Static and Repeated Load Testing of Polymer Mortar Materials

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Four polymer mortar materials and one non-polymer cement grout were studied in static and repeated load compression tests. The materials included two epoxy mortars, one latex mortar, one acrylic mortar and a non-polymeric non-shrink cement grout. Static compression tests were run to determine compressive strength and modulus of the materials. Based on the static results, repeated load tests were run by placing a continuous sine wave loading on the specimen. The maximum load was selected as a percentage of the ultimate compressive strength. The number of load cycles to failure versus the maximum load percentage was recorded. Additionally, the stress range versus the number of load cycles to failure was plotted. The non-polymeric grout proved to have the most absolute fatigue resistance relative to its compressive strength. For the polymeric mortars, an exponential relationship between cycles to failure and loading percentage is suggested in the data analysis.

Polymer concrete and mortar materials have proved useful in several construction applications, including highway and transportation structures. Applications include using polymer mortar as an interface material between prefabricated components of modular structural construction *(1)*. The polymer mortar materials are especially attractive when high strength, rapid setting and low permeability properties are required. However, previous investigations have shown polymer mortar's strength to be sensitive to temperature and moisture conditions *(2, 3)*. Once engineers have sufficient confidence in the material's behavior, the full potential of the materials can be realized.

In many applications, such as bridges, the mortar becomes an integral part of the structure, and must transfer compressive shear and tensile loads and withstand the thermal and loading cycles to which bridges are subjected *(1)*.

This report includes experimental testing results of four polymer mortars under static and repeated-load compressive loading. A non-shrink cement grout material was also tested for comparative evaluation. The fatigue resistance of the material is plotted in two ways: first, as the number of loading cycles versus the percentage of the ultimate compressive strength, and second, as loading cycles versus the stress range of the repeated loading. The stress range is the difference between the maximum and the minimum stress on the specimen during the repeated load testing. The results are a part of an ongoing investigation of damage characteristics of polymer mortars.

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EXPERIMENTAL MATERIALS AND METHODS

Test Materials

The following five materials were subjected to static and repeated load compression testing:

1. Epoxy mortar: Designated E1, a three-component epoxy resin mortar consisting of two liquid components and one aggregate component, all supplied by the resin manufacturer. Mix ratios were computed following the manufacturer's recommendations.
2. Epoxy mortar: Designated E2, a three-component epoxy resin mortar consisting of two liquid resin components supplied by the manufacturer and graded silica sand conforming to ASTM C109 as an aggregate component. The two liquid components were mixed at a ratio of 2:1, A:B, by volume, and sand was added by a weight ratio of 3:1, sand to epoxy (A plus B).
3. Acrylic mortar: Designated A, a two-component acrylic mortar material with a nearly free-flowing viscosity. Both the liquid and the aggregate component were supplied by the acrylic manufacturer and mixed according to their specifications.
4. Latex-modified mortar: Designated L, a styrene-butadiene latex mixed with portland cement, silica sand, and water according to the following mix design:

   20.0 lb portland cement Type I
   20.0 lb graded silica sand (ASTM C109)
   6.25 lb latex
   1.00 lb water
   Water/cement ratio = 0.22

5. Non-shrink grout: Designated G, a two-component non-shrink cement grout consisting of manufacturer-supplied grout mix and water. Mix ratios were according to grout manufacturer's recommendations.

Additional properties of the resins as provided by respective manufacturers are given in Table 1.

Mixing was completed in the laboratory using a bench-top mixer capable of mixing at 75 rpm with 3 planetary rotations per revolution. Mix times were either following manufacturer specifications or 2 minutes/batch after all components were added. Specimens were 3-in. diam., 6-in.-high cylinders. The epoxy E1, latex, and grout mortars were cast in plastic molds, with a steel stub at the mold base. The epoxy E2 and the acrylic mortar were cast in cardboard cylinder molds. All molds and

TABLE 1 ADDITIONAL INFORMATION ON RESIN COMPONENTS PROVIDED BY MANUFACTURERS

Material Component	Viscosity (poise)	Tensile Strength (psi)	Flexural Strength (rupture) (psi)
Epoxy E1			
A	7.0		
B	0.6		
A + B	7.4	3,000	5,820
Epoxy E2[a]			
A + B	0.9		
Acrylic			
A	0.5		
B	Powder		
A + B		1,600	4,500
Latex	No additional information available, mortar properties will vary with mix design		
Grout	No additional information available		

[a]Meets ASTM C-881, Type I, Grade I, Class C.

the steel stubs were greased with high-vacuum silicone grease before use. Some rodding, approximately 20 tamps at each ½ level during casting, was completed to reduce air bubbles. Epoxy E2 showed some bleeding during cure. Only a minor amount of plastic shrinkage was observed during cure for all materials.

Epoxies E1 and E2 were placed in an oven for 24-hr at 100°F for additional curing after the initial 24-hr curing period. The grout and latex specimens were cured during the initial 24-hr period in a moisture closet. All specimens were stored at room-temperature conditions until testing. The age of the specimens at test time varied between 7 and 14 days. Specimens were capped before testing.

Testing Method

All testing was completed on an MTS closed-loop servohydraulic testing machine with a 220-kip load capacity. Static tests were run at 0.05 in./min stroke-controlled loading rate. Concurrent plots were made with an x-y plotter that allowed the determination of the compressive modulus of elasticity as well as ultimate compressive strength of the materials.

Repeated loading was accomplished by generating a force-controlled sine wave loading on the specimen. The maximum load was selected as a percentage of the ultimate compressive strength. The minimum load was selected as approximately 10 percent of the maximum-load percentage. Therefore, the minimum was typically slightly above 0 kips compression, which prevented bouncing of the specimen. A failure criterion of ⅜-in. specimen deflection proved satisfactory to ensure specimen failure. The ⅜-in. specimen deflection was measured by the loading piston's linear variable displacement transducer (LVDT) equipped with an automatic limit detector. Since the test was force controlled, as the specimen began to fail, the piston had to compress the specimen an additional amount to maintain the maximum preset load. The number of load cycles required to fail the specimen was automatically totalled. The sine wave loading was selected as 8 Hz, or 8 full load cycles per second. This frequency proved satisfactory to complete testing in a reasonable period of time. Three specimens at each static and repeated load were tested to obtain average values.

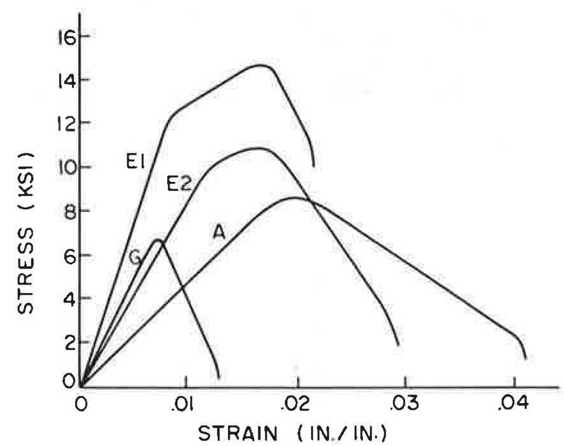
STATIC TEST RESULTS

Static compression tests were performed on three specimens of each polymer and the grout material. The ultimate compressive strength (ksi) and the compressive modulus (ksi) are shown in Table 2. The epoxy E1 was the most brittle material to be tested, showing no cracking beyond the ultimate compressive strength and then sudden explosive failure similar to typical high-strength concrete cylinder behavior. The epoxy E2, latex, acrylic, and grout each had a near-constant load-displacement curve slope, both at pre- and at post-ultimate strength. Typical curves are shown in Figure 1. In all cases, very little cracking appeared on the surface before ultimate compressive load was achieved.

TABLE 2 STATIC COMPRESSION TEST RESULTS

Material	Density (lb/ft^3)	Ultimate Strength (ksi avg)	Elastic Modulus (ksi avg)
A	125	4,.1	540
E1	133	15.4	1,400
E2	118	11.1	960
G	138	6.0	1,200
L	122	5.7	570

NOTE: All tests are an average of three, 3-in.-diameter specimens. A = acrylic, E1 = epoxy, E2 = epoxy, G = non-shrink grout, L = latex. Load rate 0.05 in./min.



Note: Load rate 0.05 in./min.

FIGURE 1 Stress-strain curve for static compression test.

Failure planes for all materials except E1 were usually near 45° shear planes. Some specimens exhibited cone failure, which suggests both good homogeneity of the material and failure occurring on the planes of maximum shear in a uniaxial loading test. The epoxy (E1) material failure pattern was typically less defined because of the explosive nature of the failure, although there were some indications of failure in shear planes.

REPEATED LOAD TEST RESULTS

Repeated loadings at 8 Hz were performed on two or three specimens of each material at one particular predetermined loading level. All materials were first tested at 40 percent of the ultimate compressive strength as the maximum and approximately 4 percent of the compressive strength as the minimum load; therefore, the stress range varied for each material. A second and third group (set of three specimens) of tests were run at 30 percent, 35 percent, 45 percent, 50 percent, 60 percent, or 70 percent compressive strength as the maximum load, depending on the results at the 40 percent load level. A summary of the repeated load test results is shown in Table 3.

Fatigue data results are often reported by plotting *S-N* curves where the number of load cycles to failure *(N)* is plotted versus the stress range *(S)*. The *S-N* curves for the polymer mortars are plotted in Figure 2.

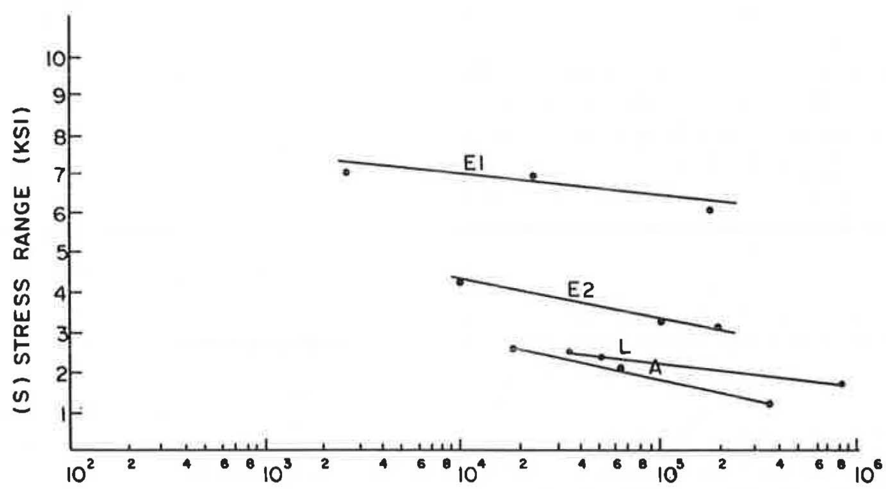
The maximum loading for the repeated load tests was selected based on a pre-selected percentage of the specimen's ultimate compressive strength *(P)*. The value of *P* versus the cycles to failure are plotted on the *P-N* curves in Figure 3.

Both the *P-N* and the *S-N* curves show an exponential decay relationship for the polymer mortar materials. The data is plotted on a semi-log scale, which results in a near-linear plot for each individual mortar material. The relationships take the form

TABLE 3 REPEATED LOAD COMPRESSION TEST RESULTS: 8-HZ SINE WAVE LOADING

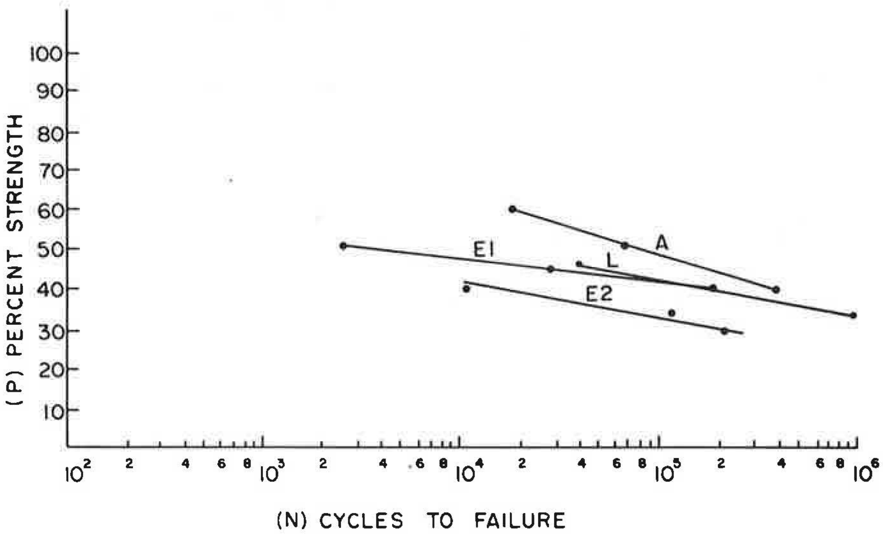
Material	Strength (ksi)	Peak Load (% of strength)	Peak (ksi)	Span (ksi)	Mean (ksi)	Cycles Avg	Cycles Standard Deviation
A	4.1	40	1.7	1.4	1.0	333,600	182,000
A	4.1	50	2.1	1.9	1.2	60,300	23,700
A	4.1	60	2.5	2.2	1.4	18,700	1,200
E1	15.4	40	6.3	5.7	3.5	183,300	14,800
E1	15.4	45	7.2	6.7	3.9	24,200	12,900
E1	15.4	50	7.7	6.8	4.3	2,500	1,200
E2	11.1	30	3.2	2.7	1.8	192,500[a]	67.500
E2	11.1	35	3,8	3.0	2.3	105,600	75,000
E2	11.1	40	4.7	4.2	2.5	10,400	3,700
G	6.9	40	2.9	2.7	1.5	>650,000	–
G	6.9	50	3.5	3.1	2.0	>650,000	–
G[b]	8.0	60	4.7	4.1	2.7	>650,000	–
G[b]	8.0	70	5.7	5.1	3.1	8,900	1,000
L	5.7	40	2.3	2.0	1.2	>650,000	–
L	5.7	45	2.6	2.3	1.5	50,000	2,500
L	5.,7	50	2.9	2.6	1.6	36,000	1,200

NOTE: All data are an average of three 3-in.-diameter specimens. Span = stress range.
[a]One specimen withstood >650,000 load cycles and did not fail. The result for this specimen is not averaged in for repeated cycles.
[b]Grout tests at 60 and 70 percent peak load were conducted using a separate batch from that used for all other testing.



Note: Grout material not shown, see Table 3.

FIGURE 2 Load cycles to failure versus stress range for polymer mortars: 8-Hz sine wave repeated load test.



Note: Grout material not shown, see Table 3.

FIGURE 3 Load cycles to failure versus peak load as a percentage of ultimate compressive strength: 8-Hz sine wave repeated load test.

$N = A \exp(-k_s S)$

and

$N = B \exp(-k_p P)$

where

N	=	number of cycles to failure
S	=	stress range
P	=	maximum stress as a percentage of ultimate compressive strength
$-k_s$	=	slope of $\ln(N)$ versus S curve
$-k_p$	=	slope of $\ln(N)$ versus P curve
A,B	=	constant determined by intercept of curve with the respective ordinate axis.

It is assumed that constants A,B, k_s, and k_p are both material and specimen geometry dependent and can be determined experimentally. The data show a range of k_s and k_p values that does not vary significantly among materials for the tests performed.

The grout material shows no failure at loadings up to 60 percent of the ultimate compressive strength. At 70 percent, the number of cycles to failure is <10,000 suggesting the grout has a critical loading stress for durability in a repeated load test at 8 Hz.

Both Figures 2 and 3 show that the fatigue strength of the material decreased monotonically with an increase in stress range or an increase in maximum stress percentage. Also it should be noted that all polymeric materials failed in a relatively small number of load cycles at maximum loadings well below their compressive strength.

Failure modes for the repeated load test were similar for all materials except the acrylic. The acrylic failed by uniform bulging at the center of the specimen transverse to the load direction until surface cracks appeared indicating a ductile material failure pattern. The other materials experienced through-thickness cracks, or severe local cracking. Failure was typically accompanied by audible explosive crack propagation. Failure planes were localized in several specimens but were predominately at 45° to the load direction, suggesting that planes of maximum shear were the primary planes of crack propagation.

Finally, when comparing the static and repeated load fatigue data, there is no obvious relationship between the modulus or static strength of the material and the fatigue resistance.

CONCLUSIONS

Repeated load testing of four polymer mortar materials shows that all are susceptible to failure in relatively few cycles at loadings below 60 percent of their compressive strength as the maximum load, and the percentage is as low as 40 for some materials. The non-polymeric grout tested did not fail in 650,000 cycles at 60 percent of its ultimate compressive strength as the maximum load, but it failed quickly when tested at 70 percent of its ultimate compressive strength.

A relationship between cycles to failure and stress range or maximum stress as a percentage of ultimate compressive strength for polymeric materials is shown to be an exponential decay relationship.

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