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PCM composites can be made using residues "as received" from the source. However, the amount of residue which can be incorporated into the composite is significantly less than that which can be added to a PC composite. In addition, compressive strengths of the PCM composites were shown to decrease with lucreasing residue content.

Based upon the data presented, it is felt that much more research is required to properly determine the long-term characteristics of PC and PCM composites before they can be utilized as a means of stabilizing hazardous geothermal residues.

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	CONCENTRATION, mg/liter									
ELEMENT ^a	RESIDUE									
	BRI	BR2	BR3	BR4						
Titanium (Ti) Vanadium (V) Chromium (Cr) Manganese (Mn) Iron (Fe) Nickel (Ni)	$12,870 \pm 1,900 7,130 \pm 1,430 1,530 \pm 390 1,980 \pm 440 31,310 \pm 6,300 $	$20,530 \pm 2,300 \\ 13,090 \pm 836 \\ 1,870 \pm 208 \\ 3,300 \pm 79 \\ 54,340 \pm 9,490 \\$	$12,500 \pm 1,710 \\ 7,080 \pm 1,080 \\ 1,180 \pm 202 \\ 1,530 \pm 220 \\ 22,680 \pm 4,870 \\$	$\begin{array}{rrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrr$						
Copper (Cu) Zinc (Zn) Arsenic (As)	$ 38 \pm 6 65 \pm 19 $	$\begin{array}{rrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrr$	296 ± 8 216 ± 86 	$\begin{array}{rrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrr$						
Bromine (Br) Rubidium (Rb) Strontium (Sr) Zirconium (Zr) Lead (Pb)	79 + 23 $4,950 + 1,430$ $9,780 + 480$ $124 + 35$	$70 \pm 14 \\ 5,130 \pm 92 \\ 1,210 \pm 160 \\ 140 \pm 19$	$\begin{array}{rrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrr$	$ \begin{array}{r} 342 \pm 10 \\ 1,660 \pm 165 \\ 340 \pm 41 \\ 1,300 \pm 124 \\ \end{array} $						

TABLE 1--PIXE SPECTROSCOPY ANALYSIS OF GEOTHERMAL RESIDUES

^a In addition to the elements listed, the residues also contained various levels of phosphorus, sulfur, chlorine, potassium and calcium.

	Half	ACTIVITY, µCi/gm						
NUCLIDE	Life,	RESIDUE						
	уI	BR1	BR2	BR3	BR4			
к-40	20,000	3.80 E5	4.13 E-5	5.79 E-5	2.34 E-5			
Bi-211	70,000	1.06 E-3	9.42 E-4	1.15 E-3	3.07 E-4			
Bi-212	14,000	1.30 E4	4.07 E-5	5.16 E-5	1.70 E-5			
Bi-214	1,602	2.97 E-4	2.75 E-4	3.49 E-4	8.76 E-5			
Pb-212	14,000	1.58 E-4	4.90 E-5	6.63 E-5	2.20 E-5			
Pb-214	70,000	4.26 E-4	3.66 E-4	4.46 E-4	1.19 E-4			
T1-208	14,000	1.25 E-4	4.07 E-5	5.16 E-5	1.71 E-5			
Ra-224	14,000	9.89 E-4	5.70 E-4	9.76 E-4	2.57 E-4			
Ra-226	1,602	3.63 E-4	2.68 E-4	3.40 E-4	8.52 E-5			
Th-228	14,000	1.48 E-4	4.71 E-5	6.38 E-5	2.12 E-5			
Th-234	70,000	2.04 E-5	2.11 E-5	4.08 E-5	4.89 E-6			
Ac-228	14,000	3.26 E-4	3.98 E-4	4.70 E-4	1.22 E-4			

TABLE 2--GAMMA PULSE HEIGHT ANALYSIS OF GEOTHERMAL RESIDUES, NATURAL PRODUCTS

TABLE 3--MOISTURE CONTENT AND pH OF GEOTHERMAL RESIDUES

		RESIDUE							
	BR1	BR2	BR3	BR4					
Moisture content of solids, wt %	15	10	19	39					
pH of excess fluid after settlement of solids	1.67	a	3.35	5.10					

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a Residue contained no free moisture.

RESTOLE					El	LEMENTA	L CONCI	ENTRATIO	N, ^a mg,	/1				
	Sb	As	Ba	Cđ	Cr	Co	Cu	РЪ	Мо	Ni	Ag	v	Zn	Hg
BR1	3	NDB	27	0.2	<0.1	0.2	0.8	3.5	ND	0.5	<0.1	ND	18	<<0.01
BR2	0.7	ND	29	<0.1	ND	<0.1	0.4	0.3	ND	ND	ND	ND	1	<<0.01
BR3	40	13	24	0.2	0.5	0.5	20	9.3	ND	0.8	<0.1	ND	17	<<0.01
BR4	17	77	19	2.3	96	0.9	0.1	136	ND	1.2	<0.1	ND	215	<<0.01
STLCC	100	5	100	1	5	80	25	5	350	20	5	24	250	0.2

TABLE 4--48 HOUR WET ANALYSIS OF "AS RECEIVED" GEOTHERMAL RESIDUES

^a Values reported are the highest concentration measured in three separate tests.

b ND = not determined.

^C STLC = soluble threshold limit concentration.

				48-hr WET Analysis					
MIX	CONDITION	COMPRESSIVE	Elemental Concentration, mg/l						
DESIGN	RESIDUE	psi	Ba	Cr	Cu	РЬ	Zn		
25 wt% resin 75 wt% BR1	As Received	3695	17.0	<0.1	0.5	1.9	18.0		
30 wt% resin 70 wt% BR1	Dried	5475	20.0	<0.1	0.5	1.4	10.2		
32 wt% resin 68 wt% BRl	Washed & Dried	12,900	23.0	<0.1	0.3	0.5	1.9		
STLC ^b			100	5	25	5	250		

TABLE 5--ENCAPSULATION OF RESIDUE BR1 USING ALTEK 78-50 EMULSIFIABLE POLYESTER

^a Average of three test specimens. 1 psi = 0.00689 MPa.
^b STLC = soluble threshold limit concentration.

TABLE 6--ENCAPSULATION OF RESIDUES USING AN MMA-BASED MONOMER

			48-hr WET Analysis				ysis	
MIX	CONDITION	COMPRESSIVE	Elemental Concentration, mg/l					
DESIGN	RESIDUE	psi ^b	Ba	Cr	Cu	РЪ	Zn	
30 wt% MMA 70 wt% BR1	Dried	4165	33	0.4	0.3	0.1	1.0	
30 wt% MMA 70 wt% BR2	Dried	16,500	30	NDe	0.3	0.1	0.6	
30 wt% MMA 70 wt% BR3	Dried	5,400	23	0.1	9.5	2.1		
30 wt% MMA 70 wt% BR4	Dried	0c		—	_			
STLC ^d			100	5	25	5	250	

- ^a Monomer system = 75 wt% MMA 25 wt% PMMA with 4 wt% BFF 50 benzoy1 peroxide initiator and 1 wt% dimethyl-para-toluidine promoter.
- ^b Average of 3 specimens. 1 psi = 0.00689 MPa.
- Unable to cure sample.
- d STLC = soluble threshold limit concentration.
- e ND = not detectable.

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PCM	CONDITION OF	28-DAY COMPRESSIVE	CONDITION OF	28-DAY COMPRESSIVE
SYSTEM ^a	RESIDUE	STRENGTH, psi ^b	RESIDUE	STRENGTH, psi
Control - No Residue		4295		
7 wt% BR1	Dried	4930	As Received	5160
18 wt% BR1			As Received	4700
7 wt% BR2	Dried	5530	As Received	5445
18 wt% BR2			As Received	2875
7 wt% BR3	Dried	4840	As Received	5265
18 wt% BR3			As Received	4450
7 wt% BR4	Dried	4135	As Received	4895
18 wt% BR4			As Received	3110

TABLE 7--COMPRESSIVE STRENGTHS OF PCM COMPOSITES CONTAINING GEOTHERMAL RESIDUES

 $^{a}\text{Residue}$ content is based on dry weight of the total solid content of mix. $^{b}\text{lpsi}$ = 0.00689 MPa.

PCM ^a System	CONDITION OF RESIDUE	CONDITION ELEMENTAL CONCENTRATION, ^a mg/ OF RESIDUE Ba Cr Cu Pb					
Control - No Residue		1.4	0.1	0.2	NDb	0.1	
7 wt% BR1 7 wt% BR2 7 wt% BR3 7 wt% BR4	Dried	NT ^C NT NT NT	0.4 0.4 0.5 1.2	0.2 0.3 0.8 2.7	ND 0.1 0.1 1.8	0.1 0.2 0.1 0.8	
7 wt% BR1 18 wt% BR1 7 wt% BR2 18 wt% BR2 7 wt% BR3 18 wt% BR3 7 wt% BR4 18 wt% BR4	As Received	2.7 2.8 2.6 3.1 3.5 2.5 3.0 1.8	0.5 0.4 0.6 0.4 0.4 0.4 1.5 5.0	0.3 0.5 0.2 0.4 0.7 2.6 2.6 9.0	ND 0.2 ND 0.2 0.1 0.3 1.4 5.4	0.1 0.1 0.1 0.1 0.1 0.1 0.5 2.5	
STLC ^d		100	5	25	5	250	

TABLE 8--48 HOUR WET ANALYSIS OF PCM COMPOSITES CONTAINING GEOTHERMAL RESIDUES

^a Residue content is based on dry weight of the total solid content of mix.

b ND = not detectable. c NT = no test.

d STLC = soluble threshold limit concentration.

<u>SP 116-7</u>

Repair of Cracked Concrete with High Molecular Weight Methacrylate Monomers

by D.J. Rodler, D.P. Whitney, D.W. Fowler, and D.L. Wheat

Three high molecular weight methacrylate Synopsis: monomer systems were tested to determine their effectiveness in repairing cracked portland cement Ultimate strains across repaired cracks, concrete. modulus of rupture, and percent of crack filled for slabs repaired with the monomers and stiffnesses of repaired beams were investigated. Tests on small, cracked slabs were also conducted under hot and wet conditions. One hundred thirty-five PCC slabs, 9 PCC beams, and 12 tension specimens were tested. The results varied with respect to the stiffnesses of the polymers. All monomer systems were shown to increase the stiffness of cracked flexural members and to fill cracks as small as 0.1 mm in width. The performance of the systems was adversely affected by moisture and heat. Minimum drying periods after saturation of the cracked concrete with water were determined.

<u>Keywords</u>: beams (supports); concrete slabs; <u>cracking</u> (<u>fracturing</u>); <u>methacrylates</u>; <u>monomers</u>; <u>repairs</u>; tests

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INTRODUCTION

Small cracks in bridge decks and reinforced pavements can allow water to infiltrate and corrode reinforcing steel. One simple solution to sealing cracks is the use of high molecular weight methacrylate (HMWM). HMWM refers to dicyclopentenyl methacrylate and its close relatives. This family of methacrylate monomers have been developed specifically for concrete repairs and all have viscosities in the range of 8 to 40 cps. The monomer system is poured or sprayed onto the concrete and brushed into the cracks. Research at The University of Texas at Austin (2,4) has shown HMWM monomers to be well suited for repair of narrow cracks in portland cement concrete.

The purpose of the research described in this paper was to evaluate the structural integrity of the repaired cracks as well as the capability of the material to fill the cracks. Adverse conditions, including moisture and heat, for applying the monomer were considered to determine the effects on the filling of cracks and the strength of the bond. The stress-strain relationship for the polymer in a repaired crack in direct tension was evaluated for two typical crack widths. Two types of flexural tests were performed. Small slabs which developed single flexural cracks were tested to compare moduli of rupture before cracking and after repair. Reinforced PCC beams which developed flexural cracks were repaired and tested to determine the change in stiffness at service loads as compared to the cracked unrepaired condition.

The monomers used for this study will be referenced as 'System 1,' 'System 2,' and 'System 3.' All systems consisted of 100 parts monomer (by weight), 4 parts initiator, and 2 parts promoter. All systems used a 6 percent solution of cobalt naphthenate as the promoter. The initiator was benzoyl peroxide for Systems 1 and 2 and cumene hydroperoxide for System 3. For this study, all cracks were filled with monomer until penetration into the cracks had stopped. The sides of all specimens were sealed at the cracks to prevent monomer from seeping out.

Specimens and Test Procedures

Strain measurements across repaired cracks were performed on specially designed tension specimens which were 1-in. diameter mortar cylinders, each with a repaired crack perpendicular to the tension load. The mortar cylinder was fixed to loading plates with epoxy as shown in Fig. 1. Cracks had widths of 0.4 mm or 1.0 mm and were sealed and repaired with one of the three monomer systems. Plain mortar specimens were also tested so that the strain in the mortar could be subtracted from the strain of the composite mortarpolymer specimen to yield the strain across the crack.

The portland cement concrete used for casting slabs and beams was designed to yield a nominal 4,000 psi concrete. Slab specimens, measuring 4-in. x 6-in. x 12-in., were cracked in flexure using third-point loading on a 10-in. span. The reinforced concrete beams measured 6-in. x 6 in. x 36-in. and were loaded at the third points of a 34-in. span. Figure 2 shows the loading arrangement for the slabs in flexure.

The slabs were reinforced with light gage wire to hold the specimen together after cracking. Beam specimens were reinforced with a single No. 4 bar placed at a depth of 4- in. from the compression face.

placed at a depth of 4- in. from the compression face. After being cracked and repaired with the monomers, the slabs were cut lengthwise. Half of the slab was recracked to determine the ratio of recracking stress to cracking stress. The other half