

Use of Alternative Aggregates and Aggregate Gradings in Trowel-Applied Polymer Concrete Floors

By A.F. Bennett, W.R. Sharman, and I.D. MacGregor

Synopsis:

New Zealand has a predominantly agricultural-based economy, and consequently a heavy investment in processing buildings such as export abattoirs and dairy factories. Component failures in such plants can have a serious effect on production and profitability. Over the past ten years the Building Research Association of New Zealand has carried out an extensive research programme on flooring materials for abattoirs, investigating properties both in the laboratory and in use.

In the course of these investigations, it became clear that the formulation of commercial polymer concrete toppings, which are widely used, could be improved: in particular, reduction of the resin content below the common figure of around 20% by weight, and alternative aggregate sources to the limited supply of light-colored quartz and quartzite sands were sought. It was necessary that new, alternative mixes could still be applied by trowelling, the traditional method.

By starting from the aggregate grading curves of Weymouth (17), and BS 882(3), and using gap-grading, it was possible to lower the resin content to 10% or less and still retain trowellability, whilst using aggregates from the traditional sources. Alternative sources of aggregates, such as sandstone (greywacke) and basalt, were found which could be used to produce the light-colored floors considered to be necessary for hygiene reasons by the industry.

The experimental polymer concrete floor toppings were tested for the necessary mechanical properties (compressive strength, abrasion and impact resistance) for abattoir use.

Keywords: abrasion resistance; absorption; acid resistance; aggregates; basalt; compressive strength; corrosion resistance; costs; epoxy resins; floor toppings; gap-graded aggregate; impact resistance; industrial buildings; polyester resins; polymer concrete; workability

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INTRODUCTION

New Zealand has a predominantly agricultural-based economy, and consequently a heavy investment in processing buildings such as export abattoirs and dairy factories. Some of these facilities are large - for example abattoirs capable of processing 30,000 sheep per day. Component failures in such plants can have a serious effect on production and profitability. Floors in many of these plants are exposed to harsh environments in which they are expected to withstand both mechanical wear and tear and resist chemically corrosive substances. This is a particular problem for the meat and dairy industries.

Mechanical wear-and-tear is due to traffic, such as forklifts and trolleys, and impact damage from falling objects. Chemical corrosion can result from the use of specific chemicals in processing plants, such as sulphuric acid in fellmongeries, or corrosive wastes and by-products, such as lactic acid in milk (14).

Portland cement concrete (PCC) has a record of poor performance under such conditions. It is attacked by acids (most food wastes are acidic) and affected to some degree by virtually all food products and food wastes. To overcome these drawbacks a variety of hardwearing, chemically resistant topping systems have been developed to protect concrete floors in such situations. One of the most popular and effective has been polymer concrete flooring systems.

The main drawback with polymer concrete (PC) systems is their cost, which adds an extra \$NZ 30 - \$NZ 50/m² on top of the basic concrete floor. The study described here was initiated in an attempt to identify any areas where the formulation of commercial polymer concrete toppings could be improved. Emphasis was placed on reducing resin content from commonly used figures of 15 to 20% by weight and finding alternative aggregate sources.

AGGREGATE GRADING TRIALS

An analysis of commercial PC samples by pyrolysis at 550°C was carried out between 1981 and 1983. This showed that the resin content ranged between 16 to 22% by weight (10). A sieve analysis of the aggregates from the pyrolysed samples showed that most were continuously graded and could be fitted into one of the fine aggregate zones described in BS 882:(3). This grading type has been successfully used to make PCC for many years.

Ideally, the aggregate when mixed with the matrix (water, cement and fine sand) forms a concrete with each aggregate size uniformly distributed throughout the mix, the voids between the larger particles being filled by smaller particles and the matrix. An input of energy is required to move smaller particles past larger ones and achieve a uniform mix. In PCC this energy is provided by rodding and vibration. The lubricating properties of the water-cement-fines mix also assist the movement.

Polymer concretes are made with resins which are viscous and hence have much less lubricating ability than the matrix of PCC; furthermore, in the case of hand applied trowelled toppings little compactive effort is available. Maximising the workability of aggregate mixes is therefore essential if PC mixes with lowered resin contents are to be produced.

Variations in aggregate grading can significantly affect the workability of mixes. Two situations in particular are:

- 1) Where an aggregate contains an excess of any particular fraction
- 2) Gap-grading

The first case, which has been described as particle interference by Weymouth (17), can cause segregation by particle size (6) which is not eliminated by compaction. Ehrenburg (7) has published information on aggregate mixes designed to eliminate particle interference.

Gap-grading is the term used to describe aggregate mixes which are missing one or more aggregate sizes from a sieving regime. A single gap-graded mix has similar energy requirements to continuously graded aggregates. However, with double gap-graded mixes the energy requirement is lower (i.e. less dependence on lubrication and better workability).

Several workers (5,8,9) have reported that PCC made with gap-graded, and more especially double gap-graded aggregates, has better workability than mixes with identical water and cement contents but made using continuously graded aggregates. Thus gap-grading appeared to be a method whereby resin content could be lowered in polymer concrete mixes while still maintaining adequate workability for trowel application.

EXPERIMENTAL METHOD

Aggregate used in the grading trials was obtained from two sources. The larger sizes (2.4-0.3mm) were rounded quartzite and the smaller sizes (0.3-0.075mm) silica sand. Both were available and used commercially. Two proprietary resins were used, a polyester and an amine cured epoxy.

The aggregate was dried in an oven at 105°C for 18 hours then separated into fractions of +2.4mm, -2.4 to +1.2mm, -1.2 to +0.6mm, -0.6 to +0.3mm -0.3 to +0.15mm, -0.15 to +0.075mm. The +2.4mm fraction was not used.

Resin was premixed with hardener then added to the aggregate. Quantities less than about 1.5 kg were mixed by hand. Larger quantities were mixed with a mechanical mixer of approximately 20 litre capacity. The polymer concrete mixture was spread on concrete slabs (300x300x50mm) in a 6 to 8mm layer, screeded, then trowelled with a steel float. The PCC base slabs were acid etched then wire brushed to remove residues before the topping was applied. Cylindrical moulds 60mm high and 30mm in diameter were filled for compressive strength tests (10).

Abrasion resistance was measured as described by Sharman (13). Impact tests were carried out essentially as described by Sharman and Corder (16). Water absorption tests were carried out as described in ASTM C413 (2) except that the moulds were 27mm high and 27mm in diameter. Adhesion of the polymer concrete topping to the PCC base was measured by a pull-off method. Samples for adhesion testing were prepared by cutting 40mm x 40mm x 40mm cubes from PC topped PCC slabs. Steel dollies were attached to the topping surface and the bottom of the cube with epoxy adhesive. A Dartec M1000 RE universal testing machine with a cross-head speed of 0.5mm/min was used to determine the tensile failure strength of the samples. Compressive strength was measured according to the method of MacGregor and Sharman (11), which is based on ASTM D695 (1).

RESULTS

12% Resin--Initial mixes were made with 12% resin by weight. The aggregate gradings are shown as A through G in Table 1. Table 2 lists compressive strength and water absorption values for these mixes. The results of abrasion tests on some of the mixes are shown in Table 3.

All the 12% resin mixes except G produced acceptable toppings with sealed non-porous surfaces. Although the difference was small, the double gap-graded mixes proved easier to mix than the single and non-gap-graded ones. Grading B produced the most resin-rich mix, but the decreased quantity of fine aggregate in this mix compared to grading A resulted in increased difficulty in achieving a satisfactory surface finish. Mix G proved impossible to trowel and resulted in a porous mass. This is a result of insufficient matrix (fine aggregate and binder) to fill the voids between the larger particles. Evidence of this can be seen in the high water absorption value of 2%.

The results of abrasion and impact resistance, and compressive strength tests were satisfactory for all the mixes except G, which failed both the impact test (by perforation of the topping) and the abrasion resistance test.

POLYMER CONCRETES WITH LOWER RESIN CONTENTS

Polymer concretes were made with 10% resin by weight using four double gap-graded mixes (B,C,I and J in Table 1) and three continuously graded aggregate mixes (K, L and M). Mix M was based on a table of ideal and quasi-ideal sand gradings published by Ehrenburg (7). This grading uses Weymouth's theory to minimise particle interference.

All seven mixes had a stiff consistency with the three continuously graded mixes having a dry sandy appearance. None of the continuously graded mixes could be screeded and floated to give a satisfactory surface finish. When viewed under a microscope (6x magnification) the surface was seen to be porous, explaining the high water absorption values. The abrasion resistance was poor (Table 4), mix K failed before the test was completed. Mixes L and M, while within the guidelines set by Sharman (13), had significantly less abrasion resistance than mixes containing 12% resin by weight.

The PC toppings made with the double gap-graded aggregate mixes proved to be far superior for trowelling and floating. After screeding, minimal effort was required to float mixes C, I and J to a pore-free surface finish. Mix B, however, proved to be too deficient in fines to achieve a good surface finish. Mix B also had less abrasion resistance and higher water absorption than C, I and J. The latter mixes had similar abrasion resistances to the 12% resin toppings.

Mix C (66% large aggregate +34% fine aggregate) appeared to be slightly easier to mix than those containing 40% fine aggregate. This mix was used to make PC toppings with a resin content of 8% by weight. The mix was dry and similar in appearance to damp sand. After screeding considerable effort was required to float to a satisfactory finish. Under the microscope the surface appeared pore-free and slightly sandy. The average abrasion rate of both the epoxy and polyester mixes was similar to the 10% and 12% mixes while the value for the initial abrasion rate was higher. This is due to loosely-bound sand being removed from the surface.

The impact resistance was determined by measuring the crater diameter after impact by a falling missile. The 12% and 10% resin mixes had high impact resistance (see Table 5), in good agreement with values reported by Sharman and Cordner (15). A decrease in impact resistance was observed for the 8% mixes - while the crater diameter did not increase the depth of penetration did. Impact testing of the 8% polyester (PE) double gap-graded and the 10% continuously graded mixes was not possible due to the topping detaching from the base slab during the test.

The results of adhesion tests are shown in Table 5. Both the polyester and epoxy 8% resin mixes had very low adhesion to the substrate. The PC toppings made with higher resin contents all had tensile adhesion strengths greater than the value of 0.7 MPa suggested by MacGregor and Sharman (11) as a minimum for export abattoir flooring. Applying a priming layer of resin to the PCC base, prior to the PC topping, resulted in satisfactory adhesion for the 8% PE mix. The priming operation raised the total quantity of resin used in this mix to nearly 9%.

COST SAVINGS

Table 6 shows a breakdown of the costs involved in producing and laying a PC floor topping in current practice. The resin accounts for approximately 50% of the total cost. By using a double gap-graded aggregate and 9-10% resin by weight, a saving of up to 25% on some commercial PC floor toppings at present in use in New Zealand could be possible. This saving in material costs may be offset to some extent by other costs. These may arise from increased aggregate costs and a requirement for labour retraining or education, and tighter specifications and quality control of ingredients and application methods. Large-scale trials will be necessary to evaluate these factors but laboratory results look promising for the large scale viability of PC toppings with reduced resin content.

ALTERNATIVE AGGREGATES

Attempts were made to locate alternative sources of quartz and quartzite aggregates which were closer to the major users. However, discussions with the New Zealand Concrete Research Association, which had conducted a survey of concrete aggregates in New Zealand (4), revealed a scarcity of such aggregates. Attention was then turned toward other aggregate types. Aggregates which have previously been used successfully to make PCC appeared to offer possibilities. Greywacke and, to a lesser extent, basalt fit this category.

Greywacke sources are widespread throughout New Zealand, and basalt is found in Northland, Auckland, Coromandel, Otago and Southland.

EXPERIMENTAL

Samples of greywacke from a local river-bed gravel pit, and basalt from an Auckland quarry were obtained. The greywacke had a reported crushing strength of 390 kN (12). The aggregates were dried for 18 hours at 105°C then sieved into fractions. Both aggregates were subangular and dark grey in color.

Trial mixtures using these aggregates produced grey to black colored polymer concretes. Black and dark colors in general are not considered desirable in a food processing environment where a hygienic appearance is required (16). Replacing the fine aggregate with white sand was not particularly effective in lightening the color. The addition of titanium dioxide pigment to a polymer concrete containing only greywacke

aggregate did however produce an acceptable color. The titanium dioxide (TiO_2) was incorporated in the polymer concrete mix by one of two methods. In the first, a polyester pigment paste containing about 50% pigment by weight was mixed with the polyester resin. In the second, TiO_2 pigment was added as a powder to the aggregate which was then mixed vigorously to disperse it.

Samples of both greywacke and basalt PC tinted with TiO_2 were made with resin contents of 13% and 15% by weight using aggregate grading H in Table 1.

RESULTS

The addition of 1.4 to 3% by weight of white, TiO_2 containing, pigment paste produced greyish colored polymer concretes similar in appearance to Portland cement concrete. The sample with 3% by weight was considered an acceptable color by the Ministry of Agriculture and Fisheries. However, by adding a small quantity of red iron oxide pigment paste to the white an acceptable coloring was produced using only 1.4% by weight of pigment paste.

The addition of TiO_2 pigment directly to the aggregate in powder form also produced acceptably colored polymer concrete. Quantities of 2 to 3% by weight were used but better dispersion techniques may result in lower levels of pigment being needed.

Table 7 shows the results of compressive strength, abrasion and water absorption tests. The results of these tests are all satisfactory. The high compressive strength values are a result of the angularity and good crushing strength of the aggregates. The workability of the mixes is not as good as that of similar graded mixes using rounded aggregates. This is to be expected as angular aggregates do not pack as densely as rounded ones.

The approximate costs for the pigment pastes and TiO_2 powder are \$NZ 7/kg and \$4.2/kg respectively. Thus pigmentation would add about \$NZ 80 - \$100/tonne of polymer concrete. This is of the same order as the cost of transporting one tonne of aggregate from Dunedin to Auckland (ie from quartzite aggregate source to the main area of use).

As sources of greywacke and basalt differ widely in characteristics such as crushing strength and density, it is recommended that tests for abrasion, impact and compressive strength should be carried out on a polymer concrete at the formulation stage when a new source of aggregate is used.

CONCLUSIONS

The results of the grading experiments show that polymer concretes can be made with resin contents of 10% and lower which have the necessary mechanical properties and workability for trowel-applied floor toppings. At these low resin levels the use of double gap-graded aggregate mixes results in superior polymer concretes to those produced with a conventional continuously graded aggregate.

The potential exists for a considerable saving (often foreign exchange) in material costs by the use of low resin-content polymer concretes. Industry must determine whether this saving in material costs outweighs any potential increases in application costs. These may arise from a requirement for labour retraining or education, and tighter specifications and quality control of ingredients and application methods. Large scale trials will be necessary to evaluate these factors, but the laboratory results look promising.

The successful use of greywacke and basalt as polymer concrete aggregates also increases the options available to manufacturers of polymer concretes. While the savings that can be made in transport costs in some centres may seem minimal, any increase in real transport costs will make these options more attractive. Furthermore a reliable local aggregate source will help prevent possible disruption to supplies. Any such source will have to be evaluated before use.

ACKNOWLEDGEMENT

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TABLE 1--AGGREGATE GRADINGS USED FOR EXPERIMENTAL POLYMER CONCRETES

		Sieve Size μm					
		75	150	300	600	1200	2400
Cumulative Mix % Passing	A	3	13	40	40	40	100
	B	0	10	26	26	26	100
	C	0	10	34	34	34	100
	D	0	1.1	39.7	40	40	100
	E	0	0.8	29.8	48	48	100
	F	0	0	40	55	74	100
	G	0	0	12	34	62	100
	H	0	3	36	36	36	100
	I	0	2	34	34	34	100
	J	0	10	40	40	40	100
	K	0	7	21	49	75	100
	L	0	14	34	50.5	72	100
	J	0	11	25	44	68	100

TABLE 2--COMPRESSIVE STRENGTHS AND WATER ABSORPTIONS FOR 12% RESIN MIXES

MIX	RESIN		COMPRESSIVE STRENGTH	WATER ABSORPTION WEIGHT %**
	TYPE	AMOUNT	MPa *	
A	PE	12%	96	0.25
B	PE	12%	94	0.30
C	PE	12%	101	0.28
D	PE	12%	89	0.29
E	PE	12%	91 **	0.43
F	PE	12%	85	0.93
G	PE	12%	68	1.93
H	EP	12.2%	76	0.29

PE = modified polyester

EP = epoxy

* mean of 5 samples

** mean of 3 samples

TABLE 3--RESULTS OF SOME ABRASION RESISTANCE TESTS ON 12% RESIN MIXES

MIX	RESIN	AVERAGE ABRASION RATE mm ³ /1000 s	INITIAL ABRASION RATE mm ³ /1000 s
A	PE	2.3	1192
C	PE	0.3	1130
C	PE	4.7	937
C	EP	2.3	322
C	EP	1.0	850

* One sample only

TABLE 4--TEST RESULTS FOR 10% RESIN POLYMER CONCRETES

MIX	RESIN		COMPRESSION STRENGTH MPa *	ABRASION RATE mm ³ /1000s**		WATER ABSORPTION % WEIGHT***
	TYPE	% WEIGHT		AVERAGE	INITIAL	
B	PE	10	100	10.2	582	0.85
C	PE	10	101	5.7	1147	0.4
I	PE	10	97	4.4	1147	0.75
J	PE	10	94	4.6	2102	0.43
K	PE	10	57	@	@	5.9
L	PE	10	79	14.5	2438	2.3
M	PE	10	77	16.8	2276	2.5
C	EP	10	81	1.6	1247	0.2
C	EP	8	73	2.4	1605	0.55
C	PE	8	84	3.7	1762	1.1

* mean of 5 samples

** one sample only

*** mean of 3 samples

@ Sample failed by potholing or excessive wear before completion of the test

TABLE 5--IMPACT RESISTANCE AND TENSILE ADHESION STRENGTH OF SOME
POLYMER CONCRETE MIXES

GRADING	RESIN % WEIGHT	TYPE	AGGREGATE TYPE	CRATER DIAMETER mm *	CRATER DEPTH mm *	TENSILE ADHESION MPa **
C	12	PE	QU	11.5	4.5	1.84
C	12	EP	QU	10.3	5.1	2.03
C	10	PE	QU	11.6	4.4	1.22
C	10	PE+	QU	12.8	4.4	2.19
C	10	EP	QU	10.9	4.8	1.72
C	8	PE+	QU	11.6	6.2	1.44
C	8	EP	QU	10.5	6.3	0.09
H	13	EP	GW	13.6	4.4	1.17
H	13	PE	GW	12.7	4.4	1.90
H	13	EP	BA	12.4	4.7	1.32
+	PCC base primed before PC topping applied					
QU	Quartzite					
GW	Greywacke					
BA	Basalt					
*	Mean of 20 craters					
**	Mean of 5 samples					

TABLE 6--COST ANALYSIS OF POLYMER CONCRETE FLOORING*

Component	Contribution to total cost
Surface preparation	10%
Aggregate	16%
Laying	22%
Resin & Hardener	52%
	<u>100%</u>

* Average of data supplied by commercial applicators

TABLE 7--TEST RESULTS FOR GREYWACKE AND BASALT POLYMER CONCRETES

RESIN		PIGMENT		AGGREGATE TYPE	COMPRESSIVE STRENGTH MPa *	ABRASION RESISTANCE **	
% BY WEIGHT	TYPE	PASTE	POWDER			AVERAGE mm ³ /1000s	INITIAL mm ³ /1000s
15	PE	1.5		GW	113	5.5	1282
13	PE	1.4		GW	113	5.3	1790
13	EP		3.0	GW	77	3.2	1134
13	EP		1.7	BA	92	4.2	564

GW = Greywacke
 BA = Basalt
 * mean of 5 samples
 ** mean of 2 samples
 *** mean of 3 samples

Creep Studies of Polyester Polymer Concrete Under Flexural Loading

By N. Dharmarajan and C.D. Armeniades

Synopsis:

The creep of unsaturated polyester/styrene polymer concrete (PC) under flexural loads was investigated using two PC systems with different resin contents, as well as the unfilled resin. Measurements were taken at temperatures, ranging from -5 to 60°C, time periods up to 160 hrs, and stress levels from 4 to 12 MN/m² which represent stress-to-strength ratios of 0.3 to 0.7. The data obtained over these ranges of temperature, stress and resin content were successfully superposed on a single master curve of creep compliance versus time. On the basis of these results we propose a single expression, which describes the creep compliance (J) of the PC system as a product of separable functions of temperature (T), stress (σ), resin content (v), and time (t):

$$J(T, \sigma, v, t) = \exp[A_0] \exp[-A_1 \sigma] \exp[-\Delta H/RT] t^m$$

A_0 is itself dependent on resin content, ranging from 5.4 to 20.1 for the most highly filled PC and pure resin respectively; A_1 is constant (1.3 ± 0.1) for all systems. The activation energy (ΔH) is independent of temperature (Arrhenius behavior) and separable into two terms, one dependent on resin content (H_0 , ranging respectively from 18.6 to 11.1 for the pure resin and most highly filled PC) the other stress-dependent ($H_1 \sigma$, where $H_1 = 0.83 \pm 0.03$ for all systems). These results indicate that the creep behavior of polyester PC is governed by its polymer matrix. The time dependence (for periods up to 60 hours) can be represented by a power law model in which the exponent m (0.66 ± 0.05 for all polyester PC systems) is a material parameter.

Keywords: creep properties; flexural strength; polyester resins; polymer concrete; strains; stresses; temperature

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INTRODUCTION

The development of polymer concrete (PC) during the past few decades has generated materials with faster setting rates, higher compressive and flexural strength and greater resistance to water penetration than conventional portland cement concrete (PCC) (1). However the polymeric matrix in PC imparts on these composites a greater tendency to creep under continuous loads than conventional PCC, loaded at the same stress-to-strength ratio (2,3). In one study (4) large, polyester PC specimens showed catastrophic creep in compression at stress-to-strength ratios as low as 0.4. Hristova (5) has observed the creep behavior of polymer concrete to be highly temperature dependent. In recent studies, Ayyar and Deshpande (6) have related creep in PC to the proportion and type of the binding polymer. Ohama (7) has investigated creep in polyester PC and described its time-dependent strain using the classical hyperbolic expression. Few investigators have attempted to describe the creep behavior of polymer concrete in terms of all the variables that affect it; experimental data to date have been primarily confined to the compressive mode of deformation.

The relatively low flexural strength of polymer concrete as compared to its compressive strength (4,8,9) coupled with its poor creep resistance, makes the long-term flexural creep compliance of PC structures their limiting material parameter when designing for load-bearing applications. Accordingly we proceeded to investigate creep in polymer concrete under flexural rather than compressive loads.

The purpose of this work is to derive on the basis of experimental data a mathematical expression, which would describe the creep behavior of a particular type

of PC (i.e. a polyester, acrylic, epoxy, etc. system) as a function of time, temperature, stress, and resin content. In addition to providing a better understanding of the creep mechanism in these systems such an expression could be used to predict the creep compliance of different PC formulations from a given resin in the temperature range below their glass transition temperature (T_g) using limited data at only two temperatures, taken for relatively short time periods (ca. 10 hours).

EXPERIMENTAL

Flexural creep experiments were conducted on specimens of unsaturated polyester/styrene PC, formulated as shown in Table I.

Two PC systems were prepared: the "fine sand" system, contained aggregate graded from 60 to 100 mesh and required a resin content of 22 weight % (volume fraction 0.41) to achieve proper consistency; the "distributed" system contained aggregate graded from 8 to 100 mesh and required 15 wt % resin (volume fraction 0.30). Specimens of the unfilled polymer matrix were also prepared: in these systems the initiator level was reduced to 0.3 wt % of resin to prevent excessive exotherm. The PC formulations were prepared in batches of 2500 g, cast in a teflon-lined steel mold in the form of a flat plate measuring 38 by 38 by 2.5 cm and cured at room temperature for 24 hours, followed by an 8 hour postcure at 100°C. Bar-shaped specimens measuring 16 by 1.6 by 1.6 cm were cut from the rectangular plate for the creep experiments using a diamond wheel. Absence of noticeable styrene odor in the cured specimens indicated that they were fully cured. The "age" of the specimens, i.e. the elapsed time from the completion of the cure to the onset of testing had no effect on their creep behavior.

The apparatus used in the flexural creep experiments is shown in Fig. 1. Constant loading was generated by the use of dead weights [1], the effect of which was multiplied by a factor of 20 through a lever arrangement [2]; the load was applied to the bar specimens [4] via hardened steel connecting rods [3]. The specimens were placed in the conventional three-point loading mode with a 15 cm span. Constant temperature was maintained to $\pm 1^\circ\text{C}$ by an external water/ethylene glycol circulating bath. Specimen deformation was measured using a linear Variable Differential Transformer (LVDT, [6]) mounted between the hardened steel rod [3] pressing on the specimen midpoint and a rigid frame [7]. Three specimens could be tested simultaneously: the signals

from the LVDT's were recorded in digital form every 10 minutes. The experiments covered temperatures ranging from - 5 to + 60°C, stress levels from 5.5 to 17.5 MN/m² and times up to 60 hours. A small number of experiments were extended to 160 hours.

In order to obtain the stress-to-strength ratios, corresponding to the loads used in the creep experiments we also measured the flexural strengths of these PC systems on an Instron Testing Machine at a crosshead speed of 0.25 cm/min, using the same specimen dimensions, loading mode and temperature range.

RESULTS AND DISCUSSION

In a creep experiment the total strain [$e(tot)$] shown by the specimen at any time may be divided into a transient component [$e(tr)$] and the creep strain [$e(crp)$]. [$e(tr)$] includes the initial strain due to the sudden imposition of the load, as well as the short-term strain changes, due to the rapid equilibration of stress concentrations, caused by small misalignments of the specimen in the apparatus. Having chosen the hour as the unit to be used for the time scale (t) in the creep experiments we have arbitrarily attributed the strains up to one hour to [$e(tr)$] and all subsequent changes in strain to [$e(crp)$].

Figure 2 shows typical creep strain measurements for the "distributed aggregate" PC system at three different temperatures. Each point in the curve represents the average value of $e(crp)$ obtained from three or more specimens. As expected the creep response is temperature dependent and the isochronal strains increase with increasing temperature. The creep compliance (J) is defined as the ratio of the creep strain to the applied constant stress (σ). When plotted versus time on logarithmic coordinates the creep compliance shows a linear relationship, as can be seen in Fig. 3. The solid lines represent the least squares fit of the data points from Fig. 2 at each of the three temperatures. These lines have essentially the same slope, thus allowing the use of a single shift factor to superpose creep data obtained at different temperatures (T) so that they may fall on the same curve at a chosen reference temperature. The creep compliance at the reference temperature is calculated from the standard expression (10):

$$J(T_r, t) = \frac{J(T, t)}{a_T} \left(\frac{T}{T(r)} \right) \left(\frac{\rho_T}{\rho_{T(r)}} \right) \quad (1)$$

where: T_r is the chosen reference temperature
 a_T is the temperature shift factor, and
 $\rho_T, \rho_{T(r)}$ are the respective densities of the system at T and $T(r)$.

In the temperature range of our creep tests (-5 to 60°C) the shift factor was found to be temperature-invariant, as seen from the linear plot of $\ln a_T$ versus $1/T$ (Fig. 4). This is not surprising since the test temperatures are well below the glass transition temperature of the polymer matrix (ca. 150°C). Consequently the creep dependence on temperature (at constant stress) can be adequately described by an Arrhenius relation:

$$J(T) = J_0 \exp(-\Delta H/RT) \quad (2)$$

The reduced creep data are plotted as a master curve on Fig. 5 based on a reference temperature of 297°K. In order to verify the superposition an additional experiment was performed at this temperature (297°K) over the time range covered by the superposed data (60 hours). The results, shown in the straight line in Fig. 5 are in good agreement with the reduced data taken at different temperatures.

In addition to being temperature dependent, the creep compliance is strongly affected by the applied stress, as well as the resin content of each PC system tested. The activation energy (ΔH) defined in equation 2 is also dependent on resin content and decreases linearly with increasing stress (Fig. 6). This observation is consistent with the rationale that increasing the stress tends to reduce the activation barrier required for conformational changes to occur in the polymer matrix. The increase in activation energy with higher resin content (Fig. 6) supports our initial assumption that the governing factor for creep in polymer concrete systems is their macromolecular matrix: the aggregate particles, owing to their high elastic modulus are relatively resistant to deformation under the applied stress levels.

On the basis of the experimental results, shown in Figs. 2 through 6 the creep behavior of unsaturated polyester polymer concrete can be described by the following expressions: as a function of time (t), temperature (T), stress (σ), and volume fraction of resin (v):

$$e_{\text{crp}}(t, T, \sigma, v) = \sigma J(t, T, \sigma, v) \quad (3)$$

$$J(t, T, \sigma, v) = A(\sigma, v) \exp[-\Delta H(\sigma, v)/RT] t^m \quad (4)$$

$$\Delta H(\sigma, v) = H_0 - H_1 \sigma \quad (5)$$

$$A(\sigma, v) = \exp[A_0 - A_1\sigma] \quad (6)$$

where the parameters H_0 , H_1 , A_0 , and A_1 may themselves be functions of stress (σ) and resin content (v). From the plots of creep compliance versus time at different stress levels (Fig. 7) and different resin contents (Fig. 8) we observe that the isochronal creep compliance increases with stress as well as with resin content. These plots also enable us to evaluate the parameters H_0 , H_1 , A_0 , and A_1 for this polyester PC system. Their values are shown in Table II.

It can be seen that H_0 and A_0 are indeed functions of v ; however H_1 and A_1 remain essentially constant through a wide range of resin content, i.e. they are independent of v . This allows us to describe the creep compliance of polyester PC as a product of separable functions of the primary variables:

$$J(T, \sigma, v, t) = \exp[A_0] \exp[-A_1\sigma] \exp[(RT)^{-1}(H_1\sigma - H_0)] t^m$$

We also note from the logarithmic plots of creep compliance versus time that these linear functions have nearly the same slope at different conditions of temperature (Fig. 3), stress (Fig. 7) and resin content (Fig. 8). This enables us to reduce creep data, obtained at different temperatures, stresses, and resin contents to a single master curve at a chosen reference state, as shown in Figure 9.

The flexural strengths of the systems discussed in this paper are shown in Table III. By interpolating the flexural strength values, corresponding to the creep test temperatures we obtain the stress-to-strength ratios for the loads used in the creep experiments. These range from 0.3 to 0.7 in the PC systems and 0.05 to 0.15 in the unfilled resin specimens. We have observed that the PC systems show the type of stable creep discussed here at stress-to-strength ratios of up to 0.6 regardless of temperature and resin content. Higher stresses give rise to catastrophic creep, the specimens failing within a few hours. This upper limit for stable creep in flexure is higher than the corresponding stress-to-strength ratio of 0.4 observed previously in compressive creep experiments (4).

The foregoing description of creep behavior and limiting stress-to-strength ratio is based on PC systems that contain only particulate aggregate and filler. Preliminary experiments with PC systems containing in addition chopped glass fibers indicate both an enhancement in flexural strength (20-30%) and stable creep behavior at stress-to-strength ratios as high as 0.75. Such systems, as well as PC's based on different resins will be addressed in a separate paper.

CONCLUSIONS

1. Creep in polyester polymer concrete is governed by the macromolecular matrix: for stress-to-strength ratios < 0.6 these systems show stable creep, which can be successfully described by a function of stress, time, temperature and resin content. Successful superposition of these parameters enables us to predict the creep compliance of different PC systems from the same resin through a range of temperatures, stresses and resin contents from limited data of a single system over short time period (e.g. 10 hours).
2. The activation energy of the creep compliance is dependent on resin content and decreases with increasing stress.
3. Creep compliance follows a power law dependence on time, with the exponent being a material constant.

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Table I: Composition of Polyester Polymer ConcretePolymeric Matrix

Resin: Dion Iso-6315*----- 97.3 wt %
 Initiator: methyl ethyl ketone peroxide (MEKPO) 1.5
 Promoter: cobalt naphthenate (CN)----- 0.2
 Coupling agent: 3-methacryloxy-
 propyltrimethoxysilane----- 1.0

Mineral Aggregate and Filler

Silica sand (Clemtex Co., Houston, TX) ranging in
 particle size from 8 to 100 mesh.

* courtesy of the Koppers Company, Pittsburgh, PA.

Table II: Parameters in Creep Equation

ν	H_0	H_1	A_0	A_1	m
0.302	11.07	0.83	5.40	1.34	0.71
0.409	12.58	0.86	5.70	1.16	0.61
1.00	18.57	0.80	20.10	1.41	0.67

Table III: Flexural Strength of PC Systems

System: Flexural Strength (mean value $\pm$ S.D. of 4 specimens): MN/m ²			
	@ 22°C	@ 50°C	@ 75°C
Distributed aggregate	18.6 $\pm$ 1.8	17.4 $\pm$ 2.0	16.8 $\pm$ 2.0
Fine sand	22.8 $\pm$ 2.3	21.2 $\pm$ 1.1	19.6 $\pm$ 0.5
Unfilled resin	113.9 $\pm$ 14.6	102.5 $\pm$ 2.5	75.2 $\pm$ 10.1

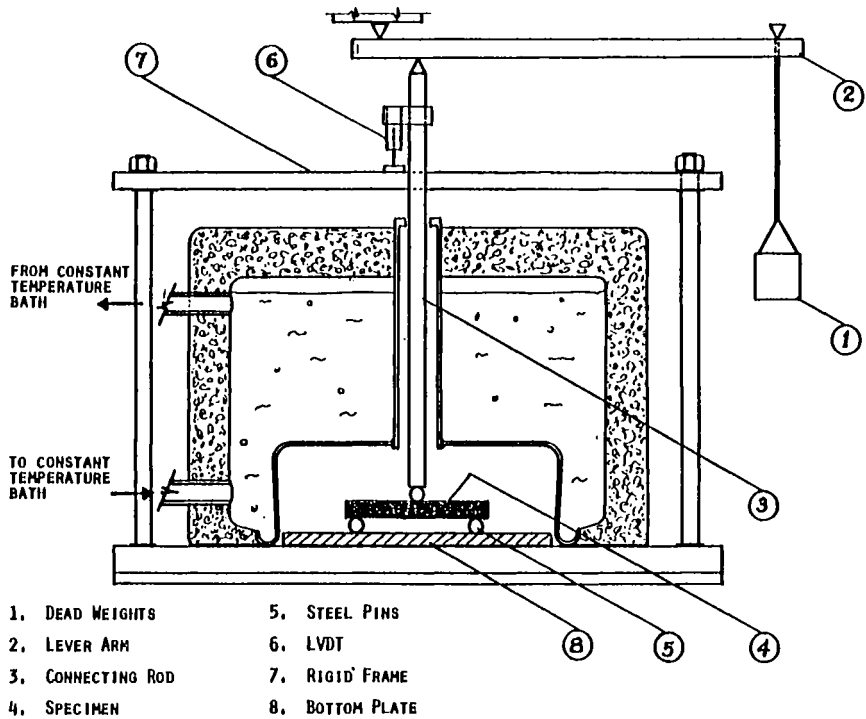


Fig. 1--Sectional view of the flexural creep apparatus

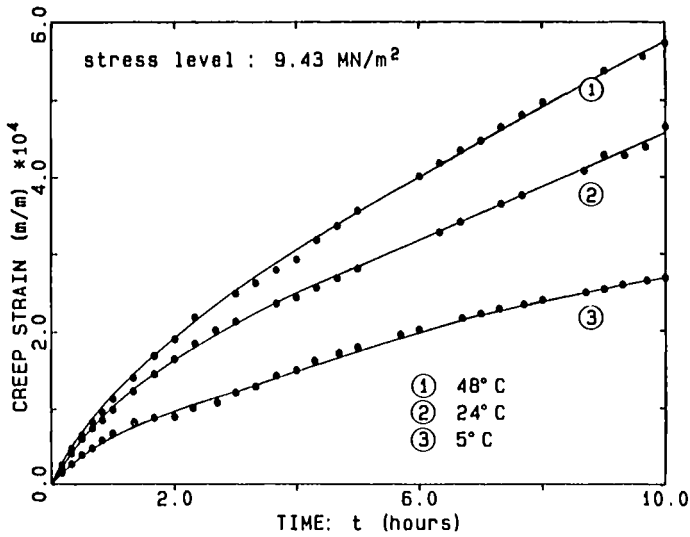


Fig. 2--Plots of creep strain versus time in distributed-aggregate polyester PC at 3 different temperatures

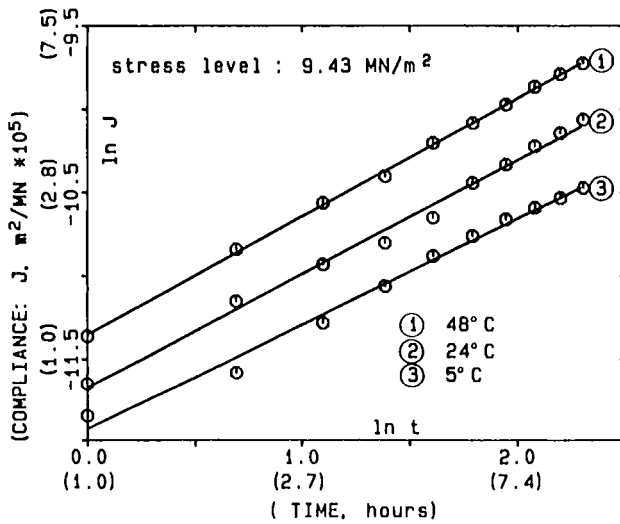


Fig. 3--Logarithmic plots of creep compliance versus time for the data from Fig. 2

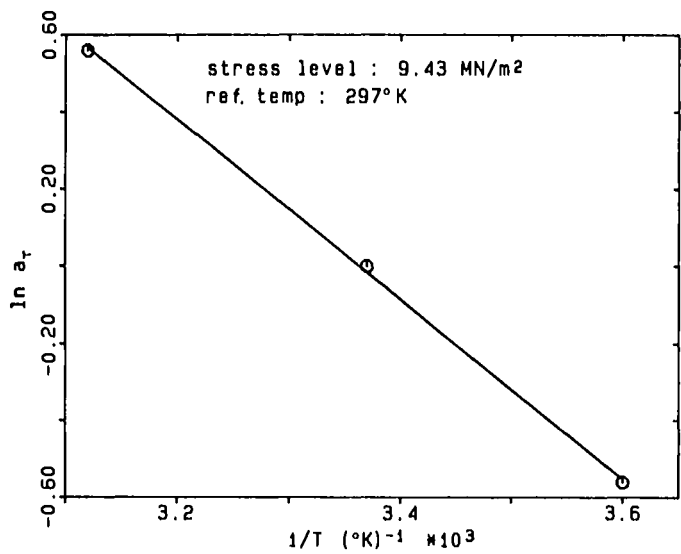


Fig. 4--Logarithmic plot of the temperature shift factor (a_T) versus reciprocal temperature, showing Arrhenius behavior

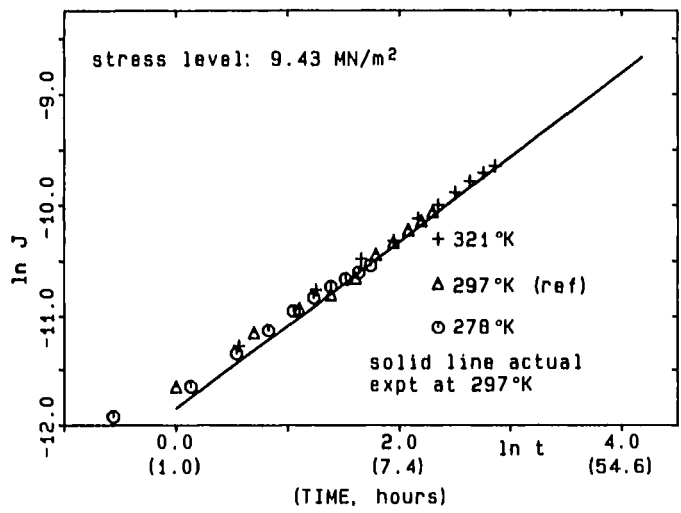


Fig. 5--Master curve of creep compliance versus time, obtained by time/temperature superposition of the data from Fig. 2 (individual points) and verification by actual measurements at 297° K (straight line)

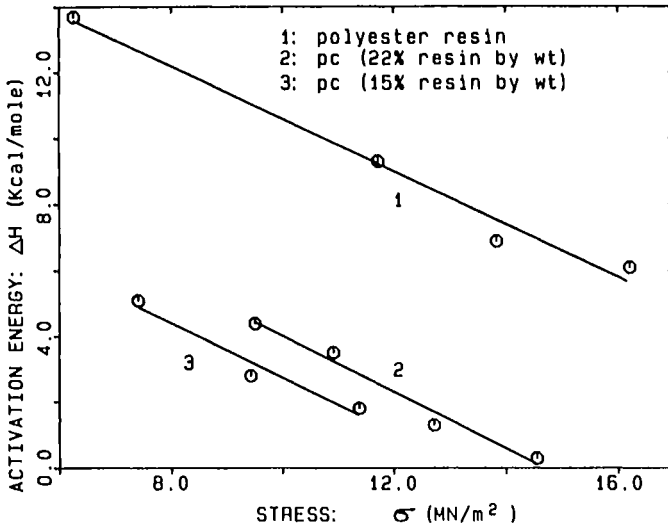


Fig. 6--Variation of the creep activation energy (ΔH) with applied stress (σ) in PC systems with different resin contents

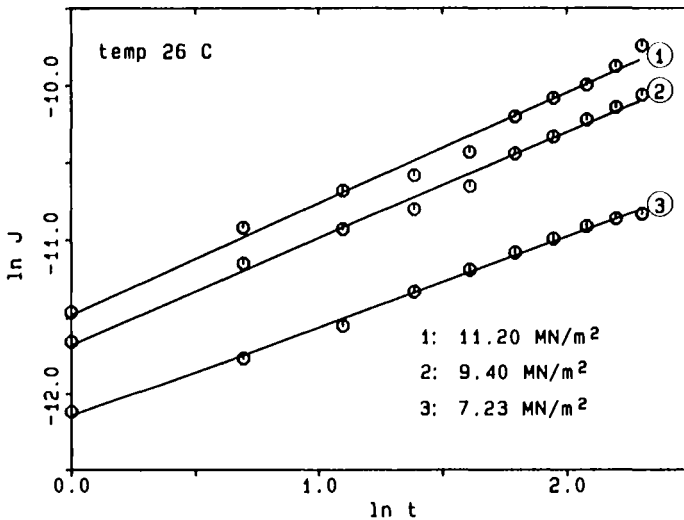


Fig. 7--Logarithmic plot of creep compliance versus time for the distributed aggregate PC at different stress levels and constant temperature

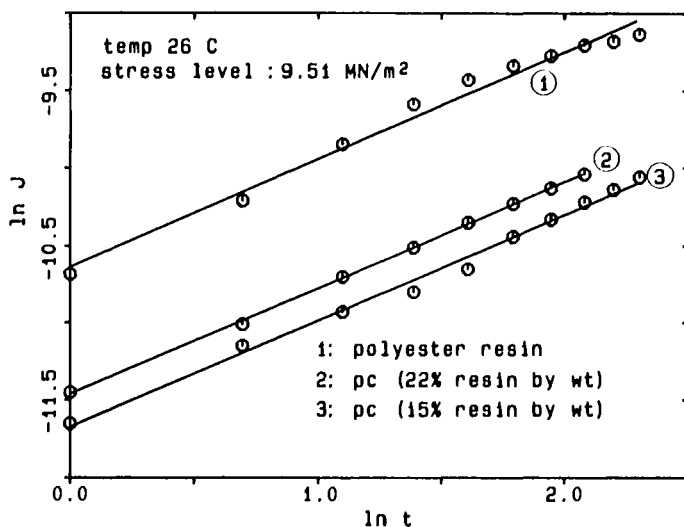


Fig. 8--Logarithmic plot of creep compliance versus time for PC systems with different resin contents at constant temperature and stress

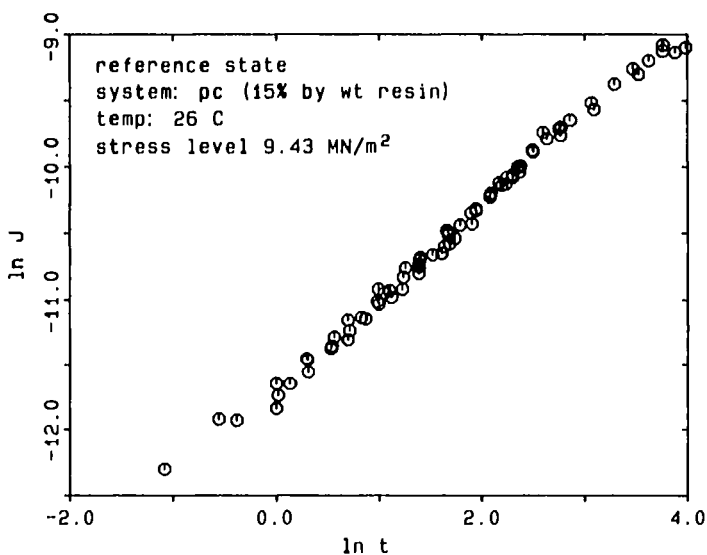


Fig. 9--Master curve constructed by time/temperature/stress/resin-content superposition of the data from Figs. 5, 7, and 8

Electrically Conductive Polymer Concrete Coatings

By J.J. Fontana

Synopsis: The corrosion of reinforcing steel embedded in concrete causes cracks and delamination in the concrete. The application of impressed current cathodic protection utilizing electrically conductive polymer concrete to distribute the current across concrete bridge deck surfaces is gradually becoming a standard practice in the highway industry. In order to protect the bridge substructures, a sprayable electrically conductive polymer concrete coating is being developed. This thin coating has a very low resistivity and can distribute the cathodic protection current across the concrete surfaces that are to be protected.

Keywords: bonding; bridge decks; cathodic protection; coatings; conductivity; corrosion; deterioration; electrical resistance; polymer concrete; substructures; vinyl resins

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INTRODUCTION

A. Background

In recent years, the deterioration of many concrete bridge structures has become a major maintenance problem. Although the deterioration of concrete is influenced to some degree by the quality of the concrete, loading conditions and environmental exposure, the primary cause of deterioration, is the result of corrosion of the reinforcing steel. The reinforcing steel embedded in concrete is passive unless the concrete becomes contaminated with chlorides from deicing salts or salt-water spray from coastal waters.

Due to its open-cell structure, concrete can allow critical quantities of chlorides to permeate its structure to the level of the embedded reinforcing steel. The chloride ions in the presence of moisture and oxygen initiate the corrosion of the reinforcing steel. As the corrosion products are formed, there is an increase in the volume of the steel, thereby, exerting tensile forces on the surrounding concrete. As these forces become larger than the tensile strength of the concrete, the concrete cracks thus allowing additional paths for the intrusion of water and chlorides. Eventually the concrete spalls and/or delaminates, and the concrete structure can become completely deteriorated.

It is common practice to repair concrete spalls and delaminations with various patching materials, however, unless all of the salt-contaminated concrete around the reinforcing steel is removed and replaced, the corrosion process will continue. Although it is technically feasible to remove and replace all of the salt-contaminated concrete, it is in many instances economically unfeasible. The one method that has shown itself to be economically as well as technically feasible to prevent and/or stop the corrosion problem is the use of impressed current cathodic protection (CP).

The use of impressed current cathodic protection in chloride-contaminated concrete bridge decks has been well documented in the literature (1-4). In the early CP systems developed for bridge deck applications, an electrically conductive asphaltic-concrete

overlay was used which performed well but required significant changes in elevation and increases in the structure "dead-load" (5). The Office of Research of the Federal Highway Administration has conducted its own research program and sponsored others to improve the highway industry's understanding of CP systems (6-9). On the basis of this work, CP systems have been installed on several dozen bridge decks throughout the United States. Some of these systems utilize electrically conductive polymer concrete mortar in slots cut into the bridge deck surface, and other systems utilize electrically conductive polymer concrete mortar strips on top of the concrete deck with a protective concrete overlay over them.

Recently, attention has been diverted to the protection of the bridge substructure. The protection of vertical and overhead concrete elements has been hampered by the lack of a suitable material and application method to effectively distribute the electrical current over the entire concrete surface.

At present, the California Department of Transportation is studying the use of metalized flame spraying to deposit a thin metal film on the concrete surface (10). In addition, another system presently available utilizes a conductive polymer wire-like primary anode that is attached to the concrete surface and then covered with a shotcrete overlay. Presently, an NCHRP Project 12-19B "Cathodic Protection of Concrete Bridge Structures" is being conducted by Wiss Janney Elstner Associates, Inc. to evaluate electrically conductive coatings that can be applied by brush or roller through which the cathodic protection currents can be uniformly distributed across the concrete surface.

The project described in this paper was to develop an electrically conductive polymer concrete coating that could be applied to vertical or overhead concrete surfaces by a spray application. The coating must be able to uniformly distribute the cathodic protection currents across the concrete surface and be permeable to allow gases generated within the concrete substrate during the cathodic protection operation to pass through the coating. The program was funded by The Office of Research of the Federal Highway Administration.

LABORATORY EVALUATIONS

A. Test Procedures Used to Measure Properties of Electrically Conductive Polymer Concrete Coatings

The test methods used to evaluate the electrical and mechanical properties of the overlay system are described herein.

1. Electrical Resistivity Test

A test circuit is set-up in which a known resistance is connected in series with the conductive coating to be measured and a current is passed through the circuit. The voltage drop across the unknown composite is compared to the voltage drop across the known resistance:

$$R_c = \frac{V_c R_k}{V_k}$$

Thus, the resistivity of the composite is

$$\rho_c = \frac{V_c R_k A_c}{V_k L}$$

where,

ρ_c = resistivity of the composite in ohm-cm.

V_c = voltage drop across the composite in volts.

R_k = resistance of known resistor in ohms.

A_c = cross-sectional area of the composite in cm².

V_k = voltage drop across the known resistor in volts.

L = length of the conductor across which V_c is measured in cm.

A schematic of the test circuit and a diagram of the conductive specimens are shown in Figure 1.

2. Bond Strength

The bond strength of the electrically conductive coating to the concrete substrate was tested with an Elcometer Adhesion Tester. In this test, a 1-in.² dolly is bonded to the coating surface with an epoxy adhesive. The coating is cut through to the concrete surface at the perimeter of the dolly. The instrument claw is engaged with the dolly and the lift force is applied. The indicator retains the value of the applied force when the dolly and coating separate from the concrete substrate. Figure 2 shows the Elcometer Adhesion Tester in place ready for testing.

3. Freeze-Thaw Durability

The freeze-thaw durability of electrically conductive polymer concrete coatings were evaluated as per ASTM C666 Part A "Resistance of Concrete to Rapid Freezing and Thawing (11)". For this test, cores were taken of sprayed conductive coatings and the concrete substrates. After 100 and 200 freeze-thaw cycles (0°F to 50°F to 0°F), the bond strength of the coating was measured with the Elcometer Adhesion Tester.

B. Evaluation of Electrically Conductive Fillers and Their Resin Binders

The electrical conductivity of polymer concrete composites was evaluated using commercially available resins and conductive fillers. Some of the resins and fillers evaluated are listed in Tables 1 and 2 respectively.

Using an orthophthalic polyester resin, a series of premixed mortars were made and cast into specimens as shown in Figure 1b. The mix proportions of filler to resin were varied for each system to obtain a smooth workable mix in each case. The electrical resistivity of all samples was measured and the data summarized in Table 3.

The Shamokin coke breeze, the Asbury calcined coke breeze, and the Loresco calcined coke breeze all produced composites with electrical resistivity values of <5 ohm-cm. The calcined coke breeze composites had electrical resistivity values of 0.59 to 1.01 ohm-cm. The Asbury 4335 calcined coke breeze was chosen for the conductive coating spray application because it had the lowest resistivity and its particle size was small enough to pass through the spray gun nozzle.

Using the resins listed in Table 1 in conjunction with the Asbury 4335 calcined coke breeze, a series of electrically conductive composites were made with 30 wt% resin and 70 wt% filler. The test results are summarized in Table 4.

Although the composite made with LB183-13 orthophthalic resin had the lowest resistivity, a previous study had indicated that electrically conductive overlays under active CP systems made with vinyl ester resins would not break-down as quickly.¹¹ Therefore, it was decided to use the vinyl ester resin in the electrically conductive spray coating applications. In addition, Hetron 921 was substituted for DPV-701 since this resin was no longer commercially available and Hetron 921 was its replacement.

C. Spray Equipment for the Application of Electrically Conductive Polymer Concrete Coatings

In the fiberglass industry spray applications of filled polyester resins are very common. Polyesters filled with up to 50% alumina trihydrate have been sprayed successfully for a number of years.

The equipment that was used consists of an air-operated piston pump mounted on a two-wheel cart. The catalyst pump is a pressurized stainless steel tank with an external flow meter. The entire system is pneumatically operated. Air is supplied to the spray system manifold from an external source, in our case, a 160 cfm compressor at 75 to 100 psi. There are four valves on the

spray system manifold which control the (a) pump pressure, (b) nozzle spray, (c) catalyst tank pressure, and (d) catalyst nozzle spray. The pump suction line is placed into a pail containing the coke breeze-resin mixture. The piston pump is started and pumps the mixture through a 0.375-in. diameter line ~35ft to the spray gun. The catalyst tank is pressurized and the catalyst is delivered to the spray gun through a 0.125-in. diameter line. As the coke breeze-resin mixture comes through the gun nozzle, air pressure causes it to spread into a fine spray. The catalyst is atomized at the external tip of the nozzle into the coke breeze-resin spray.

Figure 3 shows the two-wheel cart with the piston, catalyst tank, and air manifold with all the associated valves. Figure 4 shows a close-up of the spray gun.

When spraying, it is important for the operator to wear proper safety equipment, which includes a full-face mask with organic chemical-type filler, a full-hood, disposable coveralls, and rubber gloves. In Figure 5, an operator is shown with complete safety equipment. Although there is little rebound (<2%) during the spray application, it is important to protect the operator from the fine mist of airborne particles of resin and catalyst.

EVALUATION OF ELECTRICALLY CONDUCTIVE POLYMER CONCRETE COATINGS SPRAYED ON PORTLAND CEMENT CONCRETE SUBSTRATES

A. Calcined Coke Breeze - Resin Mixtures

Mixtures of 50 wt% Asbury 4335 calcined coke breeze and 50 wt% Hetron 921 vinyl ester resin were made and sprayed on 4 ft by 4 ft reinforced concrete slabs in a vertical position. When the coating was more than 20 mils thick, the coating sagged. It was necessary to continually stir the coke breeze-resin mixture in the supply can otherwise the coke breeze would settle out. This is unacceptable for a full-scale operation.

In order to keep the coke breeze in suspension, several thixotropic agents were tried. One of these was a very fine, lightweight, coated perlite manufactured by Fillite USA designated P2000. This helped in keeping the coke breeze in suspension during the spraying process, however, upon standing, the mix tended to separate after several hours. In addition, the coating still sagged when applied in thicknesses of 20 mils or more. If thin coatings, ~10 mils, are sprayed and allowed to gel before the next layer is applied, the sagging problem is alleviated. Resistivity readings were taken on different thickness coatings from 10 to 50 mils. In order for the resistivity to be in the order of 10 ohm-cm, the coating has to be 40 to 50 mils thick. This means that the surface has to be sprayed 4 or 5 times. Not only would this be expensive, but it would tend to make the coatings less permeable due to the multiple layer applications.

A mixture of 60 wt% calcined coke breeze and 40 wt% Hetron 921 resin with 3% of a fumed silica thixotropic agent was made and sprayed on a concrete slab. Most of the sagging was eliminated on vertical applications, however, some dripping was still noted on overhead applications. The thickness of the coating was 40 to 50 mils. Resistivity values of 11.2 ohm-cm were measured using the test circuit method previously described.

In order to obtain lower resistivity values, a different vinyl ester resin, 8084-05, was used. Mixtures of 60 wt% Asbury 4335 calcined coke breeze and 40 wt% 8084-05 resin were made and checked to determine if the coke breeze would stay in suspension. It was determined that unless a thixotropic agent was used, the coke breeze would fall out of suspension very quickly. By using 3.5 wt% of Claytone, a modified bentonite clay, in the resin, it was found that the coke breeze would stay in suspension for several days without stirring. The resistivity of this mixture was 1.6 ohm-cm. Spray applications on vertical surfaces of 10 to 30 mils thick were found to be non-sagging and overhead applications did not drip. The resistivity of this conductive coating was 3.5 ohm-cm at a thickness of 10 to 15 mils.

B. Properties of Electrically Conductive Concrete Coatings

1. Permeability

Cores were taken through the conductive coating and the concrete substrate. These cores were tested by the "Rapid Permeability Test" developed by FHWA (12).

The core with the conductive coating 40-50 mils containing Hetron 921 resin had a value of 7,962 coulombs when the coating was facing the chloride solution and 5,634 coulombs when the concrete substrate faced the chloride solution. The core with the (10-20 mil) coating containing the Dow 8084-05 resin had a value of 5,990 coulombs when the coating faced the chloride solution.

With the conductive coating removed, the concrete substrate had a reading of 14,866 coulombs in one direction and 11,163 coulombs in the opposite direction. Both samples of electrically conductive coatings are, therefore, ~50% as permeable as the concrete substrate. Thus, any formation of chlorine or hydrogen gas formed by an impressed current cathodic protection system would be able to permeate through the electrically conductive coating and escape to the surrounding atmosphere and not get trapped in the concrete substrate below the coating surface.

2. Bond Strength

A series of 3-in. diameter cores were taken from sprayed concrete slabs and cycled in a freeze-thaw box under water as per ASTM C666 Type A. The bond strength of the coating was tested periodically using an Elcometer Adhesion Tester as previously described.

The bonds strength of the Hetron 921 coating averaged 317 psi, and the coating with the Dow 8084-05 resin averaged 450 psi. After 100 and 200 freeze-thaw cycles the bond strengths were also measured and they had not decayed as a result of the freeze-thaw cycling. The bond strengths are summarized in Table 5.

3. Electrically Resistivity of Conductive Coatings Under Active CP Systems

Two 4-ft by 4-ft by 4-in. thick concrete slabs with a single mat of No. 5 reinforcing steel, 6-in. on center in both the longitudinal and transverse directions were sprayed with an electrically conductive polymer concrete coating. Each concrete slab contained 15 lb NaCl/yd³ of concrete when they were cast.

One of the slabs was coated with a conductive coating containing 60 wt% Asbury 4335 calcined coke breeze and 40 wt% Hetron 921 vinyl ester resin containing 3 wt% Cab-O-Sil. The other slab was sprayed with an electrically conductive coating containing 60 wt% Asbury 4335 calcined coke breeze and 40 wt% Dow 8084-05 vinyl ester resin containing 3.5 wt% Claytone, a thiotropic agent. An anode slot 0.25-in. wide by 0.25-in. was cut in deep the center of the slab and a 0.031-in. diameter platinum-niobium clad copper core anode wire was inserted in the slot and cemented in place using the same electrically conductive mix as the coating.

The slabs were put in active impressed current cathodic protection system and run at 2 mA current per square foot of concrete surface area. The slabs were run at this level for 8 weeks and then the current was raised to 10 mA per square foot of reinforcing steel surface area. This is 5 mA current per square foot of concrete surface.

There does not appear to be any deterioration of the conductive coating in any section of the slabs. The bond strength of the coating to the concrete substrate was measured before the CP system was activated. At that time, the bond strength of the electrically conductive coating with the Dow 8084-05 resin was 350 psi and with the Hetron 921 was 250 psi. After 4 months in an active CP system, the bond strengths are 325 psi and 200 psi, respectively.

The operating currents, voltages, and the electrical resistivity measurements, as a function of time are summarized in Tables 6 and 7.

CONCLUSIONS AND RECOMMENDATIONS

It has been shown that electrically conductive polymer concrete coatings can be applied on vertical and overhead surfaces with spray equipment. These coatings have resistivities of <10 ohm-cm and have about half the permeability of portland cement concrete.

It appears that the Dow 8084-05 vinyl ester resin with 3.5 wt% Claystone can be used to make a slurry containing 60 wt% calcined coke breeze and keep the coke breeze in suspension for several days. This system does not sag when sprayed on vertical surfaces. The electrical resistivity of a coating 10-20 mils thick made with Dow 8084-05 is less than the resistivity of a coating 30-50 mils thick made with Hetron 921 resin.

A full-scale spray application must be made with the equipment using the conductive coating containing Dow 8084-05 resin and placed in an active CP system. The long term effects on the degradation of the coating from the active CP system must be determined.

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TABLE 1--RESINS EVALUATED FOR ELECTRICALLY CONDUCTIVE COMPOSITE

Resin	Type	Prescription	Curing Ag
LB183-13	orthophthalic polyester	low-viscosity, general purpose resin	1.2% MEKP ¹ /0.5% CoN
Aropol 7532	isophthalic polyester	low-viscosity, chemical resistant resin	1.2% MEKP/0.5% CoN
DPV-701	vinyl ester	low-viscosity, chemical resistant resin	2.4% MEKP/0.4% CoN, 0.1% DMA ³
Hetron 921	vinyl ester	low viscosity, chemical resistant resin	2.0% MEKP/0.5% CoN, 0.1% DMA
8084-05	vinyl ester	medium viscosity, chemical and impact resistant resin	2.0% MEKP/0.4% CoN, 0.05% DMA

Notes 1. MEKP - methyl ethyl ketone peroxide, Lucidol DDM.

2. CoN - cobalt napthenate 6%.

3. DMA - dimethyl aniline.

TABLE 2--ELECTRICALLY CONDUCTIVE FILLERS

Filler	Type	Manufacturer
Statex 160	carbon black	Cities Service Company
Ketjenblack EC	carbon black	Armack Company
Shamokin coke breeze	coke breeze	Shamokin Filler Company
Asbury 4335	calcined coke breeze	Asbury Graphite Mills
Loresco DWI	calcined coke breeze	Cathodic Engineering Company

TABLE 3--RESISTIVITY OF ELECTRICALLY CONDUCTIVE COMPOSITE WITH DIFFERENT FILLERS

Filler	Mix Proportions, wt%		Resistivity ohm-cm
	Resin ¹	Filler	
Statex 160	76	24	18,500
Ketjenblack EC	95	5	2,900
Shamokin coke breeze	33	67	3.02
Asbury 4335	26	74	0.85
Loresco DWI	30	70	0.99

Notes 1. Resin used for tests was LB183-13 orthophthalic polyester.



TABLE 4--RESISTIVITY OF ELECTRICALLY CONDUCTIVE COMPOSITES WITH DIFFERENT RESINS

Resin	Mix Proportions, wt%		Resistivity ohm-cm
	Resin	Filler ¹	
LB183-13	30	70	0.87
Aropol 7532	30	70	2.02
DPV-701	30	70	1.20
8084-05	30	70	1.14

Note 1. Filler used in all cases was Asbury 4335 calcined coke breeze.

TABLE 5--BOND STRENGTH OF ELECTRICALLY CONDUCTIVE POLYMER CONCRETE COATINGS

Resin 1	Bond Strength, ¹ psi		
	Number of Freeze-Thaw Cycles		
	0	100	200
Hetron 921	317	313	307
Dow 8084	450	440	430

Notes 1. Bond strength tested with Elcometer Adhesion Tester. Values given are averages of three samples.

TABLE 6--ELECTRICALLY CONDUCTIVE POLYMER CONCRETE COATING
USING HETRON 921 VINYL ESTER RESIN

Total Operating Time	Operating Current mA	Operating Voltage V	Electrical Resistivity ohm-cm
0	30	14	14.4 ¹
48 hr	30	10.5	
1 wk	30	5.0	
3 wk	30	6.0	
5 wk	30	6.0	
8 wk	30	6.0	11.2 ²
0	80	19.0	
48 hr	80	17.0	
1 wk	80	27.0	
2 wk	80	16.0	
3 wk	80	27.0	
9 wk	80	38.0	

Notes 1. Resistivity measured as per "test circuit" method described in "Electrically Conductive Polymer Concrete Overlays, Final Report," BNL 35036-R, pp. 4, 5.

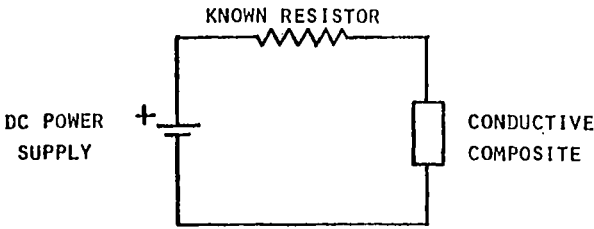
2. Resistivity measured using 4 pin method with Nilsson Model 400 AC Impedance meter.

TABLE 7--ELECTRICALLY CONDUCTIVE POLYMER CONCRETE
COATING USING DOW 8084 VINYL ESTER RESIN

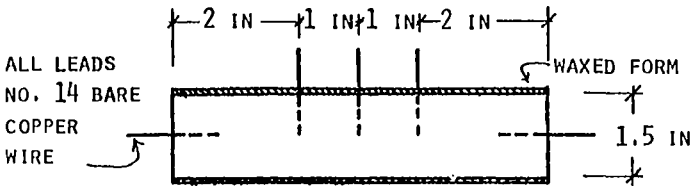
Total Operating Time	Operating Current mA	Operating Voltage V	Electrical Resistivity ohm-cm
0	30	4.5	7.2 ¹
48 hr	30	4.5	
1 wk	30	3.3	
3 wk	30	3.2	
5 wk	30	3.3	
8 wk	30	3.3	
0	80	9.0	
48 hr	80	8.3	
1 wk	80	10.0	
2 wk	80	10.0	3.6 ²
3 wk	80	8.7	
9 wk	80	22.0	

Notes 1. Resistivity measured as per "test circuit" method described in "Electrically Conductive Polymer Concrete Overlays, Final Report," BNL 35036-R, pp. 4, 5.

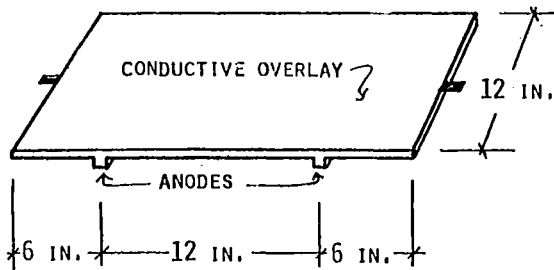
2. Resistivity measured using 4 pin method with Nilsson Model 400 AC Impedance meter.



A) SCHEMATIC OF TEST CIRCUIT



B) 6 IN. RESISTIVITY TEST SPECIMEN



C) CONDUCTIVE OVERLAY TEST SPECIMEN

Fig. 1--Resistivity test specimens and test circuit



Fig. 2--Elcometer Adhesion Tester

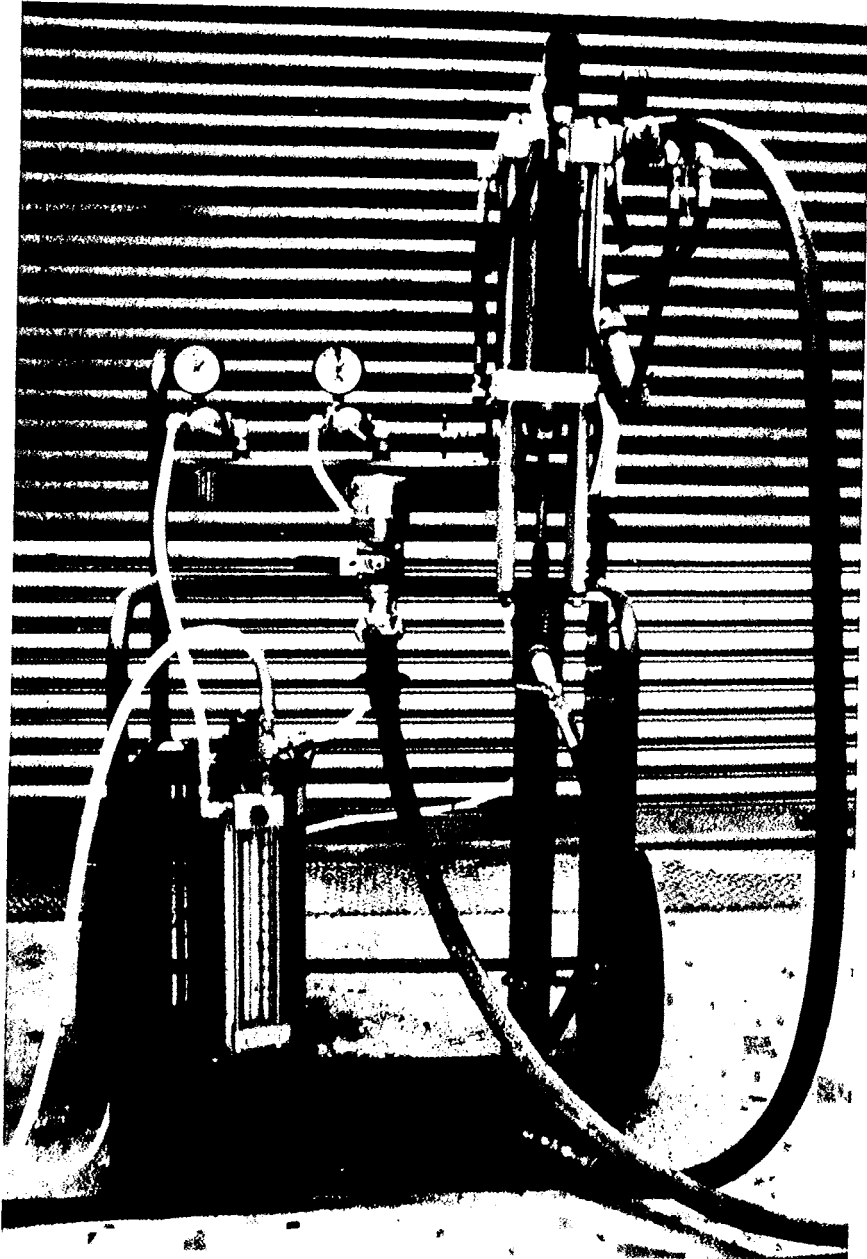


Fig. 3--Spray equipment used for electrically conductive polymer concrete coatings

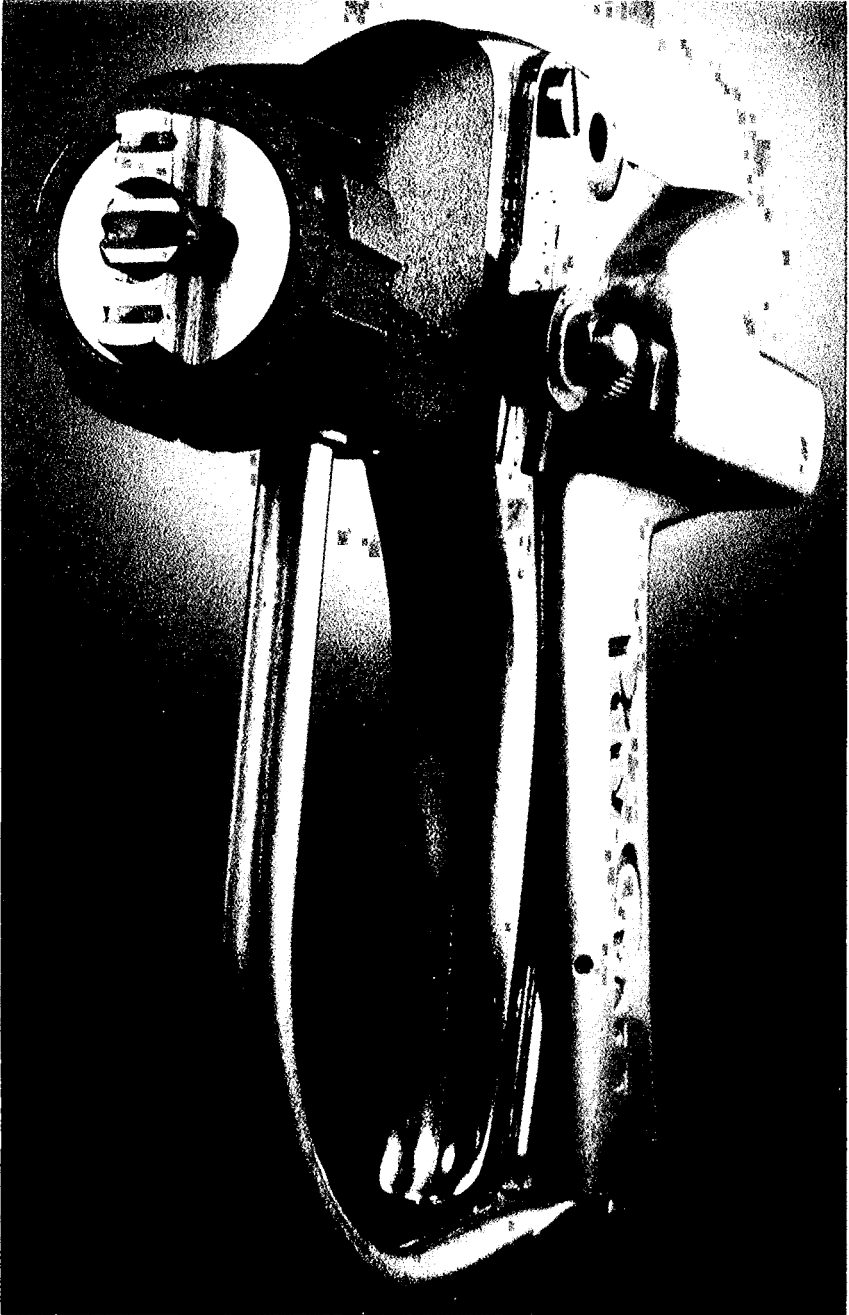


Fig. 4--Fan-jet spray gun



Fig. 5--Safety equipment to be worn by operator during spray application

Lightweight Polymer Concrete Composites

By J.J. Fontana, M. Steinberg, and W. Reams

Synopsis: Lightweight polymer concrete composites have been developed with excellent insulating properties. The composites consist of lightweight aggregates such as expanded perlites, multicellular glass nodules, or hollow alumina silicate microspheres bound together with unsaturated polyester or epoxy resins.

These composites, known as Insulating Polymer Concrete (IPC), have thermal conductivities from 0.09 to 0.19 Btu/hr-ft-°F. Compressive strengths, dependent upon the aggregates used, range from 1000 to 6000 psi.

These materials can be precast or cast-in-place on concrete substrates. Recently, it has been demonstrated that these materials can also be sprayed onto concrete and other substrates.

An overlay application of IPC is currently under way as dike insulation at an LNG storage tank facility. The composites have numerous potentials in the construction industry such as insulating building blocks or prefabricated insulating wall panels.

Keywords: dikes; epoxy resins; insulating concretes; insulation; lightweight aggregates; polyester resins; polymer concrete; thermal conductivity