

Splitting Tensile Strength Test Results

Mix Designation	Splitting Tensile Strength, Mpa				Curing Condition
	Specimen 1	Specimen 2	Specimen 3	Average	
Mix A	3.2	3.4	3.3	3.3	C1
	2.8	3.0	3.1	3.0	C2
	2.1	2.0	2.0	2.0	C3
Mix B	4.1	3.5	3.5	3.7	C1
	3.3	3.6	3.0	3.3	C2
	2.4	2.1	2.3	2.2	C3
Mix C	3.9	3.9	3.6	3.8	C1
	3.6	3.5	3.6	3.5	C2
	2.7	2.8	2.7	2.7	C3

placement the increase is about 11% for curing conditions C1, C2 and C3 whereas for 3% replacement the increase is more than 14%. This is because the splitting strength of concrete is correlated with its compressive strength.

Abrasion Resistance. To test the abrasion resistance, 6 slabs of 200 x 200 x 50 mm were cast. The results of the abrasion resistance test are summarized in Table 7. These are in terms of the average mass loss in grams after applying the rotating-cutter for 4 minutes, and are averages of three test applications on three identical slabs. From the results it can be said that the mixes B and C are almost identical and are slightly better than Mix A with no dust.

Drying shrinkage. For drying shrinkage measurements, 75 x 75 x 300 mm concrete prisms were cast and cured according to ASTM C157 (7). For each mix, six prisms were cast and moist cured using wet burlap and polyethylene covers for 24 hours (48 hours for mix C). The specimens were then demolded and placed in lime saturated water for 30 minutes and the initial comparator reading was recorded. The specimens were then cured in lime saturated water for 28 days. At the end of curing period a second comparator reading was made and three specimens each were exposed to curing condition C2.

Weekly comparator readings of each specimen were made. Each reading is an average of two measurements (second measurement was made by reversing the specimen).

Figure 5 is plot of shrinkage strains (computed as averages of the three identical specimens) versus log of elapsed time. The results show that Mix B with 2% dust replacement has slightly lower shrinkage as compared to Mix A and Mix C where shrinkage strains appear to be of the same magnitude.

TABLE 7

Abrasion Resistance of Concrete by Rotating-Cutter Method Reflected by Average Mass Loss After 4 Minutes

Curing Condition	Mix A (gms lost)	Mix B (gms lost)	Mix C (gms lost)
C2	1.34	1.30	1.29
C3	1.96	1.69	1.71

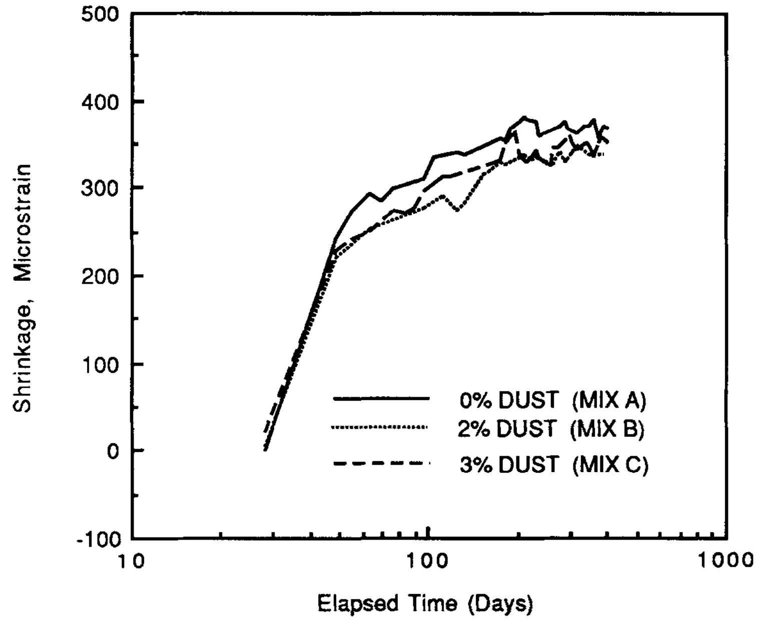

FIG. 5.
Shrinkage strains of prisms exposed to curing condition C2.

Nevertheless, it can be concluded that dust replacement has no adverse effects from drying shrinkage point of view as compared to Mix A with no dust.

Heat of hydration. The heat of hydration is the heat generated when cement and water react. The temperature rise resulting from heat of hydration is an important consideration in hot weather and mass concrete construction. The rate and total amount of temperature rise in concrete depend upon two principal factors: (1) the rate of heat generation, and (2) the rate at which the heat is dissipated.

To investigate the effect of EAFD on the rate of temperature rise in concrete, three mortar mixes of 1:2.75 cement-to-sand ratio by weight and water/cement ratio of 0.5 were used. The mixes contained 0, 2, and 3% dust replacement of cement. Two identical specimens were used for each mix. The use of cement mortar instead of concrete is to allow for higher cement content in the mix in order to generate more heat and increase the temperature rise of the test specimens.

The fresh mortar was placed in 7 litre capacity insulated containers fitted with a tight cover. Temperature of mortar specimens was monitored using embedded high accuracy thermistor probes connected to a recording thermometer (RT-meter).

The average temperature profiles from specimens with 0, 2, and 3% dust contents are compared in Fig. 6. From the figure it is clear that the addition of EAFD did not affect the temperature profile appreciably. The peak temperature rise was almost identical for all mortar specimens. However, the time to peak temperature was found to be 10, 24 and 54 hours for dust contents of 0, 2, and 3%, respectively. The effect of the EAFD on the time to peak temperature is due to the retarding effect of the dust.

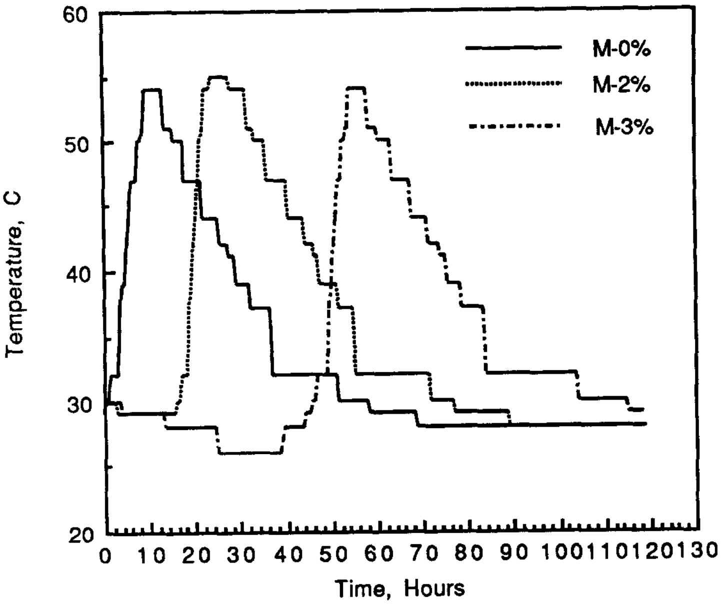

FIG. 6.
Average temperature profiles in mortar specimens with various dust contents.

Summary and Conclusions

The comprehensive test program undertaken in this study has confirmed that EAFD can be used as a set retarder for concrete. The dust was used as a replacement for cement by mass in two percentages: 2 and 3%. It is also equally valid to use the dust as an additive into concrete in these percentages. The relevant results of the test program show that:

1. The EAFD retards the setting time consistently; the more dust that is mixed with the concrete, the longer the setting time.
2. The EAFD appears to enhance the engineering properties of hardened concrete (compressive and splitting strengths, and abrasion resistance) without any serious side-effects.
3. The concrete specimens containing EAFD have shown as good drying shrinkage performance as regular concrete.
4. Heat of hydration of concrete containing EAFD is the same as regular concrete. The profile is only shifted with time as a result of the delay in setting.

The main recommendation from this study is that EAFD may be useful as an effective set retarder for concrete. It's effects on the concrete properties studied are all positive within the limitation of the study duration. Some other concrete properties are under investigation and will be reported in the future.

The EAFD satisfies international standards to be classified as a set retarder. It complies with the British Standard BS 5075 Part 1 (9) and the ASTM C494 (7) as a retarding admixture. The only requirement of ASTM C494 for which the EAFD is noncompliant is that the final setting time is delayed for more than 3.5 hours.

It is a requirement when using any set retarder, even those with a proven track record, to perform trial mixes and define the amount of set retarder that serves the user's purpose. This also applies when using EAFD as a set retarder.

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