MASTER

DESIGN AND FABRICATION OF POLYMER-CONCRETE
PIPE FOR TESTING IN GEOTHERMAL-ENERGY PROCESSES

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ABSTRACT

Polymer concrete is a composite material which has strength and durability characteristics greatly superior to those of portland cement concrete and better durability in hot brine than steel. Polymer concrete has been successfully tested in brine, flashing brine, and steam at temperatures up to 260°C (500°F). Exposures were as long as 960 days. Glass-filament-wound polymer-concrete pipe was developed with excellent strength, low weight, and a cost comparable to or less than Schedule 40 steel. Connections can be made with slip joints for low-pressure applications and flanged joints for high-pressure applications.

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EXECUTIVE SUMMARY

Hot brine and other aerated geothermal fluids are highly corrosive materials and they chemically attack most conventional materials of construction. The feasibility of using polymer concrete composites as a material of construction for handling hot brine was demonstrated in 1972 in work sponsored by the Atomic Energy Commission and the Office of Saline Water⁽¹⁾, a research program to determine if the composites were applicable to geothermal systems was initiated in April 1974 at Brookhaven National Laboratory (BNL). When the Department of Energy, through BNL, was seeking a manufacturing company to design and fabricate polymer concrete pipe for testing in a geothermal environment, Lindsey Industries was invited to submit a proposal based on their experience with polymer concrete. Lindsey Industries was awarded the contract and began work in July 1979.

During the course of this contract, the polymer concrete formulations originally specified by BNL had to be modified in order to overcome problems of settling and shrinkage. The addition of more fine aggregates and a higher temperature cure achieved the desired results. However, problems in casting single large pipe sections as originally proposed in the contract could not be that easily overcome. Therefore, a glass filament wound polymer concrete pipe was developed using a modification of the BNL formulation. Using the filament winding process, pipes with excellent burst strength and crushing resistance were produced with both slip joints for low pressure applications and flanged joints for high pressure applications.

As a result of the work performed under this contract, eight filament wound polymer concrete pipe sections 25 cm (10 in.) i.d. x 12.5 mm (0.5 in.) wall thickness were produced in 1.5 m (5 ft) lengths, with cast polymer concrete flanges. Two 25 cm (10 in.) i.d. x 25 mm (1 in.) wall thickness 90° elbows were also produced. The pipe and elbows were successfully tested to 690 kPa (100 psi) at 120°C (250°F) and shipped to Imperial Magma Company, Calipatria, California for evaluation in the field.

In addition, 61 m (200 ft) of 5 cm (2 in.) i.d. filament wound polymer concrete pipe was produced with slip joints. It was produced in sections 1.5 m (5 ft) long and tested at 276 kPa (40 psi) with water at 100°C (212°F). Six 90° and four 45° cast polymer concrete elbows, 5 cm (2 in.) i.d. were also produced. The 5 cm (2 in.) pipe and elbows were shipped to a geothermal demonstration project in Marlin, Texas for evaluation.

Based upon assumptions of projected materials and manufacturing costs, the cost of large diameter filament wound polymer concrete pipe is much less than comparable steel pipe and will have a longer life in a geothermal environment.

I. INTRODUCTION

A serious problem in the development of geothermal energy is the availability of durable and economic materials of construction for handling hot brine and steam. Hot brine and other aerated geothermal fluids are highly corrosive materials and they chemically attack most conventional materials of construction. Corrosion and scale incrustations have been

encountered in all geothermal plants, and to various degrees adversely affected plant lifetimes and power output.

General guides to materials selection for oxygen-free geothermal systems have been published by Shannon⁽²⁾. At temperatures of 120°C (250°F) and pH 6, the use of expensive materials such as titanium, zirconium, and Hastalloy C was suggested.

At a temperature of 60°C (140°F) severe corrosion of carbon steel occurs in aerated geothermal fluids. The corrosion rate in aerated systems is reported to be 100 times greater than in oxygen-free geothermal fluids⁽³⁾. As a result, all condensate and cooling water piping at the Geysers is constructed of stainless steel or plastic-lined material. It is also necessary to coat all concrete surfaces that come in contact with water with coal-tar epoxy compounds or synthetic rubber⁽⁴⁾.

The corrosion rate of carbon steel is also highly dependent on the pH of the brine. At the predicted pH of 4.9 of oxygen-free Salton Sea brines and a temperature of 50°C (122°F), a service life of 15 years is estimated⁽²⁾. At a pH of 4, the estimated service life is two years.

Electrochemical attack due to high sulfate containing soils present in many parts of the western states may restrict the use of carbon steel pipe in the development of medium temperature geothermal reservoirs. Durable and low cost piping systems with minimum thermal losses are essential.

The feasibility of using polymer concrete composites as a material of construction for handling hot brine was demonstrated in 1972 in work sponsored by the Atomic Energy Commission and the Office of Saline Water⁽¹⁾.

The results from these tests indicated that the composites had long-term stability in seawater at 177°C (350°F) and in acid solutions. Based upon these results, a research program to determine if the composites were applicable to geothermal systems was initiated in April 1974 at Brookhaven National Laboratory (BNL).

Since that time, several high temperature polymer concrete systems have been formulated by BNL, and field tests performed in brine, flashing brine and steam at temperatures up to 260°C (500°F). An exposure time of up to two years in six geothermal environments indicates good durability. The results show the potential for the successful use of polymer concrete composites as lining materials for process piping and vessels in geothermal power systems and as durable low thermal conductivity piping for process heat and district heating applications⁽⁵⁾.

A summary of results of tests on polymer concrete developed by BNL is given in Table 1. Figure 1 shows the effect of pH 1 hydrochloric acid on BNL polymer concrete samples at 90°C (194°F). Figure 2 shows the effects of 150°C (302°F) brine on a sample of BNL polymer concrete pipe. Figure 3 is a view of two 25 cm (10 in.) i.d. filament wound polymer concrete pipes manufactured by Lindsey Industries.

A. Economics of Polymer Concrete Systems

Economic studies⁽⁶⁾ performed concurrently with this research program have identified several cost-effective uses for the materials in geothermal processes. Large cost reductions as a substitute for stainless steel, titanium and Hastalloy in acid-handling systems, condensate-piping systems,

TABLE 1
Polymer Concrete Testing

Monomer mixture, weight %	Test condition	Test location	Duration	Comments	Reference
55S-36A-9T	pH 1 HCL @ 200°C	BNL	170 days	No deterioration	1
50S-33A-17T	pH 1 HCL @ 200°C	BNL	170 days	No deterioration	1
60S-40T	pH 1 HCL @ 200°C	BNL	170 days	No deterioration	1
50S-33A-17T	25% brine @ 177°C	BNL	900 days	No deterioration	2
60S-40T	25% brine @ 177°C	BNL	900 days	No deterioration	2
55S-36A-9T	Dry steam @ 238°C	Geysers	540 days	No deterioration	2
50S-33A-17T	Dry steam @ 238°C	Geysers	540 days	No deterioration	2
55S-36A-9T	Brine @ 135°C	Raft River	18 months	No deterioration	3
60S-40T	Brine @ 160°C	East Mesa	500 days	No deterioration	3
55S-36A-9T	pH 1 HCL @ 90°C	BNL	2 years	No deterioration	3
60S-40T	pH 1 HCL @ 90°C	BNL	2 years	No deterioration	3
55S-36A-9T	400 ppm brine @ 150°C	BNL	490 days	No deterioration	1
50S-33A-17T	400 ppm brine @ 150°C	BNL	490 days	No deterioration	1

Notes: S = Styrene
A = Acrylonitrile
T = Trimethylolpropane trimethacrylate

The term no deterioration indicates that no visual evidence of deterioration or weight loss after the exposures were noted.

- References: 1. Alternate Materials of Construction for Geothermal Applications, Progress Report No. 15, October 1977, March 1978, BNL 50934.
2. Ibid No. 14, July - September 1977, BNL 50751
3. Ibid No. 18, January - March 1979, BNL 51036

Figure 1. Polymer concrete after exposure to pH 1
HCL at 90°C (194°F) for two years

No. 549, 55 wt% S - 36 wt% T - 9 wt% Hetron 197
No. 544, 55 wt% S - 36 wt% A - 9 wt% T
No. R-5, 80 wt% S - 12 wt% PPO - 8 wt% T
No. 434, 60 wt% S - 40 wt% T

Note: PPO = Polyphenylene oxide

Figure 2. Polymer concrete pipe after exposure to 400 ppm brine at 150°C (302°F) for 252 days. No deterioration is apparent.

Figure 3. Two 25 cm (10 in.) i.d. glass filament wound polymer concrete pipes with flanged joints

reinjection lines, and steam separators are indicated. Uses in cooling towers, district heating systems, and in the protection of concrete surfaces also appear cost-effective.

The Burns and Roe Industrial Services Company estimated the impact of the use of non-metallic materials of construction in direct utilization processes⁽⁶⁾. Two processes, sugar beet refining and barley malting, were evaluated. The results indicated that the substitution of a polymer concrete lining for the carbon steel corrosion allowance could reduce the cost of the brine system in a 9×10^6 kg/day (9.9×10^3 ton/day) beet refining plant by 27%. In a 1.4×10^6 l/yr (3.7×10^5 gal/yr) barley malting plant, the cost was reduced by 37%. Considerably larger reductions appeared feasible if prestressed polymer concrete vessels could be used⁽⁶⁾⁽⁷⁾.

B. Lindsey Industries' Proposal

Lindsey Industries began research on polymer concrete systems in 1977. That work involved development of several types of polymer concrete systems for use as electrical insulation⁽⁸⁾⁽⁹⁾⁽¹⁰⁾, sponsored by the Electric Power Research Institute. Through visits to BNL, Lindsey Industries' experience with polymer concrete became known to the BNL staff. Therefore, when DOE, through BNL, was seeking a manufacturing company to design and fabricate polymer concrete pipe for testing in geothermal energy processes, Lindsey Industries was invited to submit a proposal.

Lindsey Industries proposed to evaluate the effects of reinforcing the BNL prescribed polymer concrete mix with glass, Kevlar^(R) and steel fibers. The evaluation was to be made on the basis of the results of compression, splitting tensile, flexural and bursting strength measurements

done at room temperature and at 75, 100, 125 and 150°C (167, 212, 257, 302°F). The polymer concrete specimens were to be made by three processes, involving mixing, vibration and evacuation. Polyethylene, polypropylene, steel and aluminum mold materials were also to be evaluated during this phase of the work.

The second objective of the proposed work was to determine the best method of producing polymer concrete pipe joints. The suggested joint configurations were a flat flanged joint, a swivel joint and a threaded joint. Ethylene-propylene, neoprene, silicone and fluorocarbon gasketing materials were to be evaluated with the flat flanged joint.

The third objective of the proposal was to produce and test 25 cm (10 in.) i.d. x 1.5 m (5 ft) long pipe sections using the material and design information obtained from the work described above. Also proposed was the design and testing of 25 cm (10 in.) i.d., 90° elbows.

Lindsey Industries was awarded the contract and began work in July 1979. Several hundred fiber reinforced samples were made by the various methods and tested at elevated temperatures, when it was learned that the curing temperature being used was incorrect. Problems were also encountered in selecting a mold material that could be removed from the inside of a cured pipe. At that time a plant visit was made to a facility producing polyester-styrene pipe reinforced with glass fibers filament wound on a mandrel. It was proposed to BNL that the project emphasis be changed from molding polymer concrete pipe to glass filament winding. Permission was given by BNL and a prototype winding machine was built.

New technology was being developed and the time remaining on the contract allowed the development of only two types of joints, flat flanges and slip joints.

As the glass filament winding procedure was being developed, BNL asked that 61 m (200 ft) of 5 cm (2 in.) i.d. pipe also be produced. The final deliverables for the project were 61 m (200 ft) of 5 cm (2 in.) i.d. glass filament wound polymer concrete pipe with slip joints, eight 1.5 m (5 ft) sections of 25 cm (10 in.) i.d. polymer concrete filament wound pipe with flat flanges, and two 25 cm (10 in.) i.d. elbows with flat flanges, cast from polymer concrete.

A filament winding machine was built that included a rotating mandrel and a carriage for moving the stringing equipment and slurry supply. Glass cloth and coarse aggregates were applied by hand. The final, successful pipe design consisted of layers of glass roving and cloth, impregnated with polymer concrete slurry alternating with polymer concrete layers containing coarse aggregates. To produce a pipe, glass reinforced layers were alternated with polymer concrete layers until the desired thickness was achieved. The elbows and flanges were cast in polyethylene or silicone rubber molds using the preferred non-reinforced polymer concrete formulation.

II. EXPERIMENTAL AND RESULTS

Polymer concrete consists of an aggregate mixed with a monomer, which is subsequently polymerized in place. The techniques used for mixing and placement are similar to those used for portland cement concrete, and after curing a high strength material is produced. The most important process

variables are monomer and aggregate composition and the aggregate particle size distribution. Specimens can be produced with compressive strength of 207 MPa (30,000 psi). Full strength is attained immediately after the polymerization reaction is completed. Polymerization can be accomplished using polymerization initiators in conjunction with heat or at ambient temperature using initiators and promoters. Depending upon the temperature and the concentration of the promoter and initiator, the cure time can be varied from a few minutes to several hours.

Several polymer systems that can be used in high temperature polymer concrete formulations have been developed by BNL(11). For components designed to operate at 1200C (2500F), the monomer mixture consisted of 55 wt% styrene (S), 36 wt% acrylonitrile (ACN), and 9 wt% trimethylolpropane trimethacrylate (TMPTMA). An additional 1%, by weight, of total monomer concentration, of A-174 gamma-methacryloxypropyltrimethoxysilane as coupling agent was added, which produced good results. Curing of the monomer mixture for high temperature applications was accomplished during a two-step polymerization process. The first stage of polymerization was performed at ambient temperature by the use of benzoyl peroxide-98% (BPO-98) as an initiator and dimethyl aniline (DMA) as a promoter. The second stage involved the use of di-tertiary-butyl peroxide (DTBP) and subsequent heating at 2000C (3920F) for four hours. The batch and procedure given above was specified for this work by BNL.

The durability of polymer concrete to geothermal fluids is highly dependent upon the composition of the aggregates. Materials such as quartz, silica, flyash and portland cement have been investigated by BNL. Above

218°C (424°F), polymer concrete materials containing aggregate consisting of 70 wt% silica sand and 30 wt% Type 1 portland cement have given the best results and were specified for this work by BNL.

After the required amounts of initiators and promoters were dissolved in the monomer, the mixture was mixed conventionally with the sand-cement aggregate using explosion-proof equipment. It was then placed in forms which were coated with a silicone release agent. External vibration was used to compact the polymer concrete. Dependent upon the initiator and promoter concentrations, size of the batch, form mass, etc., curing can generally be controlled to occur in one to two hours. After removal from the form, the polymer concrete was subjected to additional heating to insure that the polymerization reaction was complete. This formulation is listed in Appendix A. A list of sources of chemicals and aggregates is given in Appendix B.

A. Aggregate Particle Size Distribution Modification

A recommended particle size distribution of the silica sand component was furnished by BNL. The sand purchased by Lindsey Industries, when mixed in the proper proportions, did not fit the data. The crystal silica purchased on the West Coast contained more fine particles than that specified by BNL. It was necessary to replace the crystal silica 30 mesh in the BNL recipe with a mixture of 30 wt% silica 20 mesh and 70 wt% silica 30 mesh. The screen analyses for all aggregates used in this project are given in Table 2.

Batches were made using the recommended BNL formulations, as modified above, containing 12 wt% monomers and 88 wt% aggregates. The mixes were

TABLE 2

Typical Screen Analyses for the Aggregates

U.S. Sieve No.*	Opening, mm	Crystal silica #12, % retained	Crystal silica #20, % retained	Crystal silica #30, % retained	Crystal silica #60, % retained	Crystal silica #90, % retained	Sil-co-sil** 290 % retained	15 Micron min-u-sil
8	2.360	1.5						
10	2.000	16.5						
12	1.700	38.0						
16	1.180	38.0	Trace					
20	0.850	5.0	3.0					
30	0.600	4.5	69.0	3.0				
40	0.425		22.0	37.0	Trace	Trace		
50	0.300		5.0	45.0	7.0	1.0		***
70	0.212			13.0	58.0	19.0	Trace	The average
100	0.150			1.5	25.0	40.0	0.2	particle size
140	0.106				7.5	25.0	1.2	distribution
200	0.075				1.5	11.0	6.0	is 4.0 micron
270	0.053				0.5	2.5	10.8	
325	0.045						10.4	
400	0.038							
PAN		1.0	1.0	0.5	0.5	1.5	71.4	

* U.S.A. Sieve series - ASTM specification E-11-70

** Trade name for Ottawa silica No. 290

*** Manufacturers data sheet - Appendix B

very fluid and poured well. However, upon vibrating in the mold for five minutes, the coarse particles tended to settle and liquid came to the surface. This resulted in uneven shrinkage and density in the vertical direction of the sample and cracking in the top, resin rich portion of the sample. Initial attempts to overcome this problem were made by simply reducing the monomer to aggregate ratio from 0.12 to 0.10 and to 0.08. The 10% monomer batch would not pour and some settling still occurred during vibration. A second approach tried was to add additional fine silica sand to the standard BNL recipe. A mixture of two parts of 400 mesh silica (Ottawa silica No. 290) and one part of 15 micron silica was made. A standard BNL formulation was made containing 12% of monomer. While still in the mixer, small amounts of the 2:1 ratio of fine sand were added until the mix had a thick, smooth, but still pourable consistency.

This mixture exhibited no separation or differential shrinkage when vibrated, but a small amount of liquid still came to the top of the sample. More work needs to be done in this area to produce a flowable batch with no settling or liquid separation. Table 3 and Figure 4 give the aggregate particle size distribution for the batch recommended by BNL and the batch modified by Lindsey Industries.

TABLE 3

Aggregate Particle Size Distribution

<u>Aggregate</u>	<u>BNL recommended batch, wt%</u>	<u>Modified batch, wt%</u>
Crystal 16	40.2	29.0
Crystal 20	----	4.3
Crystal 30	12.3	10.2
Crystal 90	17.5	14.5
Sil-co-sil 290	----	11.3
15 Micron min-u-sil	----	5.7
Type 1 cement	30.0	25.0

B. Reinforcing Fibers

Glass, Kevlar^(R) and steel fibers were chosen for reinforcement because of their high tensile strength values. Previous work with these fibers had shown that 12.5 mm (0.5 in.) long glass fibers and 6.3 mm (0.25 in.) long Kevlar^(R) fibers were the longest fibers of those types that could be successfully incorporated into a polymer concrete mix. Twenty-five mm (1 in.) long steel fibers were chosen because they were the shortest fibers available. Since the density of each of the fibers varies so greatly, it was decided to add a constant length of fiber rather than a constant weight or volume. A number of fibers was counted, weighed and the amount to be used determined. The result was that 0.25 wt% of the mix of glass fibers were used, 0.125 wt% of the mix of Kevlar^(R) fibers were used, and 3.0 wt% of the mix of steel fibers were used.

C. Processing Methods

The coarse aggregates and cement were weighed separately and mixed for 30 seconds in an Omni-Mixer⁽⁸⁾, starting slowly and gradually increasing to

Figure 4. Aggregate particle size distribution. I, BNL recommended batch; II, modified batch.

full speed. The monomers and silane (A-174) were weighed and mixed and divided into two parts. To one part was added the DTBP and BPO-98. To the other part was added DMA. It was then mixed with the first part. Two-thirds of the monomer mixture was added to the Omni-Mixer and mixed for 30 seconds, with the dry aggregates. The remaining monomer was added and mixed an additional 30 seconds. The fibers were added at that point and mixed for 30 seconds. The fine aggregates were added and mixed for 60 seconds.

The polymer concrete was placed into 7.6 cm (3 in.) diameter paper cups, 15 cm (6 in.) high. The filled cups were placed on a vibrating table and vibrated for five minutes. The molds remained at room temperature overnight and were heated to 149°C (300°F) for an additional four hours.

Upon removal from the molds, one-half of the 7.6 x 15 cm (3 x 6 in.) long cylinders were sawed so that their ends were flat and parallel. These specimens were used for compression testing (ASTM C-39). Samples for split tensile tests were used as they came from the mold 7.6 x 15 cm long (3 x 6 in.). Flexural test specimens were cast in 5 x 5 x 28 cm (2 x 2 x 11 in.) long bars and tested just as they came from the mold.

Tests at the elevated temperatures were done by heating the samples in an oven to 5°C (9°F) above the desired temperature. The samples were removed from the oven one at a time and tested as per test specifications ASTM C-39, Compression Strength of Molded Concrete Cylinders, C-496, Test for Splitting Tensile Strength of Cylindrical Concrete Specimens, and C-293, Test for Flexural Strength of Concrete, Using Simple Beam with Center Point Loading. These test methods were developed for cement concrete samples at room temperature. The rates of loading are so low that five to ten minutes

would be required for each test. The loading rates were, therefore, increased so that the sample would fail in approximately one minute. This was done so that the specimen would not cool off while being tested.

D. Mechanical Test Results

Several hundred polymer concrete cylinders and test bars were made and tested at several temperatures. Four samples were used for each test at each temperature. These mechanical strength results are plotted versus temperature for various reinforcement methods in Figures 5 - 7.

At ambient temperature, the mechanical strength values are higher than reported by BNL for this formulation of polymer concrete. The compression strength varied from 96.6 - 158.7 MPa (14,000 - 23,000 psi), the splitting tensile strength varied from 14.49 - 21.39 MPa (2,100 - 3,100 psi), and the flexural strength varied from 34.5 - 41.4 MPa (5,000 - 6,000 psi). It is believed that the increase in the mechanical strength can be attributed to the modification in the particle size distribution, which makes the batch more uniformly dense.

E. Effect of Elevated Temperature on Mechanical Strength

The splitting tensile strength of test cylinders, made as described, was approximately 20.7 MPa (3,000 psi) at room temperature. This is nearly double the value given for this formulation by BNL. However, the strength values decreased rapidly at temperatures higher than 75°C (167°F). At 100°C (212°F) the splitting tensile strengths are only 40% of their value at room temperature and at 150°C (302°F) the splitting tensile strength is only 20% of its initial value.

Figure 5. Compression strength of polymer concrete vs temperature

Figure 6. Splitting tensile strength of polymer concrete vs temperature

Figure 7. Flexural strength of polymer concrete vs temperature

The ambient temperature compressive strength was approximately 138 MPa (20,000 psi). It decreases to 50% of that value at 100°C (212°F) and 17.5% of the ambient strength at 150°C (302°F).

The flexural strength was approximately 37.95 MPa (5,500 psi) at ambient temperature, but decreases rapidly. At 75°C (167°F) it has only 75% of its original strength, at 100°C (212°F) it has 45%, and at 150°C (302°F) it has decreased to 22% of the strength measured at room temperature.

The samples emitted an odor of monomers at 125 - 150°C (257 - 302°F). They were also a little soft and could be scratched. In discussing these results with scientists at BNL, it was suggested that results of this kind are observed when 0.1 - 0.2% of the monomers fail to polymerize. This small amount of monomer has little effect on the mechanical properties at room temperature, but at elevated temperatures they act as a plasticizer, greatly reducing the strength of the sample.

It was learned that curing samples at 195°C (383°F) increased the mechanical strength of samples when tested at 150°C (302°F). When these samples broke they emitted an odor of ammonia, which is one of the decomposition products of acrylonitrile polymers. Using the higher temperature cure cycle, samples had compressive strengths as high as 55.2 MPa (8,000 psi) at 150°C (302°F), splitting tensile strengths of 6.9 MPa (1,000 psi) at 150°C (302°F), and flexural strengths of nearly 13.8 MPa (2,100 psi) at 150°C (302°F). The effect of temperature on the mechanical strength of samples cured at 195°C (383°F) are plotted in Figures 8 - 10.

Figure 8. Compression strength vs temperature after 195°C (383°F) cure. No reinforcement

Figure 9. Splitting tensile strength vs temperature after 195°C (383°F) cure. No reinforcement

Figure 10. Flexural strength vs temperature after 195°C (383°F) cure. No reinforcement

F. Effect of Fiber Reinforcement on Mechanical Strength

Fibers with high tensile strength were incorporated into the polymer concrete batch to increase its mechanical strength. The amount of improvement in strength was dependent on the strength of the fiber, how well the polymer was bonded to the fibers and how uniformly the fibers mixed into the polymer concrete. No improvement in compression strength was expected, as the fibers must be broken in tension to be effective.

The effect of the addition of glass fibers was almost completely negative for splitting tensile test samples. Some improvement was seen for the flexural test samples, but the results are not consistent. The data from these tests is given in Table 4.

TABLE 4

Effect of Glass Fiber Reinforcement on Mechanical Properties of Polymer Concrete at Elevated Temperature

<u>Temperature, °C</u>	<u>Compression strength, MPa</u>	<u>Splitting tensile strength, MPa</u>	<u>Flexural strength, MPa</u>
25	155	21	41
75	106	16	30
100	61	8	21
125	37	4	12
150	27	2	10

The effect of the addition of Kevlar^(R) fibers was completely negative. One reason for the poor results is that it is extremely difficult to mix the fine, fuzzy Kevlar^(R) fibers into the polymer concrete. Clumps of fibers are often found in broken, cured samples that were not visible in the monomer-aggregate mix. These clumps are not completely wetted by the

mix and, therefore, act as large volume voids. The data from these tests is given in Table 5.

TABLE 5
Effect of Kevlar^(R) Fiber Reinforcement on Mechanical
Properties of Polymer Concrete

<u>Temperature, °C</u>	<u>Compression strength, MPa</u>	<u>Splitting tensile strength, MPa</u>	<u>Flexural strength, MPa</u>
25	97	14	32
75	83	11	21
100	61	7	10
125	47	4	7
150	25	3	6

The effect of steel fibers on the mechanical properties of polymer concrete was also insignificant. The steel fibers were easily and uniformly mixed into the polymer concrete. However, the bond between the steel and the polymer was not strong. Steel fibers could be pulled from broken samples with pliers. The data from these tests is given in Table 6.

TABLE 6
Effect of Steel Fiber Reinforcement on Mechanical
Properties of Polymer Concrete

<u>Temperature, °C</u>	<u>Compression strength, MPa</u>	<u>Splitting tensile strength, MPa</u>	<u>Flexural strength, MPa</u>
25	137	20	39
75	106	16	24
100	76	10	19
125	61	6	12
150	23	4	10

In summary, the addition of short fibers into the mix was not effective because they could not be uniformly distributed within the mix. However, with the addition of more fine aggregates and a curing temperature of 195°C (383°F), good strengths were achieved at temperatures up to 150°C (302°F).

III. POLYMER CONCRETE PIPE DEVELOPMENT

A. Mold Materials

Aluminum, polyethylene and silicone rubber (Dow Corning Silastic-E) were evaluated for their effectiveness as mold materials. The criteria for evaluation were how easily the polymer concrete can be removed from the mold, how many parts can be made in the mold before its surface characteristics change, how easily the mold can be cleaned, and is a mold release required.

Aluminum, when smooth and polished, gives a clean shiny part. A mold release is required. The disadvantage of aluminum is that it can be easily scratched. Polymer concrete adheres to a scratched or rough surface and the aluminum soon loses its effectiveness as a mold.

Polyethylene produces parts as smooth and shiny as the mold. No mold release is required. Polyethylene is also easily scratched and roughened, and even though the polymer concrete does not wet the polyethylene, the parts come out as rough as the mold.

Silicone rubber produces parts that are very smooth, the mold needs almost no cleaning, and is not easily damaged by abrasion. However, the monomers, and especially the catalysts and promoter, slowly attack the rubber, leading eventually to its deterioration. Another disadvantage of

silicone is its high cost. For a production process the best method may be to line a steel or other metal mold with a thin skin of silicone rubber and replace it periodically as it deteriorates.

Mold material is not the only problem to overcome in casting polymer concrete pipe. To be cost effective, each section should be three to six meters (10 - 20 ft) long, the longer the better. Polymer concrete pipe between 20 - 25 mm (0.8 - 1 in.) wall thickness would be very difficult to cast in such lengths. Even if a method of casting such long pieces of pipe could be found, they would be very fragile. At the time that casting and mold problems were being addressed, a visit was made to a commercial polyester-styrene, glass fiber reinforced pipe manufacturing facility. Thin, strong lightweight pipe was being produced by filament winding a polyester-styrene impregnated glass fiber onto a rotating mandrel. The mandrels were 10 m (32.8 ft) long and the pipe could be as thin as 2 mm (0.078 in.) depending on the pipe diameter. It was felt that this method could be adapted to the BNL polymer concrete formulation to produce a lightweight glass filament reinforced polymer concrete pipe that would meet the corrosion, strength and cost requirements of this project. BNL agreed that the method was worth investigating and gave permission to proceed with the development.

B. Pipe Formulation for Filament Winding

Twenty percent of polystyrene dissolved in styrene was substituted in the BNL recipe for the styrene without any loss in strength. The benefit of adding polystyrene was that the shrinkage of the system during curing was reduced. This helps reduce the stresses on the pipe while it is on the

mandrel and also makes it easier to remove a pipe from the mandrel. Another benefit of using polystyrene is that the resultant polymer concrete slurry is thicker and no settling of aggregate particles occur. Other than the addition of polystyrene, the organic portion of the polymer concrete slurry mix was identical to that specified by BNL, as described earlier in this report.

The aggregate mix was modified a great deal to be used as a filament winding slurry. All of the coarse particles were removed as they would settle out and could not be carried by the glass roving, through the stringing apparatus, to the pipe. The aggregate slurry contained 33.3% cement, 33.3% 15 micron silica, and 33.3% 400 mesh silica. The optimum slurry contained 66% of the aggregate mix and 34% organic liquid components by weight. The formulation is listed in Appendix A.

The glass roving was "E" glass, treated with silane A-174, 905 m/kg (450 yd/lb), made by Reichhold Chemglass, Irwindale, California. The method used was to apply 30 strands/cm (75/in.) of pipe per layer. As the roving was wound, excess polymer concrete slurry was spread evenly over the surface with a fabric covered roller. Additional coarse aggregate was sprinkled onto the pipe at that time and rolled to give a thick polymer concrete layer. It was learned that leak-proof pipe could not be made without the polymer concrete layer. The aggregate consisted of 33.3% cement, 33.3% 60 mesh silica and 33.3% 90 mesh silica (see Appendix A).

The initial pipe samples, only 25 cm (10 in.) long, were made with glass fiber roving and slurry only. No force was needed to remove them from the mandrel because a collapsing mandrel was used (see Figure 11).

Figure 11. Split mandrel design

The pipe sections were tested by clamping them in place in a test fixture and pressurizing them until they failed. This same method of using only glass roving and slurry was used to make the first 5 cm (2 in.) i.d. pipe, 1.5 m (5 ft) long, on a rubber mandrel. The rubber mandrel stretched when pulled, reducing its diameter so that it was easily removed from the pipe. It was learned that this pipe was very weak in the axial direction. The pipe could not withstand any impact or cantilever loads.

Glass cloth was wound onto the pipe and wetted with slurry to increase the strength in the axial direction. The number of cloth layers required depends on the axial strength requirements and the weight of the cloth used. One-hundred seventy gram (6 oz) and 255 g (9 oz) cloths were evaluated. The former was preferred because it was easier to completely wet it with slurry and was less expensive. The width of the cloth used was dependent on the diameter of the pipe being made. The best results were achieved with cloth tape widths equal to the pipe diameter. However, when making 25 cm (10 in.) i.d. pipe, 15 cm (6 in.) wide cloth was used as this is the widest available in small quantities. The glass cloth was applied to the mandrel over the layer of polymer concrete made by adding coarse aggregate to the slurry on the pipe. In a production facility the cloth would be applied by machine.

The optimum method for the fabrication of filament wound polymer concrete pipe is as follows:

1. Apply mylar tape covered with petroleum jelly to the metal mandrel
2. Apply glass fiber roving 30 strands/cm (75/in.) and slurry to the mandrel

3. Apply coarse aggregate directly onto the mandrel, producing a thicker polymer concrete which is uniformly distributed with a fiber covered roller
4. Wind a layer of glass cloth, wetting it thoroughly with a slurry covered roller
5. Repeat steps 2 through 4
6. When the desired thickness is reached, finish the pipe by ending with step 2 and add additional coarse aggregate until the outer surface of the pipe appears dry
7. Cover the pipe with a vapor barrier to keep the monomers from evaporating before the polymer concrete cures. A schematic of a 12.5 mm (0.5 in.) wall thickness pipe cross-section is shown in Figure 12.

The pipe must cure for at least four hours, using this formulation (see Appendix A) before removing from the mandrel. The mandrel should also be cool before removing the pipe, or if it is still hot, the pipe must be at the same temperature. If the mandrel is hotter than the pipe, removal will be more difficult because of the relatively greater expansion of the mandrel. Removal of the pipe from the mandrel is done by holding the pipe in compression at one end and pulling the mandrel out of the pipe. A number of small holes were drilled into the 15 and 25 cm (6 and 10 in.) diameter mandrel and connected to a compressed air source. Before removing the pipe, compressed air was forced between the pipe and mandrel, breaking the pipe loose. A sketch of this mandrel is shown in Figure 13. A force of approximately 725 kPa (105 psi) of pipe of inner surface area was

Figure 12. Cross-section of filament wound pipe

Figure 13. Solid mandrel with air break

required to remove a 25 cm (10 in.) i.d. x 1.5 m (5 ft) long pipe from the mandrel.

The filament winding machine built for making laboratory sized samples 1.5 m (5 ft) maximum length is shown in Figure 14. A bucket of polymer concrete slurry was placed on a small platform driven in a horizontal direction by a threaded rod. The stringing equipment (see Figure 15) was strung with glass roving and placed in the slurry. The roving and slurry were, therefore, applied to the mandrel in a regular and controlled manner. The glass cloth was put on by hand but can be done with good reproducibility. The coarse aggregate was sprinkled on by hand but its thickness was quite reproducible because it was applied and rolled until the layer was dry.

The most important factor in winding pipe was the surface speed of the mandrel and not the rotational speed. However, the optimum surface speed was not directly proportional to the mandrel diameter. For example, the optimum rotational speed for making a 5 cm (2 in.) i.d. pipe was 210 rpm while the optimum rotational speed for making a 15 cm (6 in.) i.d. pipe was 125 rpm. The optimum speeds were determined empirically. The optimum speed for making a 25 cm (10 in.) i.d. pipe was 75 rpm. The "optimum" spinning rate is one that is slow enough to keep from throwing the polymer concrete slurry off of the pipe, yet fast enough so that the acrylonitrile does not evaporate before another pass of slurry covers the surface.

The initial string handling equipment had rubber covered wheels for controlling the tension of the glass strands (see Figure 15). This method did not work well as the stringing equipment moves in relation to the stationary balls of glass roving. This caused the angles of the glass

Figure 14. Filament winding Machine

Figure 15. Glass fiber stringing equipment with tensioning device

Figure 16. Simple glass fiber stringing equipment

strands relative to the wheel to continually change and resulted in the strands becoming entangled. The second stringing device (see Figure 16) was of a simple design which eliminated the tangling problem and was easier to clean. The tension of the glass roving was controlled by the mandrel rotational speed and the viscosity of the polymer concrete slurry. The tension required is that necessary to keep the glass roving straight.

The next generation of pipe winding equipment would have a mandrel that moves back and forth as well as rotates. This would enable the stringing equipment, glass cloth winding equipment, slurry supply and aggregate supply to remain stationary. With this arrangement, the glass roving, slurry and aggregate for each 3.75 mm (0.15 in.) thick layer could be applied with one pass on the mandrel. A sketch of this equipment is shown in Figure 17.

C. Elbows

An elbow mold core was made by filling a 20 cm (8 in.) sheet metal pipe with a flexible polyurethane foam. A 90° split steel elbow mold 25 cm (10 in.) i.d. was made in the shape of the polymer concrete elbow inner diameter. The 20 cm (8 in.) flexible polyurethane part was held in the center of the steel mold by two steel rods. The annulus between the steel and polyurethane was filled with Dow Corning Silastic E silicone rubber. When cured, the silicone rubber annulus becomes the inner mold.

A wooden 90° elbow mold was made in two parts with a 36 cm (14.4 in.) inner diameter and reinforced with steel. The 25 cm (10 in.) diameter annulus was wrapped with 2.5 cm (1 in.) of sponge rubber and mylar tape and held in place in the 36 cm (14.4 in.) space with two steel rods. The

Figure 17. Next generation of pipe winding equipment

annular space created was filled with Dow Corning Silastic E rubber and cured. An outer split mold was thus created with a silicone rubber liner. The 25 cm (10 in.) silicone rubber annulus was held in place by two steel rods and the resulting space cast with polymer concrete (see Appendix A for the formulation). A 2.5 cm (1 in.) wall thickness polymer concrete elbow was formed with an inside diameter of 25 cm (10 in.).

The first elbow was successfully cast using the mold described above. However, the inner mold core was destroyed when removing it from the mold. A rigid urethane foam core was made for casting the second elbow. The second elbow formed cracks due to the inflexibility of the urethane core. A third elbow was cast with a flexible urethane foam core. As before, the core was destroyed upon removal from the elbow. Two good elbows were thus produced but the method of producing inner mold cores is not completely satisfactory as a new core must be produced for each casting. Flanges were cast on each end of the elbows using the method and design described in the next section for filament wound pipe sections.

IV. PIPE JOINTS

A. Slip Joints

Slip joints were made on the 5 cm (2 in.) i.d. pipe as it was filament wound. The slip joint chosen was the bell and spigot type. A male form was slipped onto one end of the mandrel and the pipe wound over it producing the bell. The spigot was formed on the opposite end by grinding a taper so that it fit the bell. The dimensions of the bell and spigot are given in Figure 18. An elastomeric material or polymer concrete can be used to seal

Figure 18. Small slip joint design

the joint. The polymer concrete has to be formulated to withstand the temperature of brine and must have a zero curing shrinkage but requires very little strength. A polymer concrete with these properties was not developed as part of this project. A commercially available elastomer (Dow Corning 732 CL11) was used to seal a 5 cm (2 in.) i.d. pipe. This material is capable of withstanding 107°C (225°F) in aqueous solution indefinitely. This joint and sealing method was successfully tested at 276 kPa (40 psi) and 100°C (212°F).

B. Flanged Joints

Flanged joints were produced with similar dimensions as the steel flange specified for each diameter of steel pipe. Those dimensions are given in Figures 19 and 20. The flange was cast from polymer concrete with an 88% loading of the aggregate particle size distribution shown in Figure 4. The filament wound pipe was fully cured at 195°C (383°F) for four hours and cooled before casting the flanges on the ends. The end of the pipe was painted with the monomer mix before placement in the mold. The polymer concrete was mixed in an Omni-Mixer and was placed in the flange mold and vibrated.

After filling, the vibration was stopped and the polymer concrete cured overnight before the mold was removed.

After both flanges had been cast in place the whole pipe was again cured for four hours at 195°C (383°F) (see Figure 21). After cooling, steel plates were bolted on over 1 cm (0.4 in.) thick neoprene rubber gaskets. The assembly instructions are given in Appendix C. The pipes were filled with water, pressurized to 276 kPa (40 psi) with compressed air, and laid

Figure 19. Flange design for 15 cm (6 in.) i.d. pipe

Note: Dimensions in parentheses are for elbows only

Figure 20. Flange design for 25 cm (10 in.) i.d. pipe and elbow

Figure 21. Glass filament wound polymer concrete pipe.

Left, 15 cm (6 in.) i.d. pipe with small flanges

Middle, 15 cm (6 in.) i.d. pipe with slip joint
on the top and a large flange design on the bottom

Right, 25 cm (10 in.) i.d. pipe with flanges

in a horizontal position in an oven. The temperature was raised to 120°C (250°F) at which time the pressure was raised to 690 kPa (100 psi). If the pipe or flange did not leak, the pipe was deemed satisfactory for use in the field testing program.

The initial flange design had a smaller collar than shown in Figure 20. This flange cracked and blew off of the pipe when pressurized to 862.5 kPa (125 psi). The problem was solved by increasing the collar thickness to the dimensions shown in Figure 20, and taking greater care in assembling the pipe for test (see Appendix C). Pipes with the modified flange and proper assembly methods were tested to 690 kPa (100 psi) at 120°C (250°F) with no failures. The 90° elbows had flanges with slightly larger dimensions (as shown in parenthesis in Figure 20) because of the larger wall thickness of the cast elbows. Both elbows were tested at 690 kPa (100 psi) and 120°C (250°F) without failure.

V. TESTING OF PIPES, ELBOWS AND JOINTS

Several sizes of filament wound pipe were made for testing and evaluation by BNL and Lindsey Industries. Filament wound pipe with a 5 cm (2 in.) i.d. and a wall thickness of 9 mm (0.35 in.) was made for evaluation in a direct utilization project in Marlin, Texas. The test at Lindsey Industries consisted of putting each pipe between two rubber pads and loading it in compression so that it would not leak when pressurized to 690 kPa (100 psi). The pipes were filled with water and pressurized with compressed air to 690 kPa (100 psi). Approximately 25% of the first 30 samples had slow leaks in some places. These pipes were thoroughly dried

and built-up with another filament wound polymer concrete layer to a total thickness of 1.25 cm (0.5 in.). The remaining pipes were made with a wall thickness of 1.25 cm (0.5 in.). None of the thicker pipes leaked when tested as described above.

Fifteen centimeter (6 in.) i.d. filament wound pipe sections were made in several thicknesses for hydrostatic testing. They were cut into sections approximately 20 cm (8 in.) long with the ends sanded to remove any sharp edges. The hydrostatic test was done by placing the specimens between two steel plates with neoprene rubber gasketing and loading the ends to 172.5 MPa (25,000 psi). The pipe section was then filled with hydraulic fluid and pressurized. The hydraulic pressure gage used had a maximum capacity of 4.1 MPa (600 psi). Two pipe sections with a wall thickness of 7 mm (0.28 in.) were tested to 4.1 MPa (600 psi). One sample had two areas of 1 x 10 mm (0.04 x 0.4 in.) that had a small amount of "weeping", i.e., a few drops of hydraulic fluid appeared on the surface at that pressure. The second sample showed no indication of leaks. Two pipe sections approximately 11 mm (0.44 in.) wall thickness were tested in the same manner. No leaks were detected at pressures up to 4.5 MPa (660 psi).

There is some question as to the value of this test, as it was necessary to load the specimen so highly to keep leaks from occurring around the gasketed ends. In the field, buried pipe would also be constrained but not with so much force. However, no other means were available to hydrostatically test pipe sections 1.5 m (5 ft) or more in length.

After the hydrostatic tests were completed, the same pipe sections were broken in a crushing test. Two thin pipe sections (7 mm wall thickness)

(0.28 in.) and one thicker pipe (11 mm wall thickness) (0.44 in.) were crushed. All three pipes were approximately 20 cm (8 in.) long. The thin pipes could sustain a load of approximately 54 kg/cm (3,780 lb/ft) before cracking, while the thicker pipe could sustain a load of 100 kg/cm (6,996 lb/ft) before cracking. These values are of interest to users who will use shallow burial of pipe under roadways.

VI. COST AND WEIGHT OF 30 CM (12 IN.) I.D. GLASS FILAMENT WOUND POLYMER CONCRETE PIPE AND CAST ELBOWS

The cost of glass filament wound polymer concrete pipe and cast elbows, with flanges, is based upon the following raw materials costs; aggregates, \$0.26/kg (\$0.12/lb); organic materials, \$1.65/kg (\$0.75/lb); 255 g (9 oz) cloth 15 cm (6 in.) wide, \$0.25/m (\$0.08/ft) or \$5.30/kg (\$2.40/lb); glass roving 100 m/kg (149 ft/lb), \$1.75/kg (\$0.79/lb). A burdened labor charge of \$30/hr was used and a best estimate of labor required in a production process. The cost estimate is based on producing pipe in 6 m (20 ft) lengths with cast on flanges. Capital equipment costs, selling costs and profit would add an estimated \$38/m (\$11.60/ft) for 30 cm (12 in.) i.d. pipe, based on the assumptions given in Table 7. The cost of glass filament wound polymer concrete pipe and cast elbows is summarized in Table 8. The cost and weight of 30 cm (12 in.) i.d. polymer concrete pipe with flanges is compared to 30 cm (12 in.) i.d. steel pipe with flanges in Table 9. The cost of 30 cm (12 in.) i.d. filament wound polymer concrete pipe (\$74.41/m) (\$22.68/ft) is much less than steel pipe (\$112.00/m) (\$34.13/ft) and will have a longer life in hot corrosive fluids. The cost savings will

TABLE 7

Assumptions Used for Pipe and Elbow Cost Analysis

	Pipe	Elbows
Production quantity:	30,000 m/yr (6 m/section) plus 10,000 flanges	100/yr plus 200 flanges
Labor:	20 man min/m 100 man min/flange	180 man min/elbow 100 man min/flange
Capital equipment:	4 Mandrels	\$ 80,000
	1 Automatic winding machine	500,000
	1 Demolding machine	100,000
	1 Continuous mixer	150,000
	Ovens	100,000
	Safety equipment	60,000
	50 Flange molds	50,000
	2 Elbow molds	10,000
		<u>\$1,050,000</u>
Three year payback at 20% interest:	\$550,000/yr \$18.33/m	(\$5.58/ft)
Overhead (G & A, selling, engineering):	20%	
Profit:	20%	

TABLE 8

Cost Analysis for 30 cm (12 in.) i.d. Section

	<u>Pipe with flanges</u>	<u>Elbow with flanges</u>
Raw materials	\$21.80/m	\$ 61.00/elbow
Labor	<u>14.60/m</u>	<u>93.00/elbow</u>
Cost of goods sold	\$36.40/m	\$154.00/elbow
Overhead	\$ 7.28/m	\$ 30.80/elbow
Payback on capital equipment	<u>18.33/m</u>	<u>80.00/elbow</u>
	\$62.01/m	\$264.80/elbow
Profit	<u>12.40/m</u>	<u>52.90/elbow</u>
Total	\$74.41/m (\$22.68/ft)	\$317.70/elbow

TABLE 9

Cost and Weight Comparison for 30 cm (12 in.) i.d. Steel
and Polymer Concrete Pipe with Flanges

	<u>Schedule 40 steel</u>	<u>Polymer concrete 1.25 cm (0.5 in.) wall thickness</u>
Weight of 6 m (20 ft) long section with two flanges	395 kg	166 kg
Cost, f.o.b. factory	\$112.00/m (\$34.13/ft)	\$74.41/m (\$22.68/ft)

be even greater as the pipe diameter is increased. The polymer concrete pipe and elbows are more fragile than steel pipe and elbows so greater care will have to be taken during installation, which will add an undetermined amount to the installation cost.

VII. SAFETY

Acrylonitrile monomer is a carcinogen with an allowed exposure level of only 20 ppm over an eight hour period or 2 ppm for a short time (20 minutes). No acrylonitrile contact with the skin is allowed. If exposure does occur, the skin should be thoroughly washed immediately. Exposure levels of acrylonitrile are given in OSHA specifications (Section 1045, Part 1019 of Title 29 of the Code of Federal Regulations).

At Lindsey Industries procedures for the handling of all materials used are as outlined in material safety data sheets supplied by the manufacturers (see Material Suppliers List, Appendix B). The monomers were all weighed and mixed in a well exhausted restricted area. The workers doing the preparations wore lab coats, neoprene rubber gloves, 36 cm (14.4 in.) long, 0.75 mm (0.03 in.) thick, and an externally supplied air breathing apparatus (3M Model W-2806). The casting of polymer concrete test samples, filament wound pipe and flanges were done in well ventilated areas with the workers wearing the protective equipment already described.

In a production facility, the mixing of monomers would be done automatically in an enclosed area. Filament winding of pipe would be done in an enclosed area with exhausting through a refrigerated condenser unit which would keep monomers from the atmosphere and return them back to the process.

This unit would not only protect the persons near the production equipment, but would pay for itself by reclaiming monomers.

VIII. CONCLUSIONS

Polymer concrete is a composite material which has a high temperature strength and chemical durability greatly superior to those of portland cement concrete. It has better chemical durability and weighs less than one-third as much as steel (approximately 2.5 vs 7.6 g/cc). A special polymer concrete for use in hot geothermal fluids was developed by BNL. That material has been successfully tested in brine, flashing brine and steam at temperatures up to 260°C (500°F). Exposures were as long as 960 days.

Glass filament wound polymer concrete pipe was developed using a modification of the BNL formulation. The pipe can be produced relatively easily in lengths up to 6 m (20 ft). It has excellent burst strength and crushing resistance at a thickness of 1.25 cm (0.5 in.). Pipe connections can be made with slip joints for low pressure applications and flanged joints for high pressure applications. A 6 m (20 ft) long section of 30 cm (12 in.) i.d. polymer concrete pipe, with flanges, would weigh 166 kg (365 lb) and cost less than \$75/m (\$22.86/ft). A similar length Schedule 40 steel pipe, with flanges, would weigh 395 kg (869 lb) and cost almost \$112/m (\$34.13/ft). The polymer concrete pipe will have even greater cost savings in larger diameters and its resistance to hot corrosive fluids will also be greater than that of steel.

Sixty-one meters (200 ft) of 5 cm (2 in.) i.d. filament wound polymer concrete pipe was produced with bell and spigot slip joints. It was produced in sections 1.5 m (5 ft) long and tested at 276 kPa (40 psi) with water at 100°C (212°F). A silicone rubber (Dow Corning 732 CL11) was used to seal the joint. Six 90° and four 45° cast polymer concrete elbows, 5 cm (2 in.) i.d. were also produced. The 5 cm (2 in.) i.d. pipe and elbows were shipped to a geothermal demonstration project in Marlin, Texas for evaluation.

Eight filament wound polymer concrete pipe sections 25 cm (10 in.) i.d. x 1.25 cm (0.5 in.) wall thickness were produced in 1.5 m (5 ft) lengths, with cast polymer concrete flanges. Two 25 cm (10 in.) i.d. x 2.5 cm (1 in.) wall thickness elbows were also produced. The pipe and elbows were successfully tested to 690 kPa (100 psi) at 120°C (250°F) and shipped to Imperial Magma Company, Calipatria, California for evaluation in the field.

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APPENDIX A

Polymer Concrete Formulations Elbow and Flange Casts

Chemicals	wt%	Aggregates	wt%
20% polystyrene in styrene	55.0	Crystal Silica #12	32.2
Acrylonitrile monomer (ACN)	36.0	Crystal Silica #20	16.8
Trimethylolpropane trimethacrylate (TMPTMA)	9.0	Crystal Silica #90	16.8
	100.0		
Gamma-methacryloxypropyltrimethoxysilane (A-174)	1.0	Type 1 Cement (non-air entrained)	27.3
Benzoyl peroxide - 98% (BPO-98)	2.0	Sil-Co-Sil-290	4.6
Di-tertiary-butyl peroxide (DTBP)	0.5	15 Micron Mil-U-Sil	2.3
Dimethyl aniline (DMA)	1.0		

APPENDIX A (continued)

Polymer Concrete Formulations Filament Wound Pipe

Chemicals	wt%	Slurry Aggregates	wt%	Coarse Aggregates	wt%
20% polystyrene in styrene	55.0	Type 1 Cement	33.3	Type 1 Cement	33.3
Acrylonitrile monomer (ACN)	36.0	Sil-Co-Sil-290	33.3	Crystal Silica #60	33.3
Trimethylolpropane trimethacrylate (TMPTMA)	9.0	15 Micron Min-U-Sil	33.3	Crystal Silica #90	33.3
	100.0				
Gamma-methacryloxypropyltrimethoxysilane (A-174)	1.0				
Benzoyl peroxide - 98% (BPO-98)	2.0				
Di-tertiary-butyl peroxide (DTBP)	0.5				
Dimethyl aniline (DMA)	1.0				

APPENDIX B

List of Sources of Required Materials

Styrene monomer:

McKesson Chemical Company, City of Commerce, California

Polystyrene:

Mobil Chemical Company, Petrochemical Division, Paramus, New Jersey

Acrylonitrile monomer:

American Cyanamid Company, Organic Chemical Division, Los Angeles, California

Trimethylolpropane trimethacrylate monomer (TMPTMA):

Rohm and Haas Company, Los Angeles, California

Di-tertiary-butyl peroxide (DTBP):

Witco Chemical Corporation, U.S. Peroxygen Division, Richmond, California

Benzoyl peroxide - 98%:

Aztec Chemical Division, Dart Industries, Elyria, Ohio

Dimethyl aniline:

Ram Chemicals, Gardena, California

Silane (A-174) gamma-methacryloxypropyltrimethoxysilane:

Union Carbide Corporation, Long Beach, California

Type 1 Cement (non-air entrained):

Universal Atlas Cement, Division of U.S.S., Kansas City, Missouri

Crystal Silica - 12 Mesh, 20 Mesh, 60 Mesh, 90 Mesh:

Ottawa Silica Company, Oceanside, California

Sil-Co-Sil-290 (Silica Flour):

Ottawa Silica, Ottawa, Illinois

APPENDIX B (continued)

List of Sources of Required Materials

15 Micron Min-U-Sil:

Pennsylvania Glass Sand Corporation, Pittsburgh, Pennsylvania

Fiberglass Wind Filament (905 m/kg) (450 yds/lb) - roving:

Chemglass (Reichhold Chemicals, Inc.), Irwindale, California

255 g (9 oz) - 15 cm (6 in.) Wide Glass Tape:

Reichhold Chemglass, Huntington Beach, California

Silastic-E RTV Silicone Rubber:

Dow Corning Corporation, Midland, Michigan

APPENDIX C

Pipe Joint Assembly Detail

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Item no.		Number per joint
1	25 cm (10 in.) i.d. pipe	2
2	Neoprene flange gasket - 44.5 cm o.d. x 25 cm i.d. x 9.5 mm thick (17.5 x 10 x 0.375 in.)	1
3	Neoprene backing plate gaskets - 44.5 cm o.d. x 34 cm i.d. x 9.5 mm thick (17.5 x 13.5 x 0.375 in.)	2
4	Backing plates, 6.4 mm (0.25 in.) galvanized steel	2 sets (4 pieces)
5	Bolts - 1.25 cm (0.5 in.) diameter x 25 cm (8 in.) long	16
6	Flat washers	32
7	Nuts	16
8	Approximately 6 mm (0.25 in.) bead of vacuum grease on each flange	

APPENDIX C (continued)
Torqueing Sequence

Assembly Instructions

1. Clean pipe flange face.
2. Apply 6 mm (0.25 in.) bead of vacuum grease to each flange face approximately 2.5 cm (1 in.) out from i.d. of pipe.
3. Make one slit in each backing plate gasket and install on back side of flange.
4. Clean flange gasket.
5. Assemble joint running bolts through backing plates (refer to figure on previous page).
6. Torque bolts to 41 N-m (30 ft-lb) in three increments following sequence in the above figure. Go through sequence twice at 41 N-m (30 ft-lb) to compensate for set taken by gaskets.

CAUTION---testing has shown proper torqueing procedure to be essential if pipe flanges are not to be over stressed.

7. After pipe placed in use check all joints for leaks.
8. Bolt torque may be increased to 47 N-m (30 ft-lb) to seal any minor leaks. Do not exceed 54 N-m (40 ft-lb).