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ENCAPSULATION OF PHASE CHANGE MATERIALS IN CONCRETE MASONRY CONSTRUCTION

PROGRESS REPORT NO. 1
AUGUST 1977 - FEBRUARY 1978

PROCESS SCIENCES DIVISION
DEPARTMENT OF ENERGY AND ENVIRONMENT

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Abstract

Work performed at Brookhaven National Laboratory on Union Carbide Nuclear Division ORNL order number 19Y-14279V, "Encapsulation of Phase Change Materials in Concrete Masonry Construction", is summarized in this First Progress Report for the period ending February 1978.

The improvement of thermal energy storage capacity of potential building materials by incorporation of phase change materials (PCM's) is being explored. Both inorganic salt hydrates and organic systems are potentially useful PCM's for encapsulation in concrete, polymer concrete, and/or polymer-impregnated concrete matrices. It is felt at this time that most PCM's melting at or above 40°C can be encapsulated in large quantities in polymer concrete. Methods relating to the encapsulation of lower melting materials in various matrices are currently being studied.

Summary

Space conditioning represents the major energy consuming function for both commercial and residential buildings. Efficient storage of thermal energy in the walls of these structures through incorporation into building materials of substances which undergo phase transitions offers the potential of substantial energy savings through the use of optimized enthalpy management strategies. The problem of designing materials of high heat capacity which can be utilized in the construction industry is the subject of this report

Such materials can be fabricated by incorporation of large amounts (15-50%) of substances which undergo phase transitions in the desired temperature range of 20°C-35°C (68°F-95°F) or optimally 20°C-24°C (68°F-78°F). The large heats of solid-liquid transitions (generally between 30 and 50 calories per gram) result in substantial increases in the total heat which can be stored in the final material. The phase change materials of interest include inorganic salt hydrates ($\text{CaCl}_2 \cdot 6\text{H}_2\text{O}$, $\text{Zn}(\text{NO}_3)_2 \cdot 6\text{H}_2\text{O}$, $\text{Na}_2\text{SO}_4 \cdot 10\text{H}_2\text{O}$, $\text{Na}_2\text{CO}_3 \cdot 10\text{H}_2\text{O}$, $\text{Na}_2\text{S}_2\text{O}_3 \cdot 5\text{H}_2\text{O}$ and several eutectic systems) and organic compounds (fatty acids and their eutectics, polyethylene glycols, and some others). The matrix materials include ordinary concrete, polymer-impregnated concrete, and polymer concrete.

Phase change materials (PCM's) with transition temperatures above 40°C have been successfully encapsulated in large quantities (up to 60%) in a polymer concrete matrix. Work on encapsulating lower melting materials has met with limited success. Work is

continuing in this area by focusing attention on methods of micro-encapsulation of low melting PCM's prior to incorporation into the matrix. Phase change materials which can be successfully encapsulated in an ordinary concrete matrix have yet to be found. It is expected that prior microencapsulation will also solve this problem. Several systems composed of polymer plus phase change material without other aggregate have been made. They tend to require a minimum of 25% polymer (some as much as 50%) and lack strength. No further effort in this area is planned.

Encapsulation of Phase Change Materials in

Concrete Masonry Construction

Progress Report No. 1

August 1977 - February 1978

Introduction

Space conditioning is the major energy consuming function for both commercial and residential buildings. The potential for savings through system modifications such as increased efficiencies of heating and cooling devices, effective insulation, enthalpy management strategies, thermal energy storage, etc. is substantial.¹

The most efficient way to store thermal energy is in the walls of the structure. These walls should have high heat capacities and should be insulated on the exterior to prevent heat loss. Concrete has an average specific heat² of $0.22 \text{ cal gram}^{-1} \text{ }^{\circ}\text{C}^{-1}$, less than one fourth that of water. Thus, when the temperature changes from 20°C to 30°C , 2.2 cal per gram of concrete is stored. One way of increasing the heat capacity of concrete and other building materials is the incorporation of a phase change material (PCM) which will alternately store and release its latent heat of transition upon thermal cycling. The most likely PCM candidates are substances undergoing a solid-liquid transformation at the desired temperature of energy storage. Such materials should have a high heat of fusion, stability with respect

to thermal cycling, and chemical compatibility with the encapsulating medium. It is readily calculated that the incorporation of 20% of an active PCM with a heat of fusion of 35 cal/gram and transition temperature of 25°C will raise the stored heat from 2.2 cal gram⁻¹ to 9.0 cal gram⁻¹ over the temperature interval 20°C-30°C. At the 30% level, 15.7 cal gram⁻¹ would be stored. Thus substantial increases in heat storage can be achieved with relatively small amounts of PCM.

The PCM transition temperatures for thermal energy storage are determined by the desired application: hydronic heating, 75-80°C; hot water, 55-75°C; hot air, 35-55°C; wall panel, 20-35°C; cold storage, 5-20°C.³ For the present study, the main concern will be the encapsulation of PCM's which undergo phase transition in the 20-35°C range and preferably in the 20-24°C range. This latter range is ideal for a completely passive thermal energy storage system which would require no fans or blowers or other supporting devices for energy delivery.

The emphasis in this work is on the microencapsulation of phase change material rather than macroencapsulation. The matrix material throughout which the PCM is dispersed is ordinary concrete, polymer impregnated concrete, or polymer concrete.

The encapsulation of phase change material in ordinary concrete offers a low cost method for energy storage. Since normal weight concrete is roughly 75-80% aggregate, a partial replacement of this aggregate with cement-compatible PCM will increase its energy storage capacity. Since the curing of Portland cement depends upon hydration reactions, it is imperative that the PCM not interfere with these

reactions. The PCM must also not react with the aggregate and must not interfere with the bonding between cement and aggregate.

Polymer-impregnated concrete (PIC) consists of pre-cast concrete impregnated with a suitable monomer and polymerized in situ. Significant improvements in strength and durability as well as an impermeable material result from this procedure.

Polymer concrete (PC) consists of aggregate mixed with a suitable monomer instead of Portland cement. Subsequent polymerization yields a high strength, durable, and impervious material. The methods for mixing and placement are comparable to ordinary cement. High strength PC (and PIC) can both be made from relatively low quality, low strength aggregate.

The objectives of this project are to develop techniques for the encapsulation of phase change materials into concrete, polymer-impregnated concrete, and/or polymer concrete and to characterize the physical and thermal properties of these materials. Economic studies and technology transfer efforts will also be initiated at the appropriate stages of development.

Task 1. Identification and Selection of Phase Change Materials

A literature search⁴ by Dow Chemical Company of 20,000 compounds for effective phase change materials (PCM's) revealed 200 potentially useful compounds with transition temperatures in the 10°C-90°C (50°F-194°F) range. For thermal energy storage in the passive systems under consideration in this report, the temperature range of interest is 20°C-35°C (68°F-95°F) and preferably 20°C-24°C (68°F-75°F).

This restriction limits the available choices to a few inorganic hydrated salts and several organic systems. The inorganic systems are listed in Table 1 and the organic systems in Table 2. The two systems which have received the most attention are $\text{CaCl}_2 \cdot 6\text{H}_2\text{O}$ and $\text{Na}_2\text{SO}_4 \cdot 10\text{H}_2\text{O}$.⁵

The organic systems provide a wider range of temperatures and tend to exhibit less supercooling than the inorganic salts. In general, they are also much more expensive.

Since the choice of a PCM is so integrally tied to the choice of encapsulating material, no final selections are possible at this time.

Task 2. Encapsulation Techniques

Ordinary concrete is an inexpensive building material, a standard 8 in. x 8 in. x 16 in. block costing about 45¢. If a phase change material can be successfully incorporated into ordinary concrete, a low cost energy storage medium will result. Portland cement consists of a finely divided mixture of tricalcium silicate, β -dicalcium silicate, tricalcium aluminate, and tetracalcium aluminoferrite. Hardening of cement (and concrete which is cement plus 75% sand or other aggregate) is due to hydration. It is of the utmost importance that any PCM added to a concrete mix not interfere with the hydration mechanism or impair the bond between cement and aggregate. All of the PCM's initially selected as potentially useful exhibited either a chemical or physical interference with the setting of cement. In particular, the fatty acids react chemically with cement while the polyethylene glycols are water miscible. In both cases, the cement

Table 1

Inorganic Phase Change Materials

<u>Compound</u>	<u>MP (°C)</u>	<u>ΔH_{fus} (cal/gram)</u>	<u>Nucleating Agent</u>	<u>Disadvantages</u>
$\text{Na}_2\text{S}_2\text{O}_3 \cdot 5\text{H}_2\text{O}$	45	50	unknown	high supercooling; melting temperature too high for passive applications
$\text{Zn}(\text{NO}_3)_2 \cdot 6\text{H}_2\text{O}$	36	35	unknown	potential hazard with organic systems
$\text{Na}_2\text{SO}_4 \cdot 10\text{H}_2\text{O}$	32	60	2.5% $\text{Na}_2\text{B}_4\text{O}_7$	incongruent melt
$\text{CaCl}_2 \cdot 6\text{H}_2\text{O}$	29	45	2% $\text{Ba}(\text{OH})_2$	hygroscopic
$\left. \begin{array}{l} \text{CaCl}_2 \quad 38.3\% \\ \text{MgCl}_2 \quad 9.4\% \\ \text{H}_2\text{O} \quad 52.3\% \end{array} \right\}$	25	--	unknown	hygroscopic
$\left. \begin{array}{l} \text{CaCl}_2 \quad 31.2\% \\ \text{MgCl}_2 \quad 14.2\% \\ \text{H}_2\text{O} \quad 54.6\% \end{array} \right\}$	22	--	unknown	hygroscopic

Table 2

Organic Phase Change Materials

<u>Compound</u>	<u>MP (°C)</u>	<u>ΔH_{fus} (cal/gram)</u>
lauric acid	42.5	42.4
polyglycol E 1000	33.5	--
decanoic acid	31.4	36.5
decanoic + myristic acids	24	35.3
polyglycol E 600	22	30.4
decanoic + palmitic acids	21.5	--
acetophenone	20	--
octanoic acid	15	35.5

does not set. A similar result was obtained with $\text{CaCl}_2 \cdot 6\text{H}_2\text{O}$. It is obvious that some method of containment is necessary if PCM is to be used with cement systems.

Foamed glass beads (see Figure 1) manufactured by Teledyne National are potentially worthwhile candidates for impregnation with phase change materials. The beads are manufactured with 15% fly ash which inhibits reaction between silica and the basic cement and are thus compatible with Portland cement. The beads are highly porous ($\sim 40\%$ pores) and can therefore hold considerable quantities of PCM. Table 3 lists some properties of the beads.

Penniman and Browne, an independent testing laboratory, has made concrete samples using foamed glass beads as coarse aggregate. They report 28 day average compressive strengths of 4065 psi. The mix proportions are given in Table 4. The fine and coarse aggregate weights reported in Table 4 are on a saturated surface dry basis (SSD).

Samples of concrete using foamed glass aggregate and prepared at Brookhaven are shown in Figure 2. Seven day strength tests gave an average compressive strength of 1750 psi which extrapolates to 2187 psi at 28 days. While this is lower than the results reported by Penniman and Browne, it was felt that further time should not be spent in this area since strengths in excess of 1000 psi are sufficient for non-load bearing walls which are being given priority for near-term application of our materials. The fractured sample shows clearly that good bonding between cement and beads has been achieved. Two samples were then impregnated with a 95/5 mixture of MMA/TMPTMA* with 1% benzoyl peroxide

* methyl methacrylate/trimethylolpropane trimethacrylate

Table 3

Properties of Foamed Glass Beads

Density	0.15-1.5 g/cm ³
Size	2.5-10 mm diameter
Compressive Strength	1000 psi @ 0.5 g/cm ³
Porosity	~ 40%
Thermal Conductivity	0.40 $\frac{\text{Btu}}{\text{hr-ft}^2-\text{°F/in.}}$
	4.96 $\frac{\text{Kcal}}{\text{hr-m}^2-\text{°C/cm.}}$

Table 4

Batch Proportions for Concrete Using
Foamed Glass Beads

Cement: Portland Type I
Coarse Aggregate: Foamed Glass Beads
Fine Aggregate: Sand
Water-Cement Ratio: 0.425

Cement	25.0 parts
Coarse Aggregate	33.0 parts
Fine Aggregate	31.4 parts
Water	10.6 parts

and cured at 70°C forming PIC. The average compressive strength was 7156 psi.

The problem of impregnating the beads with PCM was next addressed. The interior pores of the beads are quite large and are accessible through holes in the surface which are pin size and smaller. The beads will hold approximately 40% of their weight in water. It was hoped that the impregnated PCM would be trapped in place inside the beads at least long enough for the cement to cure.

The impregnation procedure consists of placing the beads in a vacuum flask or vessel and pulling a coarse vacuum for about 1/2 hour. The melted phase change material is then introduced without breaking vacuum and a pressure of 60 psig is then introduced with an air or nitrogen cylinder over the submerged beads for about one hour. These times are probably not too critical and have not been optimized. The beads were impregnated with $\text{CaCl}_2 \cdot 6\text{H}_2\text{O}$, decanoic acid, polyethylene glycol 600, and polyethylene glycol 1000. Samples were then prepared using the impregnated foamed glass beads for coarse aggregate. Figure 3 is a photograph of a sample containing $\text{CaCl}_2 \cdot 6\text{H}_2\text{O}$. The concrete expanded and there was no bonding between cement and the foamed glass aggregate. The samples using PEG 600 (see Figure 4) and PEG 1000 failed to cure, probably because of the miscibility of these materials with water. The decanoic acid samples did set up but could be broken by hand. There was no bonding between the cement and coarse aggregate as is readily apparent from Figure 5. Table 5 summarizes the results. It is probably safe to assume at this point that the only method for

Table 5
Composition of Systems with Cement Matrix

<u>Figure</u>	<u>Binder</u>	<u>Aggregate</u>	<u>Foamed Glass Beads</u>	<u>PCM</u>	<u>Comments</u>
2	Portland Cement #1 22.0%	Sand* 37.9%	40.1% SSD ⁺ 22.0% dry	0	Control samples. Cured to acceptable strength. Polymer impregnated showed high strength.
5	Portland Cement #1 21.2%	Sand 36.5%	21.2% dry	Decanoic acid 16.5%	All samples were unacceptable. Polymer impregnation did not produce strength or impermeability.
4	Portland Cement #1 18.5%	Sand 31.8%	24.2% dry	PEG 600 25.5%	These samples never set.
3	Portland Cement #1 17.6%	Sand 30.3%	22.9% dry	CaCl ₂ ·6H ₂ O 29.0%	Samples cracked and fell apart.

* Sand ratios in all cases were 2:1:1 #16 mesh: # 30 mesh: #100 mesh

+ SSD - saturated surface dry basis.

Note: The water/cement ratio for all samples was 0.4.

utilizing the foamed glass beads with ordinary concrete will entail encapsulating the beads after impregnation with a cement compatible coating.

Polymer concrete⁶ systems have some decided advantages over ordinary concrete. They are 3-4 times stronger, highly impermeable, and less sensitive to the nature of aggregate and PCM. On the negative side, they are more expensive (2-3 times) and are not standard items of production. A typical polymer concrete is 8-12% polymer and 88-92% aggregate by weight. The phase change material can be added directly as a partial aggregate substitute or confined in some other medium such as the foamed glass beads.

Two polymer systems were used for the polymer concrete samples. The first is a vinyl polyester pre-polymer copolymerized with styrene (PES-polyester styrene) marketed as LB-183-13. The system is typically initiated with MEKP (methyl ethyl ketone peroxide) and promoted with CoN (cobalt naphthenate). The second polymer system is 95% MMA (methyl methacrylate) crosslinked with 5% TMPTMA (trimethylolpropane trimethacrylate) and initiated with BPO (benzoyl peroxide) and promoted with DMA (dimethyl aniline) and DMT (dimethyl toluidene).

Control samples (see Figure 6) of polymer concrete were cast in parafin coated cylindrical cardboard molds of dimension 4-in. x 1-1/2 in. The samples contained 88% sand aggregate (16 mesh-44%, 30 mesh-22%, 100 mesh-22%) and 12% PES resin (LB 183-13). The MEKP initiator and cobalt naphthenate promoter comprised 1% and 1/2% of the resin weight respectively. Other controls using 12% MMA/TMPTMA (95/5) and 88%

sand aggregate were also cast and cured with 1% benzoyl peroxide initiator and 1/2% DMA and 1/2% DMT promoters. These controls cured rapidly to the desired high strength PC.

Samples were then cast using 10% granulated $\text{CaCl}_2 \cdot 6\text{H}_2\text{O}$ as a partial aggregate replacement. The samples turned green and failed to cure within two months.

Sodium thiosulfate pentahydrate can be encapsulated in large quantities. Samples with up to 88% $\text{Na}_2\text{S}_2\text{O}_3 \cdot 5\text{H}_2\text{O}$ (total aggregate replacement) have been prepared. The major problems are that the phase transition temperature is 45°C and that all these systems required a final encapsulation since the PCM at the sample surface is lost upon phase change (see Figure 7). Samples have been successfully brush-coated, dip-coated or recast (see Figure 8) with polymer systems to contain the PCM. Another method, which yielded excellent results, entailed lining pre-coated glass molds with fiberglass (4 ounce/yd²) and casting. The fiberglass prevents the PCM from contacting the surface. The high melting temperature of $\text{Na}_2\text{S}_2\text{O}_3 \cdot 5\text{H}_2\text{O}$ is an advantage for PC encapsulation since the gel point is reached before the phase transition temperature, thus fixing the PCM in the polymer matrix (see Figure 9). Two samples of fiberglass coated polymer concrete containing 60% and 40% $\text{Na}_2\text{S}_2\text{O}_3 \cdot 5\text{H}_2\text{O}$ are being thermally cycled between 0 and 65°C (over twenty times so far) with no apparent ill effects. Surface integrity has been maintained and there is no weight loss. However, sodium thiosulfate supercools and it has been necessary to go to low temperatures (10°C and lower) to effect

recrystallization. It is felt that any PCM melting over 40°C can be readily encapsulated in large quantities by the above method.

The problem of encapsulating a low melting PCM was next addressed. Decanoic acid (mp = 31.4°C) was selected since it forms even lower melting eutectics with myristic acid and palmitic acid. Since these systems are chemically similar, it was felt that if decanoic acid could be encapsulated the eutectics could also be successfully encapsulated. An apparatus was assembled for making pellets from the melted PCM and these pellets were blended in with the aggregate. Without fiberglass lining the molds, the results of Figure 10 were obtained. Fiberglass was then used again as a liner. In order to prevent melting and dissolution of the PCM in the MMA/TMPTMA in which it is quite soluble, all ingredients were chilled and low quantities of initiator and promoter were used. Nevertheless, a significant amount of the decanoic acid pellets dissolved in the monomer and, when the polymerization was complete, the PCM had run to the walls and the top of the sample in spite of the fiberglass. The experiment was repeated with high levels of initiator and promoter in order to minimize dissolution. Less PCM dissolved but more ran to the walls. The experiment was repeated using decanoic acid impregnated into the foamed glass beads to hold the PCM in place until gelation occurred. Again the PCM flowed to the sample exterior whether or not a fiberglass lining was employed (see Figures 11 and 12). The compositions of the various polymer concrete composites are given in Table 6.

Table 6
Composition of Polymer Concrete Systems

Figure	Binder	Initiator/Promoter	Sand Aggregate	Foamed Glass Beads	PCM	Comments
--	PES 12%	MEKP 1% CoN 1/2%	88%	0	0	Controls
6	MMA/TMPTMA (90/10) 15%	BPO 1% DMA 1/2% DMT 1/2%	85%	0	0	Controls
--	PES 12%	MEKP 1% CoN 1/2%	78%	0	CaCl ₂ ·6H ₂ O 10%	Samples required over two months to cure.
--	PES 12%	MEKP 1% CoN 1/2%	0	0	Na ₂ S ₂ O ₃ ·5H ₂ O 88%	Sample requires outside coating to retain PCM. No strength above transition temperature.
7	PES 12%	MEKP 1% CoN 1/2%	44%	0	Na ₂ S ₂ O ₃ ·5H ₂ O 44%	Sample requires outside coating to retain PCM.
--	MMA/TMPTMA (90/10) 12%	BPO 1% DMA 1/2% DMT 1/2%	0	0	Na ₂ S ₂ O ₃ ·5H ₂ O 88%	Sample requires outside coating. Not as good as PES system.
--	MMA/TMPTMA (95/5) 12%	BPO 2% DMA 1% DMT 1%	66%	0	Decanoic acid 22%	Large amount of catalyst used in attempt to avoid dissolution as above. PCM ran to walls of sample through the fiberglass.
8	MMA/TMPTMA (90/10) 12%	BPO 1-1/2% DMA 1%	44%	0	Na ₂ S ₂ O ₃ ·5H ₂ O 44%	Excellent samples made by recasting with PES to cover exterior.
9	MMA/TMPTMA (90/10) 15%	BPO 1% DMA 1%	22.5%	0	Na ₂ S ₂ O ₃ ·5H ₂ O 62.5%	Mold surfaces lined with fiberglass. Excellent, non-leaking samples resulted.
--	PES 11.3%	MEKP 1% CoN 1/2%	34.6%	24.2%	PEG 600 25.5%	Samples cured but require external coating.
--	PES 38.1%	MEKP 1% CoN 1/2%	0	38.9%	Decanoic acid 21.1%	Samples prepared by pouring resin over beads in large test tube. Cured, but require further coating.
--	MMA/TMPTMA (90/10) 33.5%	BPO 1% DMA 1/2%	0	41.8%	Decanoic acid 24.7%	Same as above.
10	MMA/TMPTMA (95/5)	BPO 1% DMA 1%	66%	0	Decanoic acid 22%	Decanoic acid added to mix as pellets. All ingredients chilled. Dissolution of large amount of PCM prior to cure.
11	MMA/TMPTMA (95/5)	BPO 1-1/2% DMA 1%	38.5%	26.9%	Decanoic acid 17.7%	Attempt to retain PCM in foamed glass bead until gelation. PCM ran to walls of sample through the fiberglass.

Notes:

- Abbreviations: PES - polyester/styrene 50/50 LB183-13
MMA/TMPTMA - methyl methacrylate/trimethylolpropane trimethacrylate
MEKP - methyl ethyl ketone peroxide
CoN - cobalt naphthenate
BPO - benzoyl peroxide
DMA - dimethylaniline
DMT - dimethyltoluidene

- Sand aggregate is proportioned 2:1:1, #16 mesh: #30 mesh #100 mesh.

- Percentages of initiators and promoters refer to polymer weights.

Samples were also prepared blending liquid PCM's with various polymer systems. Both inorganic and organic PCM's were used. All of these materials require from 25 to 50% polymer and must be further encapsulated. Some of them are rubber-like and all of them become greatly weakened above the phase transition temperature. We do not feel at this time that these materials offer the best prospects for potential building materials and work in this area has been curtailed. The systems that have been investigated are outlined in Table 7.

Task 3. Mechanical and Physical Properties Measurements

Work in this area has been delayed principally due to our primary emphasis on task 2 (producing good samples) and due also in part to equipment delays. We are still awaiting delivery on a refrigeration accessory for the DuPont 990 Thermal Analyzer which will allow efficient multiple cycling of phase change materials. Also on order is a refrigerated bath for thermal cycling of our composite samples. A calorimeter suitable for the determination of specific heats of solid samples is also being purchased.

Conclusions and Future Work

Satisfactory samples of polymer concrete incorporating relatively large amounts of phase change materials (up to 60% by weight) can be prepared with PCM's melting at 40°C and above. We intend to try to extend this method of preparation to samples incorporating PCM's with transition temperatures in the range of 20°C-30°C.

Satisfactory samples of ordinary concrete plus phase change material have yet to be made due to the interference of the PCM's with

Table 7

Composition of Systems of PCM/Polymer Blends

<u>Binder</u>	<u>Initiator/Promoter</u>	<u>PCM</u>	<u>Comments</u>
MMA/TMPTMA (95/5)	BPO 2% DMA 1%	Decanoic acid 50%	Sample cured and was coated with PES. Activity of PCM not yet established.
Derakane 50%	MEKP 1% CoN 1/2%	MEG 600 50%	Sample cured to hard solid. Requires further encapsulation.
PES 50%	BPO 1-1/2% DMA 1/2%	$\text{CaCl}_2 \cdot 6\text{H}_2\text{O}$ 50%	Sample cured to hard rubber- like mass. Requires further encapsulation.
PES 25%	BPO 1-1/2% DMA 1/2%	$\text{CaCl}_2 \cdot 6\text{H}_2\text{O}$ 75%	Sample did not cure. Soft, spongy mass with pockets of free PCM.
Corezyn 158-5 50%	MEKP 1% CoN 1/2% DMA 1/10%	$\text{CaCl}_2 \cdot 6\text{H}_2\text{O}$ 50%	Blended in waring blender. Then catalyzed. Cures to a soft, rubbery material.

the cement hydration reactions. It is clear that the PCM must be chemically isolated from the system during cure. A literature survey has been conducted on materials and methods of microencapsulation in order to devise systems which minimize interferences between PCM and cement or polymer. A major effort toward separate encapsulation of the PCM's, preferably as liquids, will be undertaken during the next quarter. Some of the proposed methods include encapsulation by interfacial polycondensation, complex conservation (NCR process), and starch and poly (vinyl alcohol) xanthates. The encapsulated PCM's would then be mixed with concrete, polymer-impregnated concrete, or polymer concrete depending upon compatibility.

Thermal characterization and strength measurements on composite systems utilizing $\text{Na}_2\text{S}_2\text{O}_3 \cdot 5\text{H}_2\text{O}$ PCM will be conducted to test the basic concept of PCM effectiveness while encapsulated and the integrity of the material after many thermal cycles. Composite strengths at temperatures above and below the phase transition point will also be determined.

We also anticipate that progress in the area of economic studies and energy savings calculations will be made during the next quarter. It is hoped that a model system (or systems) utilizing the potential materials from this program can be defined and economic calculations for a total system can be performed.

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Figure 1. Foamed glass beads. The beads have a porosity of roughly 40%.

Figure 2. Concrete samples with foamed glass bead aggregate.

Figure 3. Concrete using foamed glass beads impregnated with $\text{CaCl}_2 \cdot 6\text{H}_2\text{O}$.

Figure 4. Concrete with foamed glass beads impregnated with PEG (polyethylene glycol) 600.

Figure 5. Concrete with foamed glass beads impregnated with decanoic acid.

Figure 6. Polymer concrete samples using polyester-styrene polymer binder.

Figure 7. Polymer concrete with 44% $\text{Na}_2\text{S}_2\text{O}_3 \cdot 5\text{H}_2\text{O}$. Exterior is coated with resolidified PCM which has ready access to the surface.

Figure 8. Polymer concrete with 44% $\text{Na}_2\text{S}_2\text{O}_3 \cdot 5\text{H}_2\text{O}$. Polymer is MMA/TMPTMA. Outer surface recast with PFS LB183-13.

Figure 9. Polymer concrete with 62% $\text{Na}_2\text{S}_2\text{O}_3 \cdot 5\text{H}_2\text{O}$. PCM does not leach out.

Figure 10. Polymer concrete with 22% decanoic acid pellets.
No fiberglass was used to line mold.

Figure 11. Polymer concrete with foamed glass beads
impregnated with decanoic acid. Mold was not lined
with fiberglass.

Figure 12. Polymer concrete with foamed glass beads impregnated with decanoic acid. Mold was lined with fiberglass.