An Investigation of Physical Properties of an Epoxy Bonding Compound for Composite Beam Bridge Construction

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This paper presents information on the basic properties of an epoxy resin bonding compound which is being studied for use as a structural connection for highway construction, including composite beam bridges. Several important physical properties of this resin have been determined, such as the tensile, compressive, shear, flexural fatigue, and torsional fatigue strength of the resin as a plastic, and also its modulus of elasticity and coefficient of expansion. Additional tests on the resin as an adhesive included the single shear strength and tensile strength between steel and concrete, effect of freeze-thaw cycling, effect of concrete curing on adhesive bond, consistency of adhesive, strength development of adhesive, storage life of adhesive, working life of liquid adhesive, and other related properties.

The results show that an epoxy resin formulation satisfying the strength demands of a composite beam bridge can be achieved, subject to the restrictions imposed by the testing program. However, further studies of performance and characteristics are necessary before the selected epoxy resin formulation can be approved for use as a connector; such as creep, fatigue on glued joints, impact, strength gain under various temperature conditions, and durability.

•THE WIDESPREAD industrial and commercial applications of epoxy bonding compounds have demonstrated that these materials are extremely durable and possess such properties as hardness and an ability for adhering to metal and other materials. Although these same properties would appear to qualify epoxy resins as a means of effecting structural connections, this field of application has remained relatively unexplored. The subject of this report is concerned with the investigation of physical properties of an epoxy resin bonding compound for use as a connection device for highway construction, including composite beam bridges. The work was performed at Rensselaer Polytechnic Institute for the Bureau of Physical Research, Department of Public Works, State of New York, in cooperation with the U.S. Department of Commerce, Bureau of Public Roads.

Because a large number of compounds can be formulated using the epoxy resins in combination with different catalysts, curing agents, fillers, flexibilizers, etc., the first problem was the selection of a suitable formulation for detailed study. This was accomplished by requesting recommendations in consultation with representatives of several producers of epoxy resins. With the recommended formulations as a starting point, a series of physical tests was conducted to classify the various formulations on a comparative basis, and also as a means for revising the formulations to serve the intended applications best. Several basic tests were conducted.

Paper sponsored by Materials and Construction Department and Committee on Bridges.

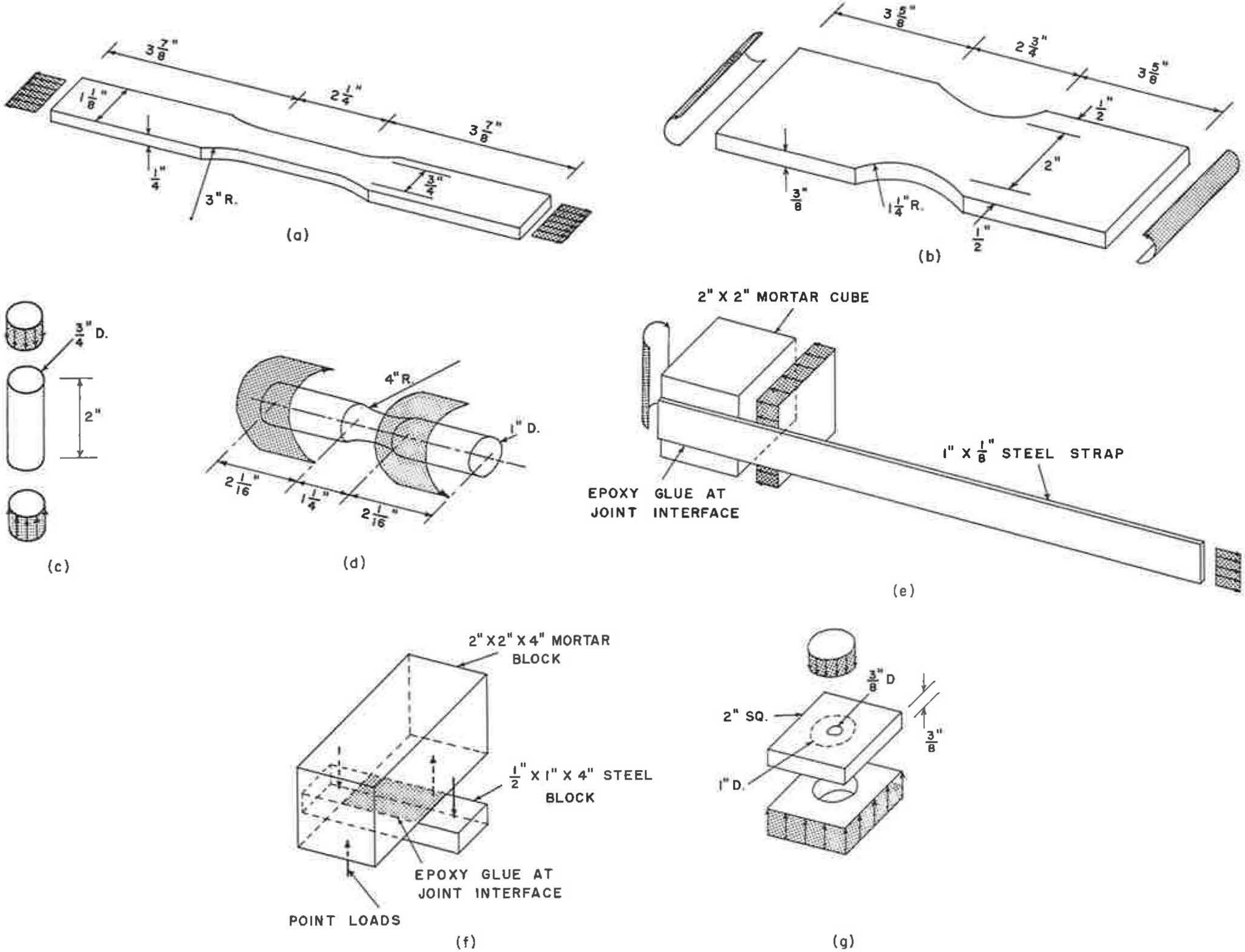
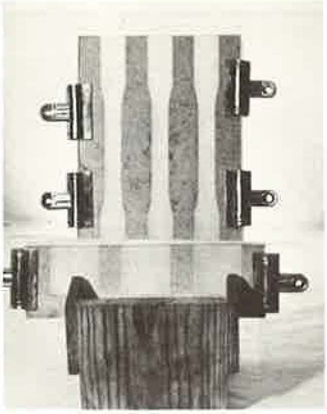


Figure 1. Specimen dimensions: (a) tension, (b) bending fatigue, (c) compression, (d) torsion fatigue, (e) single shear adhesion, (f) tension adhesion, (g) shear.



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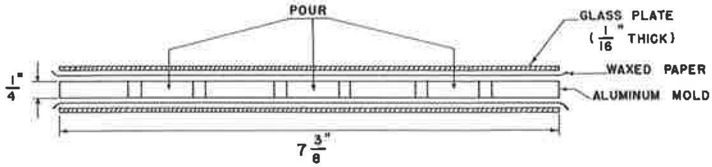

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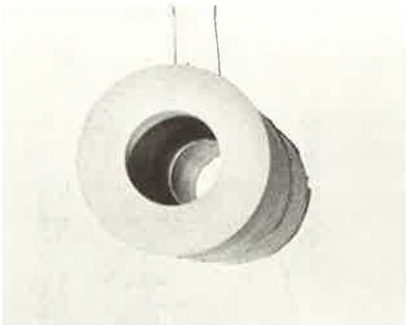

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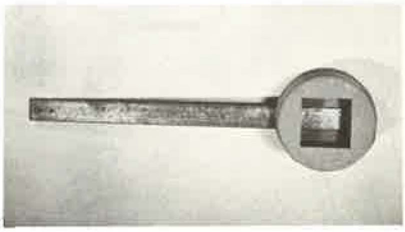

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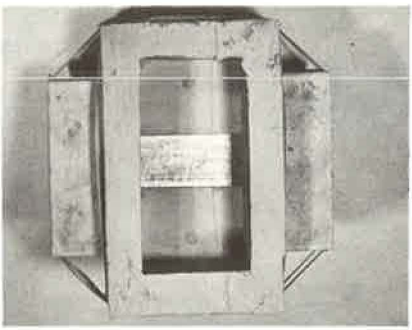


(e)

Figure 2. Mold types for casting specimens: (a) molds for tension and shear plastic specimens, (b) open-end view of tension specimen mold assembly, (c) silicone rubber mold for torsion specimen, (d) steel strap inserted in silicone rubber mold before casting single shear adhesion specimen, (e) steel bar inserted in silicone rubber mold before casting tension adhesion specimen.

TEST SPECIMENS

Figure 1 shows seven types of test specimens, their dimensions, and the manner of loading. The method of testing was similar in detail to the 1961 Standards of the American Society for Testing Materials, as identified in Table 1, but were modified or extended whenever necessary or convenient to do so (1). These tests were essentially intended to provide a means of classifying the various compounds, as well as to serve as a basis for control and comparison with other research results.

The tension, bending fatigue, and shear specimens were cast in aluminum molds which were coated with a thin film of silicone rubber; the silicone rubber acted as a release agent for the epoxy resin (Fig. 2a). Each mold was prepared by sandwiching the sheet of aluminum (with a cut-out the shape of the specimen) between two sheets of glass. On assembly of the mold, the inside surfaces of the glass were lined with heavy waxed paper to prevent the epoxy sticking to the glass. After the poured epoxy specimen had cured for approximately 24 hr, the molds were disassembled and the specimens were removed and placed in conditioning according to the schedule shown in Table 1. Table 1 gives the combinations of conditioning times and conditioning temperatures studied.

The compression and torsion fatigue specimens were cast in silicone rubber molds (Fig. 2c). Before testing, the ends of the compression specimen were machined square with the specimen axis.

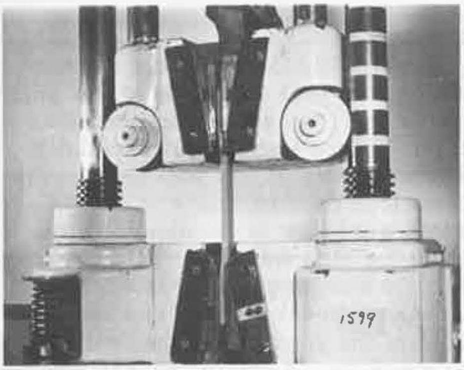
To simulate the single shear condition in adhesive bond which would exist in a composite beam, mortar blocks glued to steel straps were tested in single shear. These specimens were cast in silicone rubber molds (Fig. 2d). Each mold consisted of two pieces which could be disassembled, one of which previously had been sandblasted. After the steel strap was inserted into the mold, the surface was coated with a thin layer of epoxy using a small paint brush. The thickness of the layer was approximately 0.015 in. The two pieces of the mold were held together by means of rubber bands. A 2-in. mortar cube was then cast on top of the epoxy in three layers, each of which was densified by tamping with fingers. The top of the mortar cube was struck off even with the top of the mold, and a sheet of waxed paper and a sheet of glass placed on top to prevent evaporation of the mortar moisture.

TABLE 1

CONDITIONING SCHEDULE FOR SEVEN TYPES OF TEST SPECIMENS

Test	Equivalent ASTM	Conditioning Time of[a]				Conditioning Temperature of				
		3 Days	7 Days	21 Days	90 Days	-40 F	20 F	77 F	120 F	180 F
Tension	D 638-60T	x	x	x	x	x	x	x	x	x
Flexural fatigue	D 671-51T		x					x		
Compression	D 695-54	x	x	x	x	x	x	x	x	x
Shear	D 732-46	x	x	x	x	x	x	x	x	x
Torsional fatigue	D 671-51T			x				x		
Single shear adhesion[b]	---	x	x	x	x	x	x	x	x	x
Tension adhesion[b]	C 321-57	x	x	x	x[c]	x	x	x	x	x

[a]Add two days at room temperature: one before conditioning, one after conditioning.
[b]Cured three days in water at room temperature before conditioning.
[c]90-day tests not conducted for -40 and 20 F.



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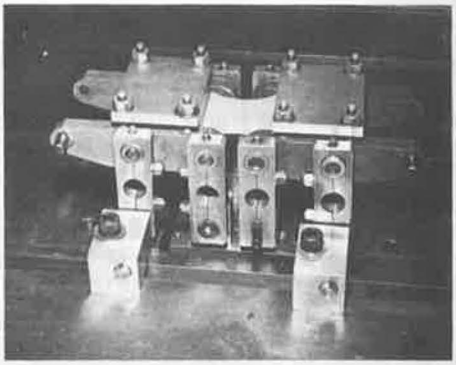

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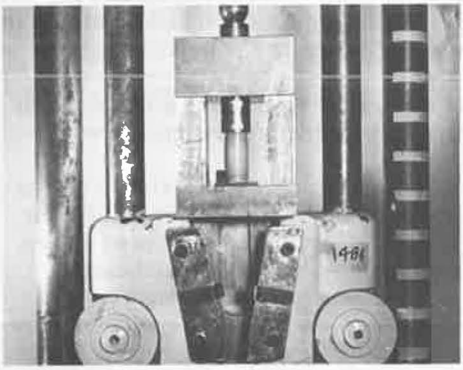

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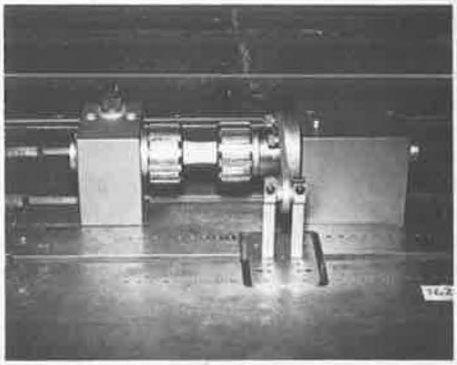

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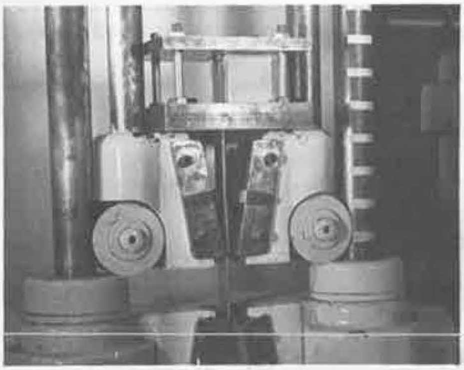

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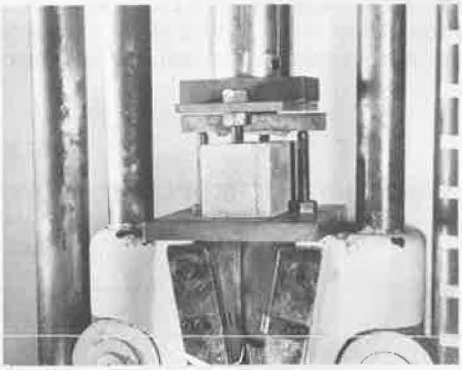

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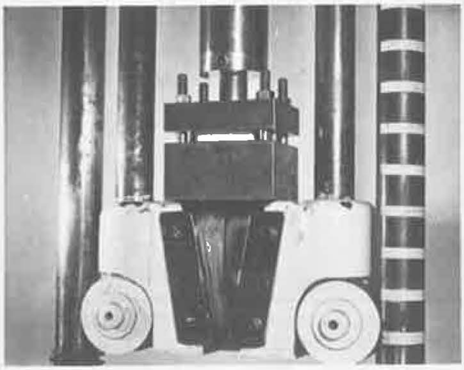


(g)

Figure 3. Specimens in testing machines: (a) tension test, (b) bending fatigue test, (c) compression test, (d) torsion fatigue test, (e) single shear adhesion test, (f) tension adhesion test, (g) shear test.

The single shear specimens were allowed to cure in their molds for one day; after which the molds were disassembled, and the specimens placed in a water tank for three days to insure adequate mortar curing. The specimens were then placed in conditioning according to Table 1.

The tension adhesion specimens were prepared in the same manner as the single shear adhesion specimens. Figure 2e shows the type of silicone rubber mold used for casting.

Figure 3 shows the various specimens being tested. A Riehle Model P-3 precision hydraulic universal testing machine was used for static tests, with a deformation rate of 0.05 in. per min. Sonntag universal testing machines were used for conducting the fatigue tests, operating at a rate of 1,800 cycles per minute.

The following criteria for failure were established:

Test	Criterion
Tension	Fracture load
Bending fatigue	Number of cycles for fracture
Compression	Maximum load or load at 25 percent deformation
Torsion fatigue	Number of cycles for fracture
Single shear adhesion	Fracture load
Shear	Maximum load
Tension adhesion	Fracture load

In the cases of the compression test, single shear adhesion test, shear test, and tension adhesion test different modes of failure were noted (Figs. 4, 5 and 6). Tension adhesion failures were similar to Figure 6.

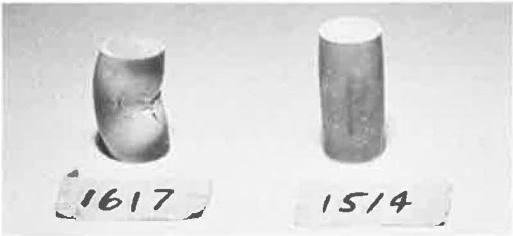


Figure 4. Compression failures by buckling (left) and bulging (right).

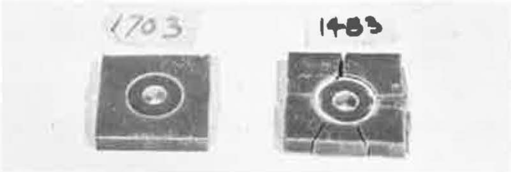


Figure 5. Shear failures by punching shear (left) and brittle shattering (right).

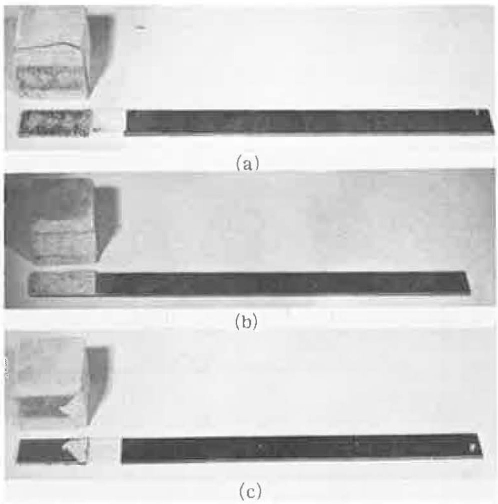


Figure 6. Single shear adhesion failures at (a) bond, (b) mortar, (c) bond and mortar.

FORMULATION

The preceding series of tests was conducted on most of the recommended formulations, and the formulations were revised as experience and test results indicated the necessity to do so. The results of the strength tests alone were not the critical factor in determining formulation revision. Other pertinent properties were viscosity, sprayability, brittleness, and flexibility. After a series of tests and observations had been made on all the recommended formulations and their revisions, enough information was accumulated to select a single formulation for detailed study. It is this formulation that is herein reported.

This formulation is given in Table 2.

Once this formulation had been selected, a production series of testing was carried out to determine the physical properties of this formulation both as a plastic and as an adhesive. In accordance with ASTM recommendations, a sufficient number of speci-

TABLE 2

STUDY FORMULATION

Component	Parts by Weight
A:	
Resin[a]	100
Silica flour No. 219	12.5
B:	
Liquid polymer, LP-3	50
Silica flour No. 219	47.3
DMP-10	6.25
DMP-30	3.75
Bentone 38	2.5
Anti-foam 24[b]	2.5

[a]Equivalent epoxide weight 175-200, viscosity 10,000-15,000 cps.
[b]General Electric product or equivalent.

mens for each conditioning time and temperature and type of test were made so that the results would represent adequate sampling. In general, between three and five specimens undergoing the same test were made from different batches so that the variation in mixing from batch to batch would be included in arriving at an average test result for each conditioning situtation. About 1,200 specimens were involved.

Figure 7 shows the strength of the tension specimens vs the ages of the specimens at the time of testing for 180 F conditioning, with scattering of test data. A large number of specimens were rejected for one reason or another: warpage, air holes, fractures at other than the critical section, damage during handling, conditioning time

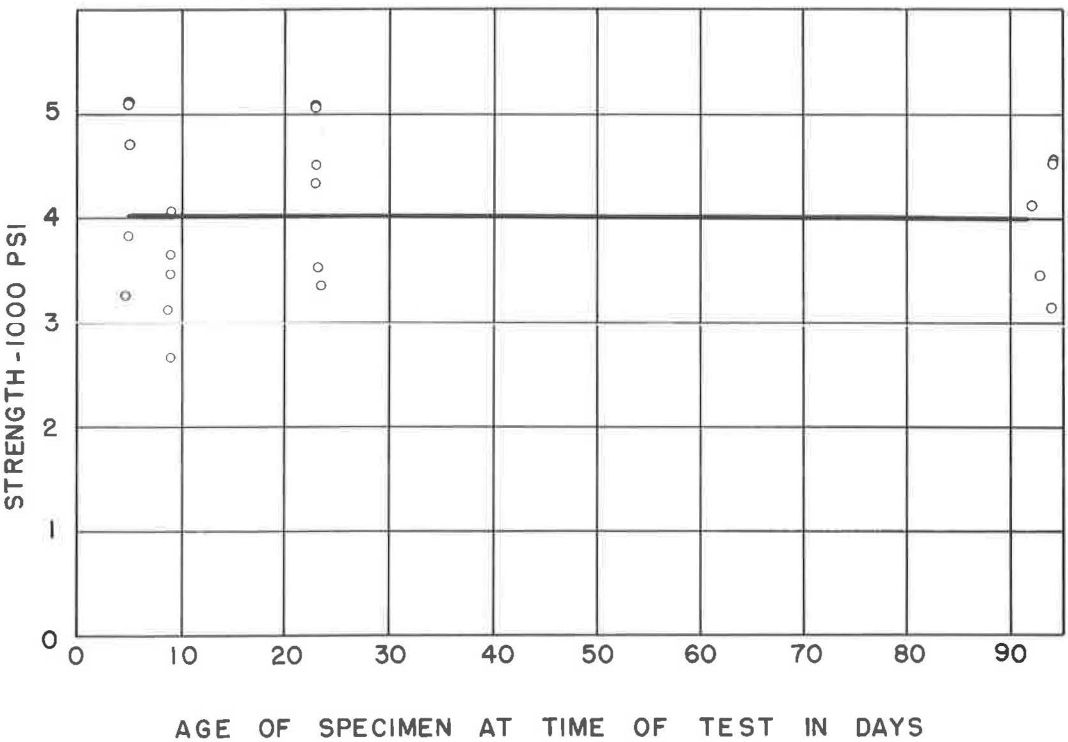


Figure 7. Strength of tension specimen vs specimen age for 180 F.

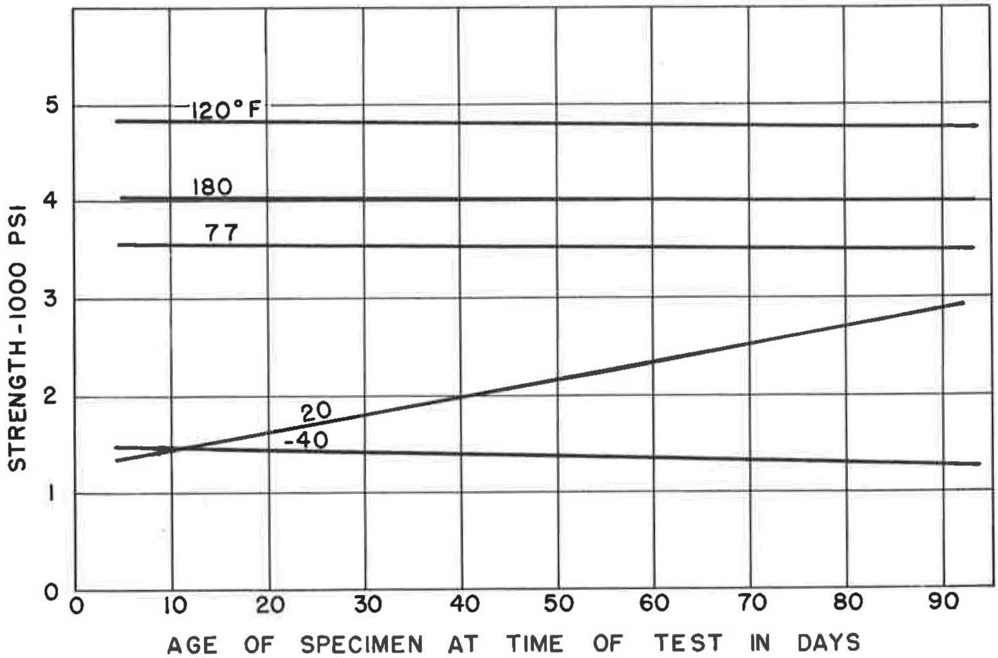


Figure 8. Strength of tension specimen vs specimen age for all conditioning temperatures.

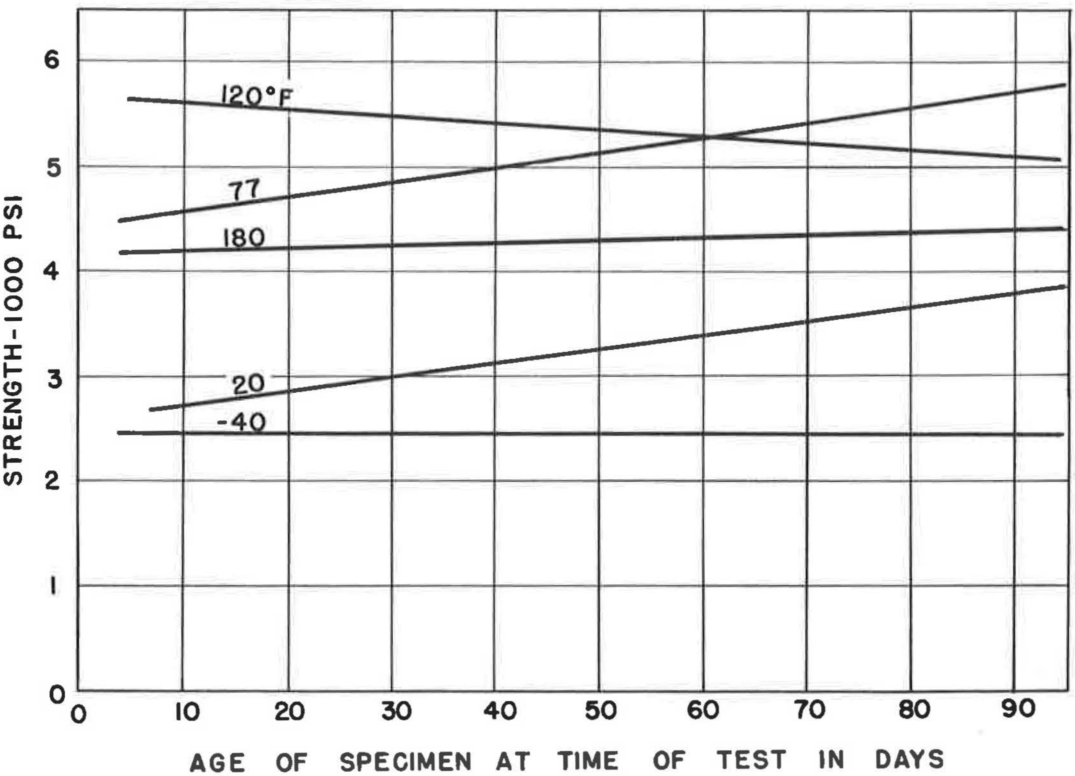


Figure 9. Strength of shear specimen vs specimen age for all conditioning temperatures.

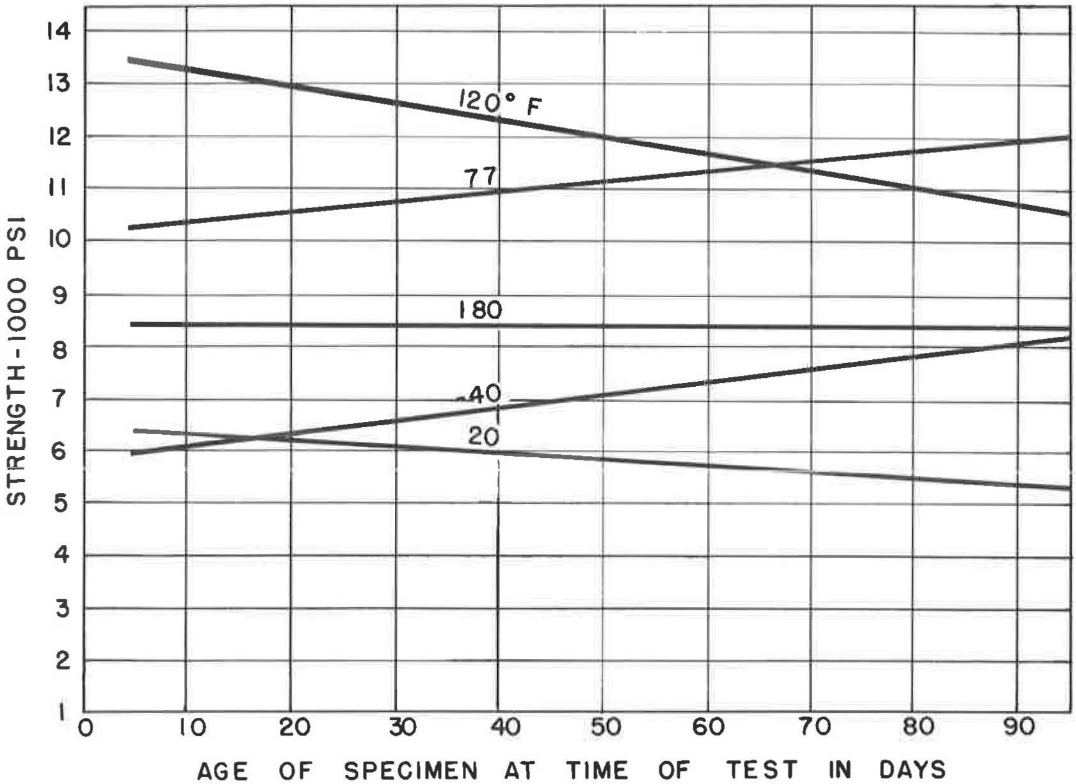


Figure 10. Strength of compression specimen vs specimen age for all conditioning temperatures.

not within an arbitrary 5 percent tolerance, or Chauvenet's criteria (2). After the test results were plotted on the graph, a least squares adjustment was made to determine a straightline relationship between strength and age of specimen. A least squares adjustment was also made using a second-order (parabolic) curve on some of the data, but the differences between straightline and parabola curves were insignificant; hence the straight line was chosen. Figures 8 through 12 show these linear relationships for the various types of tests represented by the conditioning combinations of Table 1.

A study of these figures, which are the over-all compilations for each test, shows no intelligible correlation between the types of tests; except that of the five curing temperatures used, 120 F appears consistently to be the most favorable curing temperature for the epoxy resin as a plastic in the early phases of curing. It is concluded, therefore, that each formulation must be evaluated by experiment for each test type in order to obtain reliable information. Further, tension adhesion and single shear adhesion specimens failed primarily in the mortar; therefore, these test results reflect the mortar strength only.

Figures 13 and 14 give the fatigue data for the bending fatigue and torsion fatigue specimens, respectively, in the form of S-N plots. Because numerous specimens were involved, and the process was time consuming, arbitrarily the bending fatigue S-N data was obtained for seven days conditioning at 77 F and the torsion fatigue data was obtained for 21 days conditioning at 77 F. Circles with arrows on the graphs indicate non-failure of specimen, and discontinuance of the test at the number of cycles plotted. The investigators feel that the plotted points indicate the general trend and are reluctant to define the limits of the scatter-band accurately or to write the equation of the S-N curve from the available information.

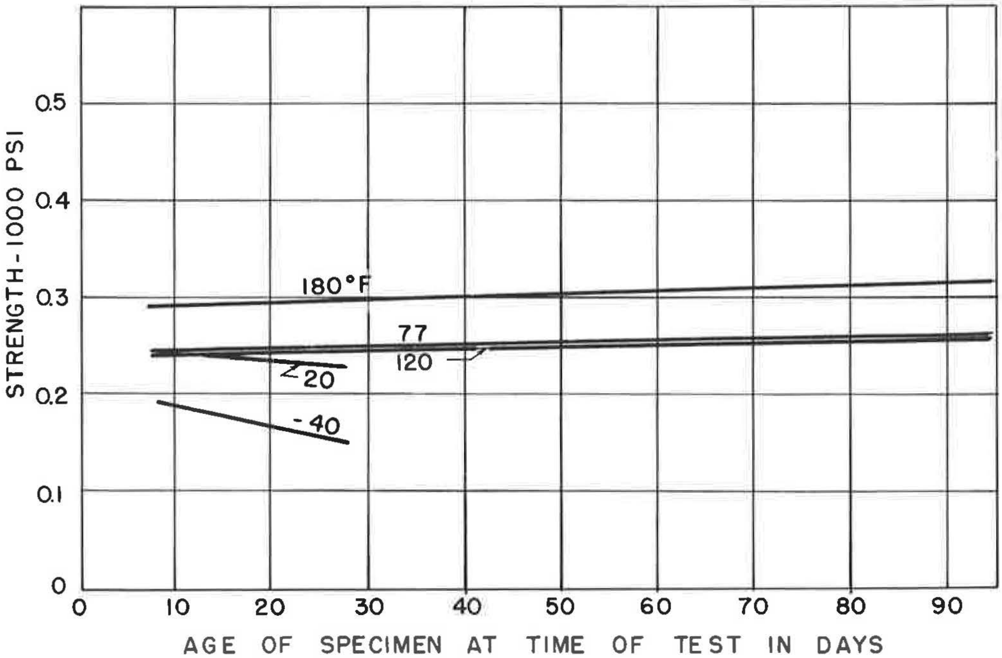


Figure 11. Strength of tension adhesion specimen vs specimen age for all conditioning temperatures.

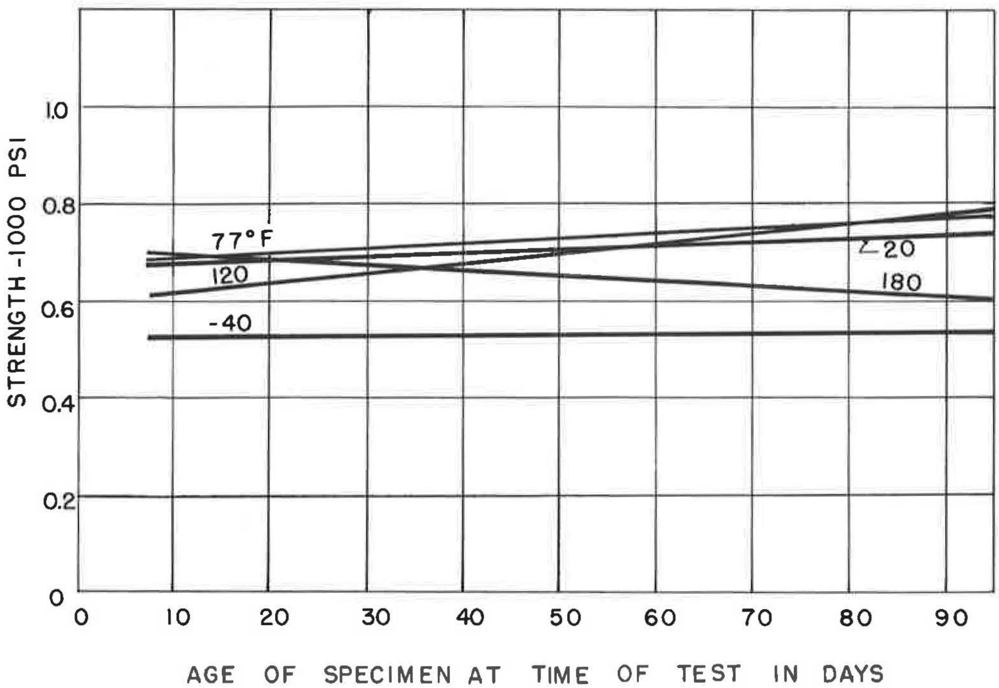


Figure 12. Strength of single shear adhesion specimen vs specimen age for all conditioning temperatures.

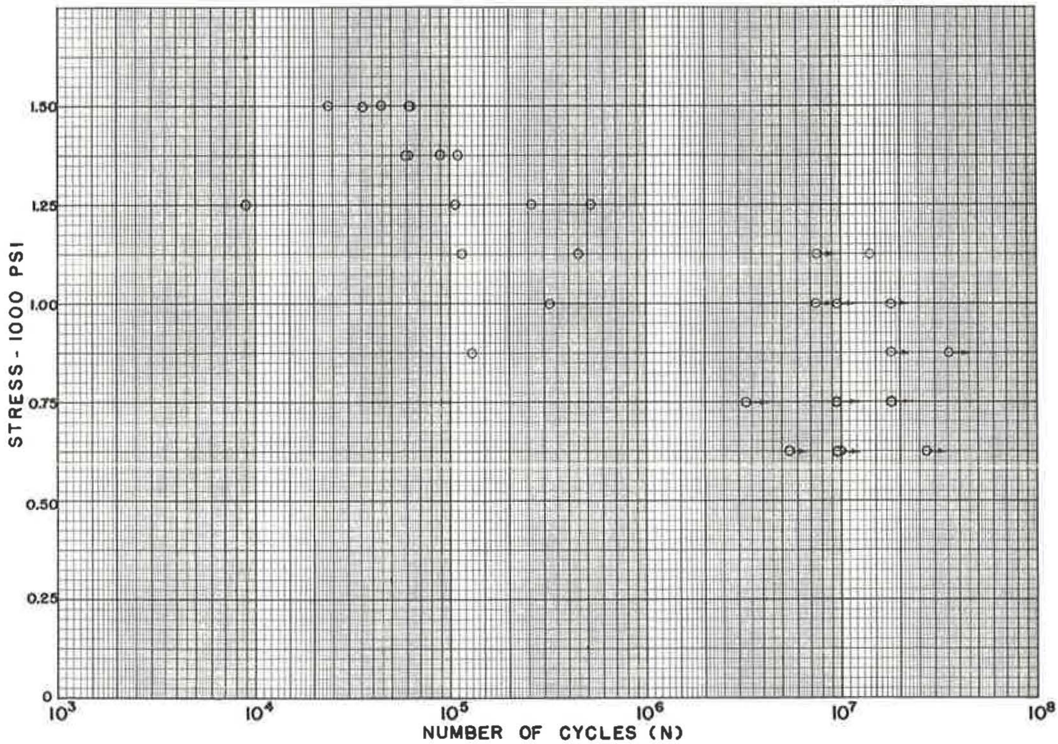


Figure 13. S-N data for bending fatigue tests.

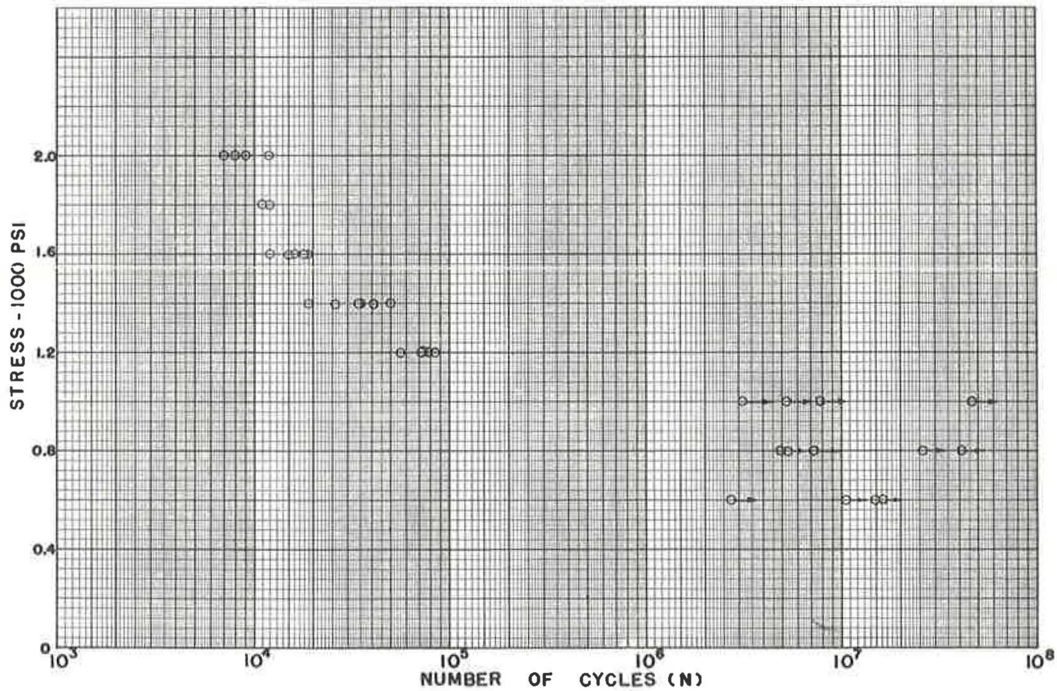


Figure 14. S-N data for torsion fatigue tests.

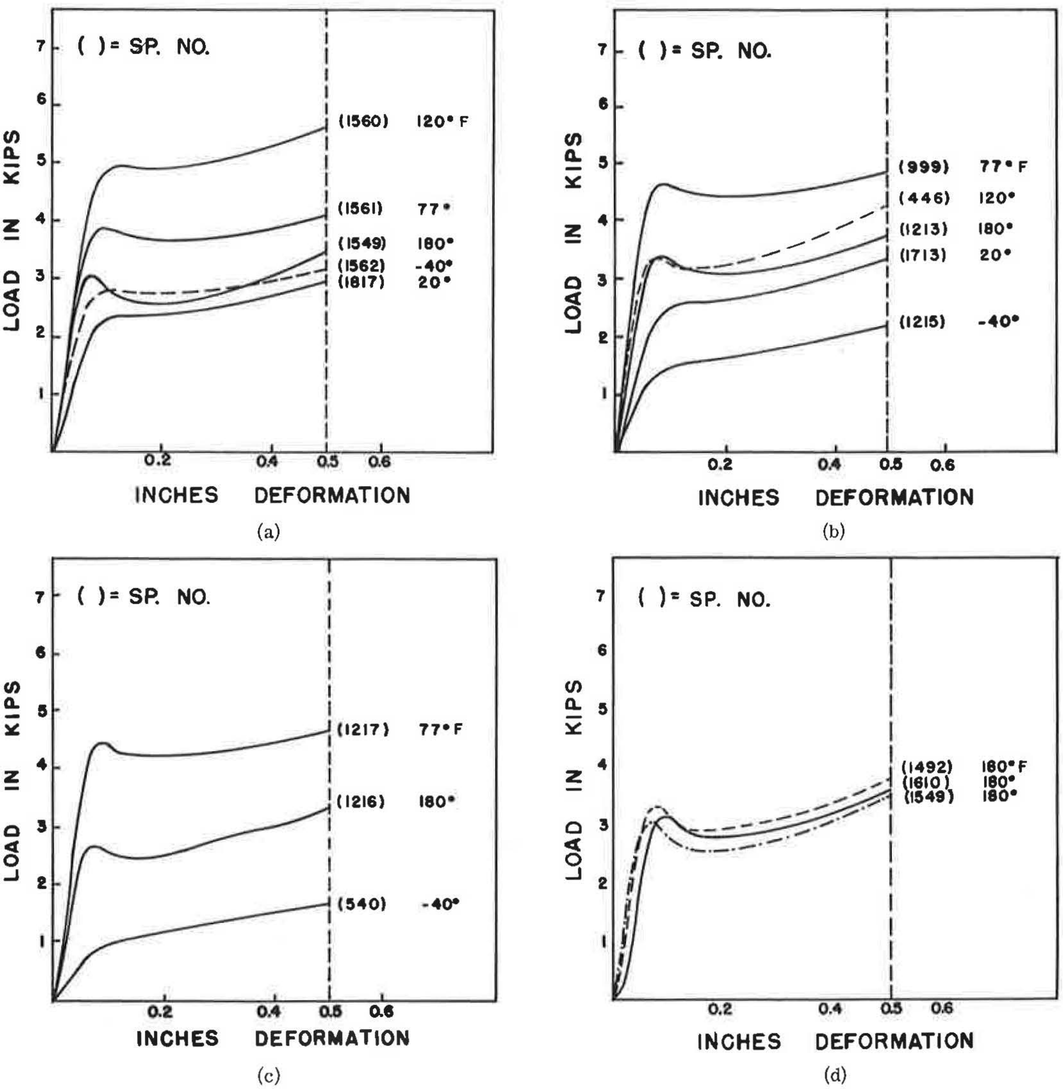
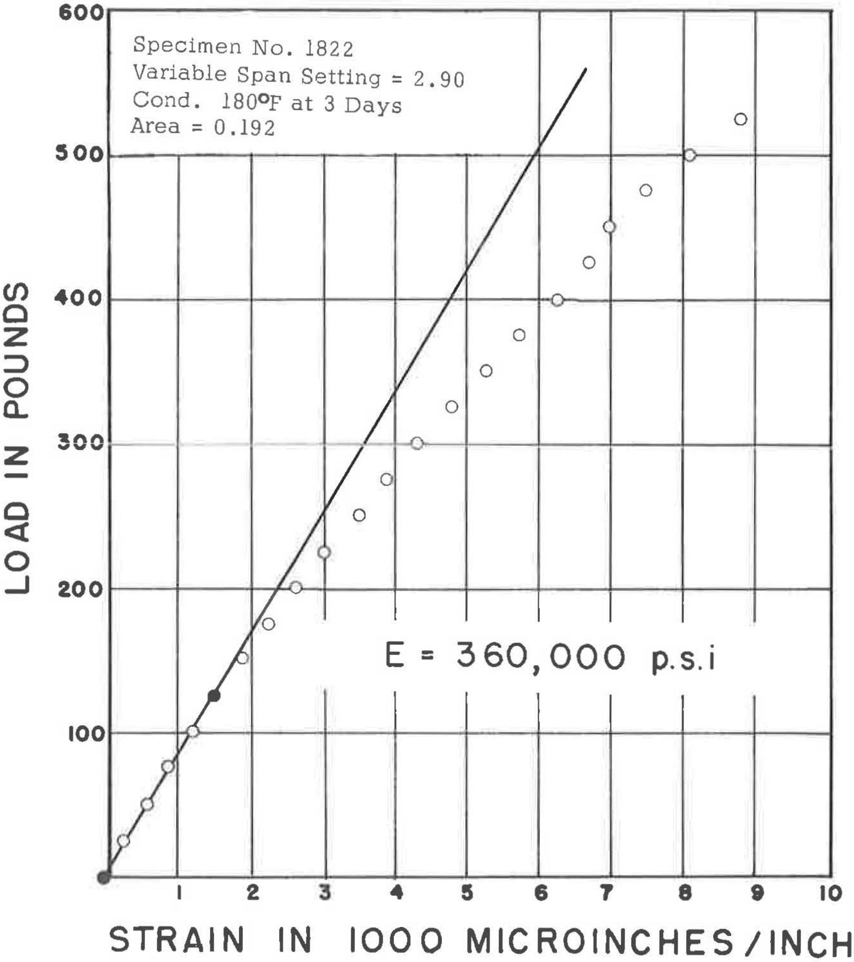


Figure 15. Compression load-deflection curves for (a) 3 days at 5 temperatures, (b) 3 mo at 5 temperatures, (c) 7 mo at 3 temperatures, (d) 3 days at 180 F.

TABLE 3

INITIAL TANGENT MODULUS OF ELASTICITY

Conditioning Temperature (°F)	Tangent Modulus of Elasticity		
	3-Day Conditioning	3-Month Conditioning	7-Month Conditioning
180	360,000		341,000
120	540,000	456,000	
77	442,000		490,000
20	323,000	315,000	
-40	357,000		262,000



(a)

Sample Calculation—Specimen No. 1822

Indicated Gage Factor for Variable Span Setting of 2.90 = 2.41
Indicated Gage Factor for Variable Span Setting of 2.18 = 2.07
Actual Gage Factor = 2.09

$$\text{Actual Strain} = \text{Indicated Strain} \times \frac{\text{Indicated Gage Factor}}{\text{Actual Gage Factor}}$$

$$= (1490 + 80)\,\frac{2.41}{2.09} = 1810$$

$$E = \frac{P}{A\,e} = \frac{125\,(10^6)}{0.192\,(1810)} = 360{,}000 \text{ p.s.i.}$$

(b)

Figure 16. Initial tangent modulus of elasticity for tension specimen: (a) load strain data for 3 days conditioning at 180 F, (b) sample calculation for modulus of elasticity for Fig. 16a.

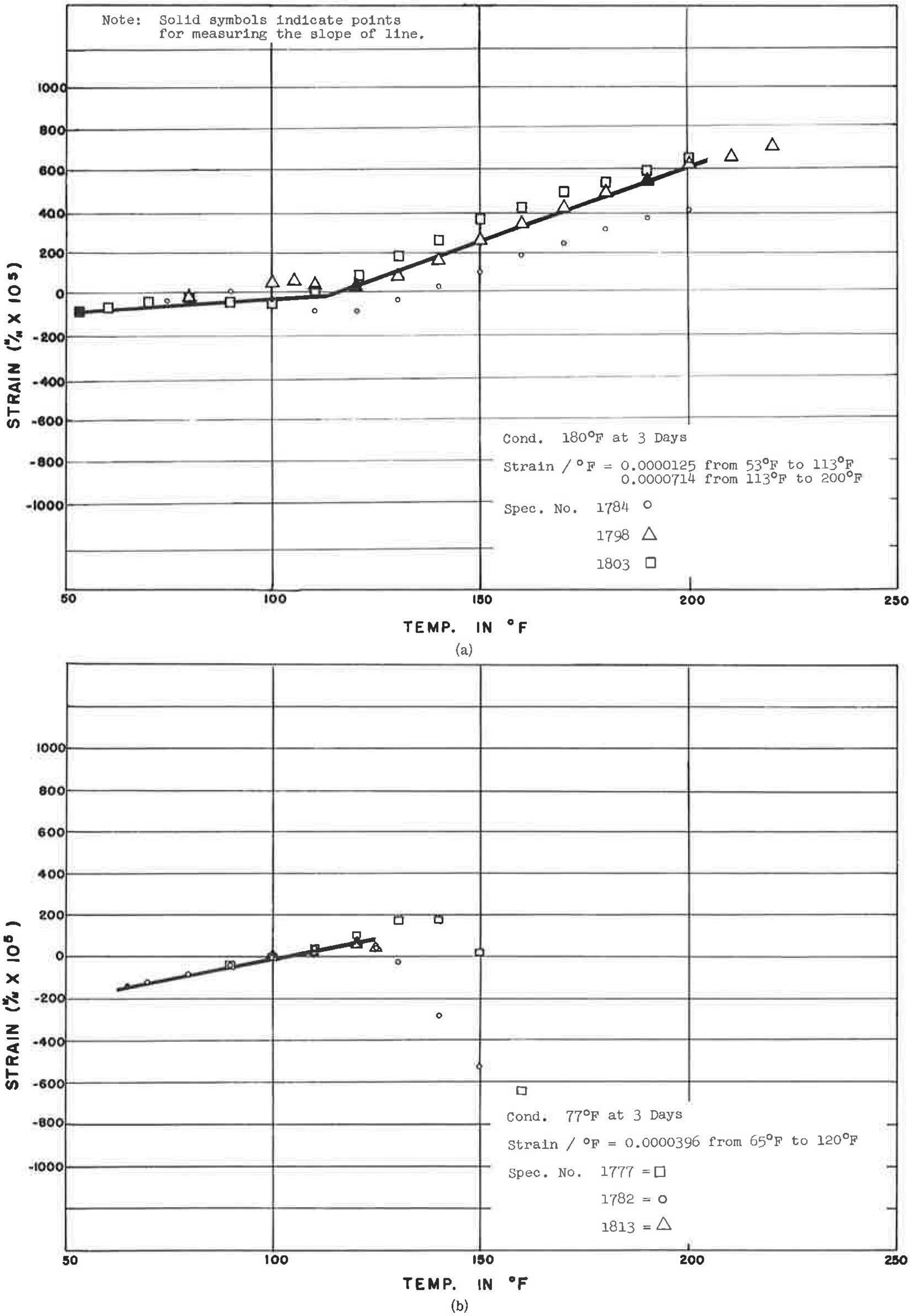


Figure 17. Coefficient of expansion data for 3 days conditioning (a) at 180 F, (b) at 77 F.

Figures 15a through 15c show load-deflection diagrams for compression specimens conditioned for three days, three months, and seven months, respectively. Only a single selected load-deflection diagram is shown for each conditioning temperature. These diagrams are merely indicated to show the general shape of the load-deflection curve, and were traced from the load-deflection indicator graph on the testing machine. These graphs show the relative displacement between the heads of the testing machine, and thereby indicate the deformation of the 2-in. long specimen for various loads. Figure 15d shows a set of load-deflection curves for compression specimens conditioned for three days at 180 F.

Modulus of elasticity tests were performed on a limited number of tension specimens, using SR-4 strain gages. Figure 16a shows the load-strain data for a tension specimen conditioned for three days at 180 F. The calculation of the initial tangent modulus of elasticity from these data is shown in Figure 16b. Table 3 summarizes the modulus of elasticity results for several conditioning situations. The purpose of these tests was only to obtain an approximate scale on the stiffness of the material and to develop the general shape of the stress-strain diagrams.

Tests for the coefficient of expansion of the epoxy resin were also conducted. In these tests, a quartz tube dilatometer, as described in ASTM D 696-44, was used to measure the elongation of 3/8-in. diameter by 3-in. long epoxy resin specimens, as they were heated in a Marshall testing furnace. A thermocouple attached to the specimen was used to measure the temperature.

Figures 17a and 17b show the coefficient of expansion data for specimens cured for three days at 180 and 77 F, respectively. Because the ambient temperature of the room could not be lowered at various times of the day, it became necessary in plotting the data to relate all strains to an arbitrary zero-strain reference temperature, which was the highest initial temperature of any set of specimens plotted on one graph. This is the reason negative initial strains appear on these graphs.

In testing, direct elongation readings for the 3-in. long specimens were recorded. These readings were converted to strains, prorated by comparison to a steel specimen of the same dimensions which was tested in the same way, and reduced to the zero reading at the base temperature before plotting on the graphs.

For each specimen tested, a transition point was observed. That is, the coefficient of linear thermal expansion changed when a certain temperature was reached. For those specimens cured at 180 F, two coefficients were calculated for the ranges of temperature indicated, both before and after the transition point. Also, for most specimens cured at temperatures below 180 F, this transition point manifested itself by complete softening of the material. On each graph a straight line is drawn over a range of temperatures which can conveniently represent an average of the data presented. This straight line has been used to compute the coefficient of thermal expan-

TABLE 4

COEFFICIENTS OF EXPANSION FOR TEMPERATURE RANGES INDICATED

Conditioning Temperature (°F)	3-Day Conditioning: Coeff. of Expansion (in./in./°F)	3-Day Conditioning: Temp. Range (°F)	7-Day Conditioning: Coeff. of Expansion (in./in./°F)	7-Day Conditioning: Temp. Range (°F)
180	0.0000125	53-113	0.0000114	70-120
	0.0000714	113-200	0.0000750	120-200
120	0.0000438	70-150	0.0000388	60-150
77	0.0000396	65-120	0.00004	65-140
20	0.0000225	70-110	0.0000213	60-100
-40	0.00004	60-100	0.000035	60-100

TABLE 5

EFFECT OF STORAGE LIFE OF COMPONENTS ON CONSISTENCY

Batch No.	Time Tested	Storage Time[a]	Room Humidity (%)	Room Temp. (°F)	Viscosity (cps) Comp. 1	Viscosity (cps) Comp. 2
73	At mixing	1 mo	39	73	23,250	20,000
	After storage		34	77	14,950	17,750
84	At mixing	3 mo	58	73	18,350	28,450
	After storage		42	72	4,000	22,750
95	After storage	19 days	33	75	12,400	25,050
98	After storage	33 days	—	78	17,500	24,500
100	After storage	61 days	32	75	14,600	22,750

[a]At 77 F, 50 percent relative humidity.

sion, which is applicable only within the range of temperatures indicated. Table 4 gives additional data for other curing schedules.

ADDITIONAL TEST DATA

In addition to the previous series of physical tests, several other tests were conducted which were considered pertinent to the problem of bonding composite concrete-to-steel beams. Some of these included the following:

1. Test for determining proper steel surface preparation. In this test, using single shear adhesion specimens, different methods for preparing the steel surface were investigated. Several solvents were tried for cleaning the steel surfaces. These were ineffective because it was found that the steel also had to be roughened in addition to being clean in order to insure adequate bonding. From the standpoint of field construction feasibility, one of the best surface preparations yielding consistent results was sandblasting.
2. Test for effect of freeze-thaw cycling on adhesive bond. Single shear specimens were prepared in the usual manner, wet cured for three days and conditioned for seven days at 77 F. They were then subjected to 53 cycles of freezing in air and thawing in water at a rate of 8 cycles per day in a Conrad machine. From the results of these tests it was concluded that freeze-thaw cycling had an adverse effect on the failure strength of the specimens. However, because all failures were mortar failures, these tests indicated the deterioration of strength occurring in the mortar, and it has not been proven whether the epoxy resin is affected by freeze-thaw cycling.
3. Effect of storage life of components on consistency. Table 5 gives information concerning the effect of storage life of formulation components on consistency. Batches 73 and 84 were hand-mixed using small wooden tongue-blades. After a one-month storage period of each component, it was discovered that much of the silica flour filler material had settled out of each component, and could not be satisfactorily remixed into the components by means of hand mixing. This phenomenon was even more pronounced in the case of a three-month storage after initial mixing. In this case, even the liquid ingredients in the components tended to separate because of differences in their specific gravities. This separation of components during storage, and resulting difficulty in remixing after storage, caused a large drop in viscosity, which once again was due mainly to the settling of the silica flour.

Batches 95, 98, and 100 were made from components mixed with an electric drill. The viscosities of the components of these batches did not vary widely after their respective storage times. This indicates that, when properly mixed, neither component undergoes a serious change in viscosity over a lengthy storage period. Visual observation also demonstrated that there was much less tendency for the filler to settle out after machine mixing, because this mix looked fairly homogeneous throughout. This was not the case with hand mixing.

TABLE 6

EFFECT OF STORAGE LIFE OF FORMULATION COMPONENTS ON STRENGTH OF CURED SPECIMENS

Batch No.	Spec. No.	Type	Stress (psi)	No. of Cycles (x 1,000)	Conditioning Time[a] (days)	Average Strength (or cycles to failure)
68[b]	842	TE	3,380		7	
	843	TE	3,440		7	3,530
	844	TE	3,770		7	
	845	BE	1,237	133	7	
	846	BE	1,250	63	7	106,000
	847	BE	1,250	122	7	
	848	S	5,230		21	
	849	S	4,810		21	5,027
	850	S	5,040		21	
	851	SS-A	773		7	
	852	SS-A	734		7	745
	853	SS-A	728		7	
	854	T	1,200	93	21	
	855	T	1,200	75	21	84,000
	856	T	1,200	84	21	
	808	C	11,200		21	
	816	C	11,310		21	11,317
	817	C	11,440		21	
73[c]	925	TE	3,780		7	
	926	TE	3,490		7	3,580
	927	TE	3,470		7	
	928	BE	1,125	171	7	
	929	BE	1,125	131	7	732,000
	930	BE	1,125	1,894	7	
	931	S	3,340		7	
	932	S	4,320		7	3,970
	933	S	4,250		7	
	934	SS-A	596		7	
	935	SS-A	721		7	655
	936	SS-A	648		7	
	937	T	1,200	90	21	
	938	T	1,200	110	21	100,000
	939	T	1,200	—[d]	21	
	940	C	9,900		7	
	941	C	10,900		7	10,427
	942	C	10,480		7	
84[e]	1,163	TE	3,190		7	
	1,164	TE	N. G.		7	3,190
	1,165	TE	N. G.		7	
	1,166	BE	1,250	10	7	
	1,167	BE	1,250	12	7	15,000
	1,168	BE	1,250	23	7	
	1,169	S	5,750		7	
	1,170	S	5,725		7	5,508
	1,171	S	5,050		7	
	1,172	SS-A	848		7	
	1,173	SS-A	833		7	845
	1,174	SS-A	853		7	
	1,175	T	1,200	51	21	
	1,176	T	1,200	93	21	72,000
	1,178	C	14,250		7	
	1,179	C	10,510		7	12,380

[a] At conditioning temperature of 77F.
[b] Stored 7 days at 77F, 50 percent relative humidity.
[c] Stored 1 mo at 77F, 50 percent relative humidity.
[d] Deflection failure.
[e] Stored 3 mo at 77F, 50 percent relative humidity.

TABLE 7

TEST RESULTS OF SINGLE SHEAR ADHESION SPECIMENS FOR VARIOUS TIME LAPSES BETWEEN APPLICATION OF EPOXY AND MORTAR[a]

Batch No.	Spec. No.	Time Lapse (min)	Strength (psi)
56	630	10	644
	631	20	687
	632	30	--[b]
	633	40	665
	634	50	718
	635	60	600
62	809	50	768
	810	60	630
	811	70	660
	812	80	680
	813	90	460
	814	100	653
73	1,790	90	640
	1,791	120	615
	1,792	150	648
	1,793	180	562
	1,794	210	716
	1,795	240	805
	934	5-15	596
	935	5-15	721
	936	5-15	648

[a]For conditioning of 7 days at 77F. All specimens suffered mortar failure.
[b]Broke in handling.

4. Effect of storage life of formulation components on strength of cured specimens. Table 6 shows the effect of storage life of the formulation components on the strength of cured specimens. A comparison of these test results with the over-all series of test results given in Figures 7 through 12 shows that the storage life of the components has no significant effect on the strength of the cured system.

5. Test for interchangeability of different brands of epoxy resins in the same formulation. A series of specimens was cast from batches of this formulation using different brands of epoxy resin. These test results, when compared with the general series of test results of Figures 7 through 12, show that there is no significant difference between different brands of epoxy resin as long as they meet the specifications of an equivalent epoxide weight 175 to 200, and viscosity between 10,000 and 15,000 cps.

6. Working life of epoxy resin formulation. Table 7 shows the results of tests that were conducted to determine the effect of a time lag between the application of epoxy to a steel strap, and the further application of mortar on top of the epoxy. These strengths are comparable with those in Figure 12, and all failures occurred in the mortar, indicating adequate bonding. Thus it can be concluded that time lapses of up to four hours, and possibly more, may safely be allowed between the application of epoxy to the steel and the further application of mortar to the epoxy.

7. Tests of single shear adhesion specimens without epoxy shear connectors. In these tests the steel was sandblasted only, and the mortar was placed wet on top of the sandblasted area. In all cases the shear strengths of these specimens were less than one-fourth the values given by Figure 12, and bond failures were observed. These tests proved the definite increase in shear strength due to the epoxy resin.

CONCLUSIONS

Several important conclusions have been drawn from the results of this investigation.

General (Applying to All Epoxy Formulations)

1. Several factors other than strength alone govern the choice of a suitable formulation. Examples are sprayability, viscosity, brittleness, ability to set in the presence of water, pot life, and resilience. A single epoxy formulation has been developed as described in this report, which satisfies all of these considerations for the applications investigated.
2. A non-standard shear test (the Single Shear Adhesion Test) has been developed which is considered reliable for predicting the shear strength of a metal-to-concrete adhesive system.
3. A viscosity of 20,000 centipoises for each component of a two-component epoxy formulation will allow for proper spraying applications. To facilitate spraying, heating the components as part of the spraying operation is desirable.
4. There appears to be no definite correlation between the different types of physical tests; therefore, each formulation should be evaluated in all types of tests for each specific application.
5. Power mixing is superior to hand mixing for preparation of the components and for mixing the components together. The use of power mixing for preparing the components provides for a longer storage life without settling of filler materials.
6. Silica flour filler is abrasive with spray equipment; nevertheless, some equipment manufacturers make allowance for this with easily replaceable parts.
7. Sandblasting is the most satisfactory method for preparing a steel surface, and is recommended for composite beam construction in the field.

Specific (Applying Primarily to Particular Epoxy Formulation Studied and Presented Herein)

1. In properly prepared adhesion specimens of steel-to-mortar, with an epoxy adhesive, the mortar is the weakest component of the cured system.
2. Epoxy resins from different manufacturers are interchangeable in the formulation described in this report, provided that they are within the limits of epoxide equivalent weight and viscosity specifications.
3. The epoxy formulation described in this report does not hinder proper concrete curing and vice versa.
4. In using the recommended formulation, the concrete should be applied within four hours after application of epoxy to the steel.
5. Freeze-thaw cycling of steel-to-mortar adhesion specimens did not noticeably affect the epoxy, but did cause considerable mortar strength loss.

Culminating this study a series of quarter-scale composite beams, using the epoxy resin as a shear connector, were statically loaded to failure and their behavior studied by means of strain gages and other deformation indicators. The performance of these beams was compared with that of monolithic concrete T-beams and stud shear connected concrete to steel composite beams which were loaded to failure under identical conditions. The results of these tests are reported elsewhere (3).

The results of this investigation show that an epoxy resin formulation satisfying the strength demands of a composite beam bridge can be achieved, subject to the restrictions imposed by the testing program. However, further studies of performance and characteristics are necessary before the selected epoxy resin formulation can be approved for use as a connector; such as creep, fatigue on glued joints, impact, strength gain under various temperature conditions, and durability. These studies are now being made in an extension to the research project.

ACKNOWLEDGMENTS

This paper is based on the experimental investigation presented elsewhere (3). The research was sponsored by the Bureau of Physical Research, New York State Depart-

ment of Public Works in cooperation with the U.S. Department of Commerce, Bureau of Public Roads. Personnel of the Bureau of Physical Research collaborated in the planning of the project, assisted in certain phases of the laboratory studies, and acted as technical advisors.

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