Fatigue and Freeze-Thaw Resistance of Epoxy Mortar

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ABSTRACT

Results of tests to investigate resistance of epoxy mortar to fatigue and freeze-thaw exposure are reported. Fatigue resistance is evaluated by number of load reversals sustained against a repeated impactive loading at different temperature levels within the range of 0 to 150°F. The results indicate that fatigue resistance decays exponentially with increasing temperature. Freeze-thaw resistance is evaluated as it is affected by the presence of moisture in fine aggregates. The results indicate that basic material strength and stiffness as well as freeze-thaw resistance of epoxy mortar diminish markedly because of the presence of even a small amount of moisture.

High-strength, fast-setting epoxy mortar is used as an interface material between prefabricated components of modular structural construction. In transportation engineering, for example, epoxy mortar has been used in several full-depth bridge deck construction and rehabilitation projects. Figure 1 shows a typical application. In such a construction method, a series of precast concrete slabs are laid on the top of steel or precast concrete stringers, and the mortar is used in at least three different interface locations, namely, at the interface of stringer and deck slab as bedding material, at the joint between two adjacent slabs, and in the shear pockets containing the mechanical shear connectors. It should be pointed out that mortars using portland cement or acrylic polymers as binders have also been applied in similar modular construction systems. In any case, the mortar becomes an integral part of the structure and fully participates in all load transfer functions. The short-term and long-term performance of the structure depend on the integrity of the mortar connections, which in effect become the links of the structural system.

Short-term static strengths of epoxy mortar are known to be higher than those of usual portland cement concrete. Severe repeated loading and freeze-thaw exposure are two critical damaging factors for structural material. The knowledge of degradation resistance of epoxy mortar is important for the consideration of the durability of the material and of the structure.

MIX DESIGN

Preliminary experimentation indicated that mortars of trowelable to flowable consistency are produced with sand-to-epoxy weight ratios in the range of 3.5:1 to 2.5:1. The workability of wet mortar depends on the gradation and characteristics of sand and on the formulation of the epoxy compound used. A constant mix design was used for the fatigue and freeze-thaw tests reported here. Graded natural silica sand meeting ASTM C 778 (Standard Specification for Sand) was selected. In accordance with ASTM C 881-78 (Standard Specification for Epoxy-Resin-Base Bonding Systems for Concrete), a Type III, Grade 1, Class C epoxy compound was selected. This is a low-viscosity epoxy, specified for use as a binder in epoxy mortars or epoxy concrete at temperatures above 60°F. The components A and B were mixed at ratios of 3.33 to 1.0 by weight, as specified by the manufacturer. The sand and the epoxy binder were mixed at a ratio of 3:1 by weight. Bench and laboratory mixers with simultaneous rotary and planetary motion were used. A relatively slow speed of 75 rpm with three planetary rotations per revolution was used to avoid formation of excessive air bubbles. The mixing was done for a total period of 1.5 min per batch. The workability of the mix allowed convenient casting of the specimens. Some bleeding and plastic shrinkage were observed. Mild rodding was necessary to eliminate air bubbles from the specimen as much as possible.

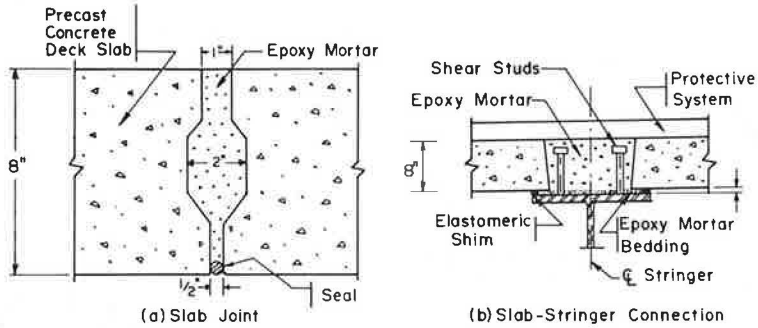

FIGURE 1 Typical application of epoxy mortar in modular bridge deck construction.

The mix design and the yield were controlled by using the physical data of the components as given in Table 1. The average compressive strength of the resulting material was 2,260 psi at room temperature, based on static tests on solid cylindrical specimens 2 in. in diameter x 4 in. long. It may be noted that this strength is somewhat lower than that of conventional portland cement concrete. This means that the use of ASTM C881 alone is not sufficient to guarantee the achievement of certain mortar strength.

TABLE 1 Physical Properties of Mortar Components

Component	Weight (g)	Volume (cm^3)	Computed Density (g/cm^3)
Graded sand	3700	2230	1.66
Component A	948	900	1.05
Component B	285	300	0.95
Epoxy mortar mix	4933	≈2460	≈2.005

FATIGUE RESISTANCE

Specimen Configuration

Figure 2 shows the specimen configuration for fatigue testing. A 1/2-in. layer of epoxy mortar was sandwiched between two plastic cylinders cut from 2-in. diameter cast acrylic rods. The overall size of the solid cylindrical specimens was 2 x 4 in. The specimen configuration was designed to simulate the use of epoxy mortar as an interface layer of moderate thickness between prefabricated or precast concrete modules. The faces of the acrylic cylinders were grooved to provide improved mechanical bond and to prevent excessive lateral deformation of epoxy mortar under axial load.

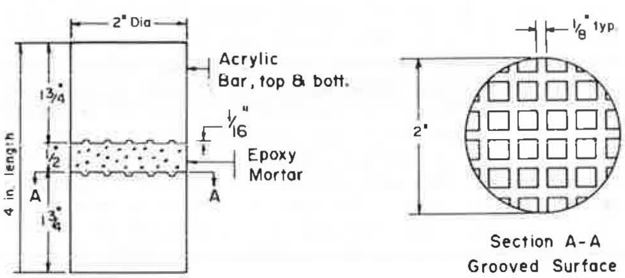

FIGURE 2 Sandwich cylinder specimen for fatigue testing.

Temperature Variable

Although epoxy resin is a thermosetting polymer and degradation of mechanical properties should be expected at a high temperature, say, about 350°F, the mechanical properties of epoxy mortar are reported to degrade at moderately elevated temperatures (1, pp.210-215). Results of static compressive strength tests on the sandwich specimens, as shown in Figure 3, confirm such reported variation of the properties of epoxy mortar with changes in temperature. In reference to Figure 3, the following points may be noted:

1. The average compressive strength of the epoxy mortar at room temperature (70°F) is 7,240 psi, on the basis of static tests on sandwich specimens. This is about three times higher than the value based on tests of bulk epoxy mortar cylinder specimens.
2. A precipitous drop of compressive strength at elevated temperatures was observed. Such a drop is characteristic of polymer resin and it is expected at a high temperature, but in the case of the subject mortar it occurred at about 80°F, which is not an unlikely temperature for bridge decks or other constructed facilities.

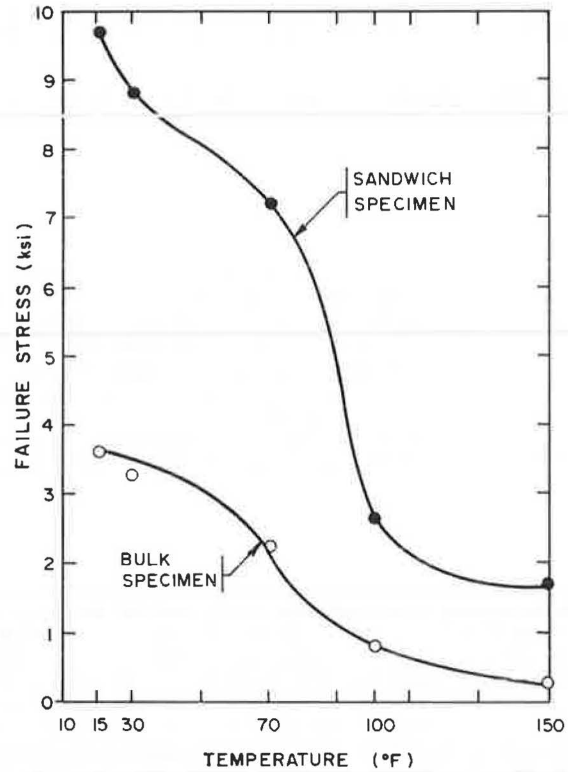

FIGURE 3 Static compressive strength of epoxy mortar at different temperature levels.

It is also evident that the mortar strength continued to rise with lowering of temperature. In fact, at 0 and 30°F, the epoxy mortar became so strong that frequently the acrylic cylinders failed before reaching the static failure load of the mortar. Because the strength of the usual epoxy mortar is expected to be higher than that reported here and because of the poor bond between the epoxy mortar and the acrylic cylinders, the use of acrylic cylinders is not recommended for such tests.

In any case, because of the observed and reported variation of the static strength of epoxy mortar with the variation of temperature, it was decided that fatigue resistance of the epoxy mortar material would be investigated at various temperature levels. Specific temperature levels of 0, 30, 65, 100, and 150°F were selected.

Time-Dependent Loading

The time-dependent loading used is shown in Figure 4. This is an invert haver-square waveform, a heavily punishing loading condition, representing an extreme situation of repeated impactive loading on a transportation structure. The valley load of (-) 7.0 kips represents a maximum compressive stress of 2,230 psi, which is about one-third of the static compres-

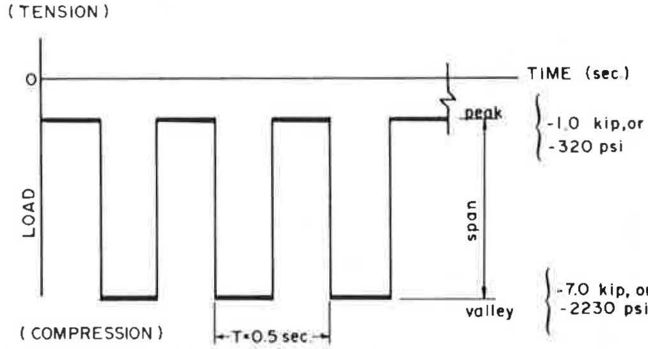

FIGURE 4 Typical haver-square waveform of repeated impactive fatigue loading.

sive strength of the sandwich specimen at room temperature. To avoid any separation of the specimen from the loading device, a peak load of (-) 1.0 kip was maintained. This was equivalent to a normal minimum compressive stress of about 5 percent of the compressive strength of the specimen at room temperature. In order to accommodate pronounced strength degradation at elevated temperatures, valley and peak loads of (-) 3.5 kips and (-) 0.5 kip, respectively, were also used. A frequency of 2 Hz (i.e., four load reversals per second) was used at all temperature levels.

Test Results

The summary of the test data is given in Figure 5, showing fatigue resistance as a number of load reversals sustained as a function of temperature level

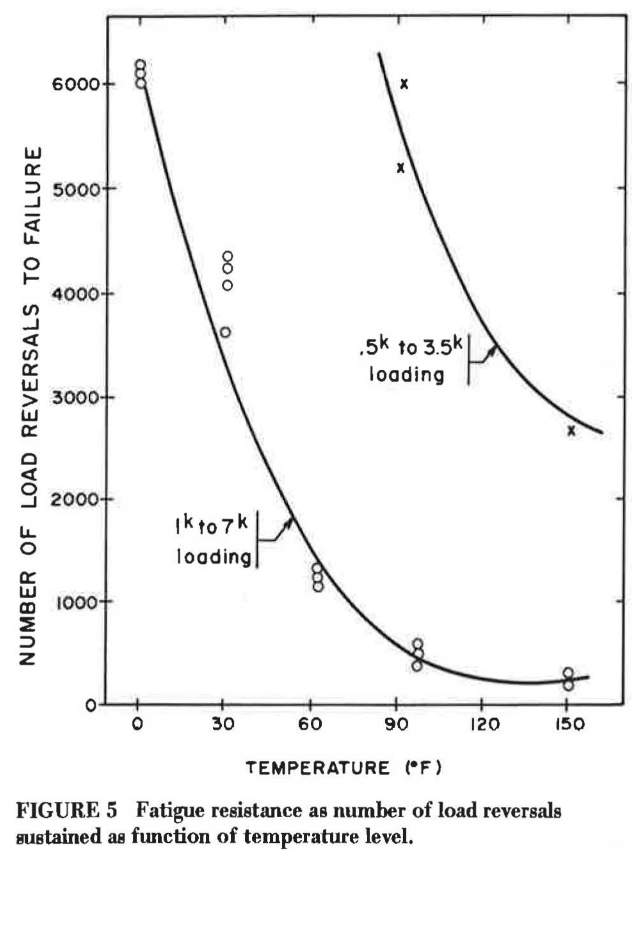

FIGURE 5 Fatigue resistance as number of load reversals sustained as function of temperature level.

plotted on linear scales. Because an exponential decay of strength was observed, the data were plotted on semilog scale, as shown in Figure 6. A nearly linear plot on this scale suggests a possible relation in the form of

$$N = A\exp(-kt) \quad (1)$$

where

N = number of load reversals sustained,
t = specimen temperature, and
(-k) = slope of $\ell n(N)$ versus t curve, which in this case was about -0.2.

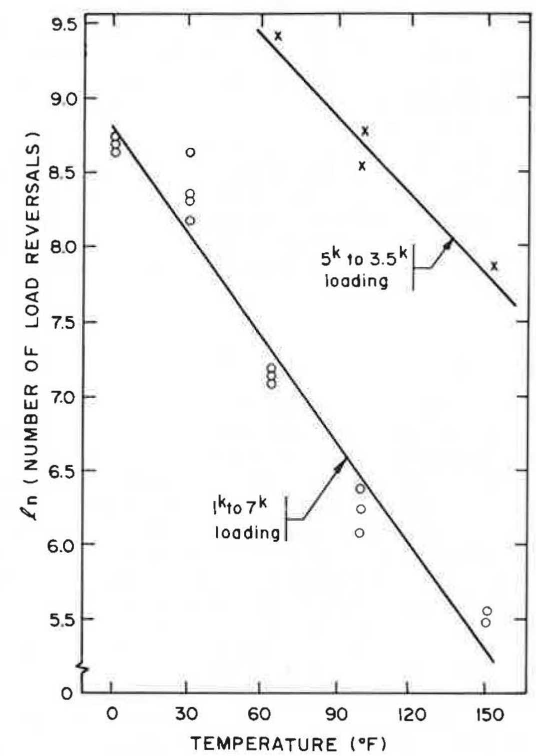

FIGURE 6 Logarithm of number of load reversals versus temperature level.

It appears that k represents a material fatigue property, and A, the intercept of the curve with the ordinate, would be a function of loading characteristics for a given material. It is evident, as expected, that for a given temperature, the number of load reversals sustained increases with the lowering of the magnitude of the maximum compressive load.

FREEZE-THAW RESISTANCE

It is generally claimed that epoxy mortar is unaffected by freeze-thaw exposure. Degradation of epoxy mortar due to freeze-thaw exposure, however, has been reported and discussed on occasion (2). Considering that water is the primary reason of freeze-thaw degradation in portland cement concrete, it may be suspected that incidental or inadvertent presence of water may also be the cause of possible freeze-thaw degradation of epoxy mortar. With this in mind, freeze-thaw experiments were designed to evaluate the effect of the presence of varying amounts of water in the sand, the fine aggregate of the epoxy mortar.

Test Procedures

Freeze-thaw experiments were conducted generally in keeping with ASTM C 666-80 (Standard Test Method for Resistance of Concrete to Rapid Freezing and Thawing), Procedure A, and ASTM C 215-60 (Standard Test Method for Fundamental Transverse, Longitudinal, and Torsional Frequencies of Concrete Specimens).

The mortar mix design was the same as that described earlier, except that the measured amount of sand for a specific batch was premixed with a certain amount of added water. The amounts of water added were 0, 1, 2, 3, and 5 percent by weight of sand, respectively, for five different test batches. Typical specimen size was 3 x 4 x 16 in. The tests were conducted by using a freeze-thaw cabinet with a capacity of 18 specimens laid in a horizontal position. A temperature range of 0 to 40°F, cycling at approximately 4 hr (i.e., 2 hr of freezing and 2 hr of thawing) was used. Physical properties were measured initially and after the completion of 60 and 120 cycles. Three different physical properties were measured, namely, static modulus of elasticity, dynamic modulus of elasticity, and modulus of rupture.

Test Results

The static modulus of elasticity was evaluated by measuring midspan deflections due to transverse loads. The initial (i.e., before freeze-thaw cycling) average value of static E as a function of moisture content is shown in Figure 7. Substantial reduction in material stiffness with even small increments of water content was evident. Because freeze-thaw degradation is characterized by a relative reduction in material stiffness, relative values of static E as a function of number of freeze-thaw cycles are shown in Figure 8. It is evident from typical values corresponding to 1 and 2 percent moisture content that freeze-thaw degradation occurs at an increasing rate with increasing moisture content. Degradation is substantial after 60 freeze-thaw cycles, and measurement could not be practically taken for samples at 120 cycles because of extreme reduction of material stiffness.

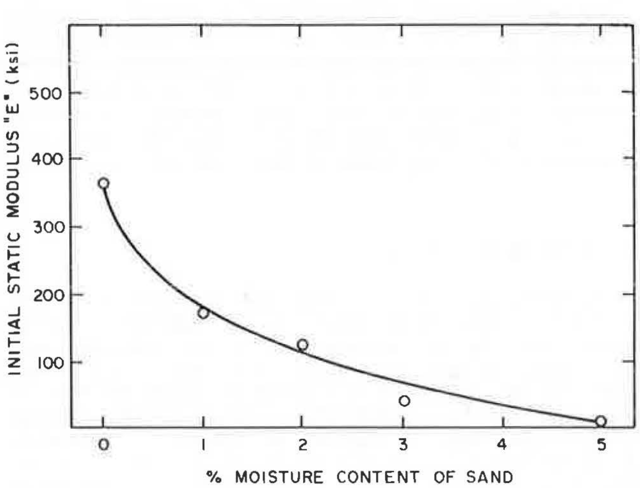

FIGURE 7 Reduction of initial static E with increasing moisture content.

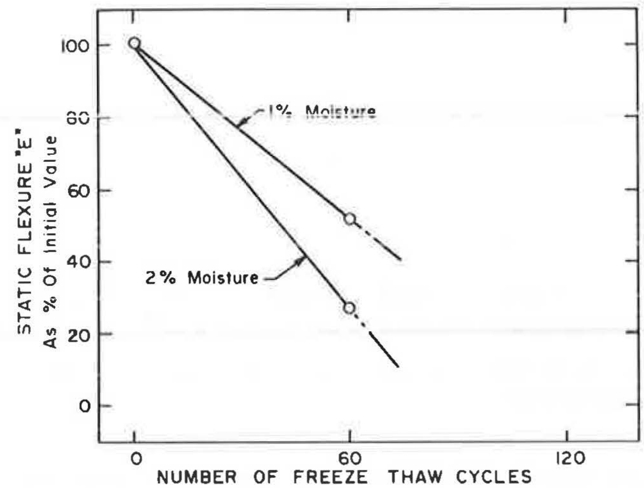

FIGURE 8 Reduction of relative value of static E with number of freeze-thaw cycles.

The dynamic modulus of elasticity was evaluated by measuring fundamental transverse frequency with instruments conventionally used for taking such measurements for portland cement concrete specimens. Relative values of dynamic E as a function of the number of freeze-thaw cycles are shown in Figure 9

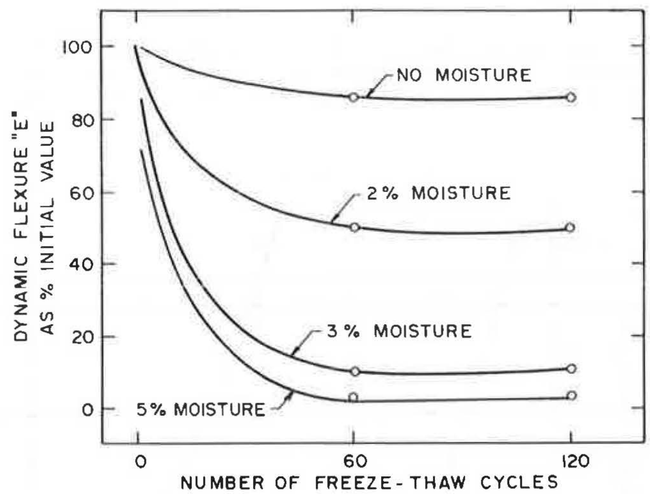

FIGURE 9 Reduction of relative values of dynamic E with number of freeze-thaw cycles.

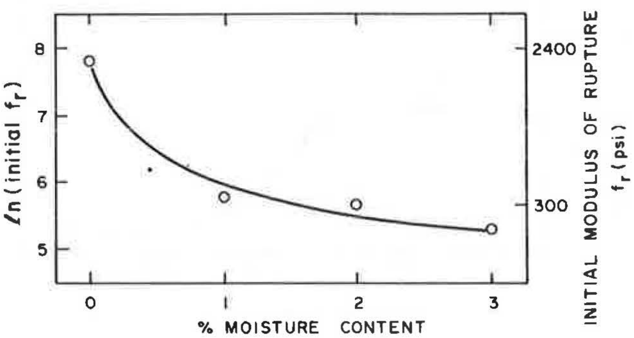

FIGURE 10 Initial modulus of rupture as function of moisture content.

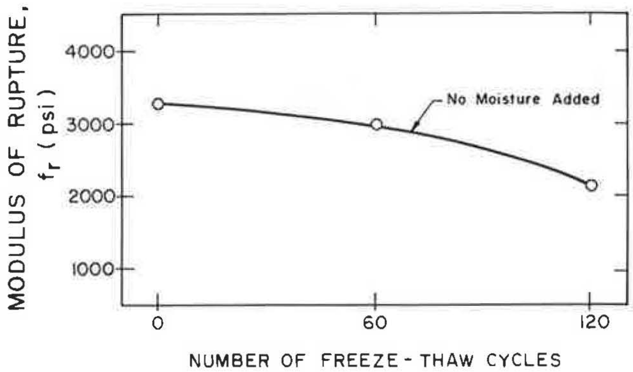

FIGURE 11 Degradation of modulus of rupture with increasing number of freeze-thaw cycles.

for varying moisture content. Increasing freeze-thaw degradation with increasing moisture content and substantial degradation after 60 cycles were evident. Small degradation due to freeze-thaw exposure was evident even for specimens with no added water.

Because the specimens remained intact after the conclusion of tests for static and dynamic E, the same specimens were utilized to obtain modulus of rupture (f_r), which was evaluated by failing the specimens in flexure. Even before any freeze-thaw cycling, the reduction in f_r is precipitous because of a small increment in added moisture. Initial f_r as a function of moisture content, plotted on a semilog scale, is shown in Figure 10. Even for specimens with no added water, degradation of f_r with increasing number of freeze-thaw cycles was evident, as shown in Figure 11.

CONCLUSIONS

Epoxy mortar is susceptible to fatigue damage due to repeated impactive loading. Within the range of 0 to 150°F, fatigue resistance degrades significantly with increasing temperature and improves with decreasing temperature.

All mechanical properties of epoxy mortar degrades significantly because of even a small amount of water added to the fine aggregate.

Epoxy mortar may be susceptible to freeze-thaw damage. Freeze-thaw resistance degrades significantly because of even a small amount of water added to the fine aggregate.

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