STRENGTH PROPERTIES OF EPOXY REPAIRED STRUCTURAL COMPONENTS DURING AND AFTER FIRE EXPOSURE

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SUMMARY

This paper presents a summary of experimental test results regarding the strength properties and behavior of epoxy repaired shear walls subjected to two standard types of fire exposures. A variety of parameters were studied including wall thicknesses, width of crack, types of epoxy adhesives and a variety of fire surface coatings including gypsum plaster. The test results show that the strength properties of epoxy repaired walls during fire exposure are substantially reduced. However, after fire exposure and cool down to room temperature, the strength properties of the un-burned portions of epoxy repaired concrete are returned to pre-fire values.

INTRODUCTION

Epoxy repair techniques have been used extensively throughout the world for the repair of concrete or masonry type structures damaged by earthquakes or other types of causes. Past research (1,2) indicates that damaged structures properly repaired, with epoxy adhesives are generally restored to original design strength levels under room temperature conditions. However, strength properties of epoxy adhesives deteriorate rapidly at elevated temperatures. This paper presents the experimental test results obtained from fire tests on small-scale and large-scale epoxy repaired shear wall specimens. Two large-scale shear wall specimens were constructed with planer dimensions of 9 ft. by 8 ft. and thicknesses of 6 in. and 8 in. Eleven intermediate scale specimens were also constructed with planer dimensions of 44 in. by 36 in. and wall thicknesses of 6 in., 8 in., and 10 in. Over 200 small-scale specimens were also tested with dimensions and parameters given in Fig. 1. For all experimental specimens, the most important specimen parameters studied include wall thickness, h, and crack width, w. The small-scale specimens were constructed with wall thickness of 6 in., 8 in., and 10 in. The crack widths studied included 0.05 in., 0.10 in., and 0.25 in. for all specimen sizes. The specimens were fabricated from ready mixed concrete using a 7 bag mix. Rounded aggregate with a 3/4 in. maximum size and Type I Portland Cement were used for the construction of all specimens. The average 28 day compressive strength of the control cylinders was 4.15 ksi with a standard deviation of 0.36 ksi.

The shear wall specimens were cured for approximately seven days prior to the formation of the crack. To simulate actual crack surfaces of concrete shear walls, each shear wall specimen was broken as a beam at an angle θ to equal 45°. Since compression loads were applied to the top and bottom surfaces (ABFE and CDGH in Fig. 1), this crack configuration provided maximum

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shear stresses within the epoxy repaired crack. The concrete shear wall specimens after having been broken into halves, were cured for a minimum of at least 90 days prior to epoxy injection. The cracked specimens were cured under laboratory conditions, that is, temperature of 70°F and relative humidity of 50%. After the 90 day curing period, the specimens were injected with appropriate epoxy adhesives.

EPOXY ADHESIVES USED IN THE EXPERIMENTAL PROGRAM

Six different structural epoxy adhesives were considered. All six epoxy adhesives are considered thermosetting resins derived from the oil refining intermediate products; epichlorhydrin and bisphenol A. Fillers were not added to the epoxy adhesives either before or during the injection of the adhesives into cracks. These six epoxy adhesives were chosen because their chemical and physical properties were representative of most epoxies that have been or are being used for the repair of damaged structures since the 1971 San Fernando Earthquake. All six epoxy adhesives with properties suppled by manufacturers which are as follows:

	Low Viscosity	High Viscosity
Viscosity (cps)	300 - 800	12,000 - 17,000
Compressive Strength at 70°F (psi)	12,000 - 17,000	13,000 - 16,000
Tensile Strength at 70°F (psi	7,000 - 12,000	6,500 - 7,800
Pot Life (minutes)	20 - 40	30 - 50
Heat Distortion Temperature (°F)	120 - 145	105 - 135
Strength Transition Temperature (°F)	220 - 240	230 - 245

Considerable variation in the strength properties of low viscosity epoxy adhesives did not affect fire test results because the heat distortion and the strength transition temperatures were relatively similar for these epoxies Hence, the test results for all low viscosity epoxies are combined into a single group of results for low viscosity epoxy adhesives. Similarly, the test results for high viscosity epoxy adhesives are combined into a single group of test results for high viscosity epoxy adhesives.

EPOXY INJECTION PROCEDURE AND EPOXY CURING

The epoxy resin and hardner for all epoxy adhesives were mixed together in proportions specified by the respective manufacturers. The epoxy was either injected into the cracks at pressures below 100 psi or simply poured into the crack whenever possible. All cracks were sealed with reinforced plastic tape and casting plaster which were both completely removed when the epoxy adhesive had cured. Since the cracked surfaces for all concrete specimens were formed as described above, cleaning of the cracks was not required. At the time of the epoxy injection, all cracks were dry. Prior to any type of experimental testing, all epoxy adhesives were allowed to cure for a minimum of seven days.

ASTM AND SDHI FIRE EXPOSURES: HOT STRENGTH AND RESIDUAL STRENGTH

The epoxy repaired shear wall specimens were subjected to "pseudo-fire exposures" designed to simulate two different types of building fires. The standard two-hour duration ASTM E119 fire exposure for shear walls attempts to model a long duration fire with constantly increasing temperature, so that the cool down behavior is not represented. A Short Duration High Intensity (SDHI) fire which peaks at about 0.2 hours, has a rapid temperature drop for a period of 0.4 hours and is followed by slow cooling to room temperature. Both the ASTM and the SDHI time-temperature curves are provided in Fig. 2. During fire exposure the specimens were subjected to loads generally below design stress levels since the most critical period or the lowest strength values are obtained shortly after fire exposure due to thermal gradient development. Upon completion of the fire exposure, "hot strength" and "residual strength" compression tests were conducted. "Hot strength" type of tests refer to epoxy repaired specimens which were subjected to ultimate compression loads immediately after the fire exposure. "Residual strength" tests refer to epoxy repaired concrete specimens that were subjected to fire exposure, allowed to cool for seven days in a laboratory environment and subsequently tested for ultimate strength.

FIRE EXPOSURE COATINGS

Relatively low ultimate strength results as indicated in Fig. 3 for epoxy repaired specimens subjected to ASTM E119 fire exposure prompted a search for effective fire surface coatings which would decrease the depth of epoxy burnout and increase both the hot and residual strengths. Therefore, a series of surface coatings were applied to the fire surface for the purpose of fire protection. These surface coatings were grouped into three categories including (1) gypsum plaster, (2) thin inorganic surface coatings and (3) thin organic surface coatings.

Gypsum plaster was mixed and applied to the fire exposed surfaces according to the appropriate specifications in the 1976 UBC. Total plaster thicknesses of 1 in. and 3/8 in. (including a 1/8 in. thick finish coat) were applied to the fire exposed surfaces. The plaster was allowed to cure for at least 90 days prior to the fire exposure. Thin inorganic coatings consisted of a one to one mixture on volume basis of sodium silicate and Type I Portland Cement. This inorganic coating was applied to the fire surface with a trowel to a thickness of 0.15 in. and cured a minimum of seven days prior to fire exposure. The fire test results showed that this type of thin inorganic surface coatings are ineffective. Thin organic surface coatings were also applied to the fire surfaces in the form of fire resistant epoxy foams and fire retardant intumescent paints. The thickness of these coatings included 0.050 in. and 0.100 in. and were applied to the fire surface with a trowel. These inorganic surface coatings were cured for a minimum of seven days prior to fire testing. The fire test results showed that thin organic surface coatings are also ineffective.

DESCRIPTION OF TEST PROCEDURE

Fire tests were conducted in the forced air natural gas furnaces at California State University, Long Beach and University of California, Berkeley. After the specimens were fully prepared, that is, the injected epoxy had been cured for a minimum of seven days and fire surface coatings applied whenever required, the specimens were placed in the furnace with only one surface (surface ABCD in Fig. 1) exposed to the fire. Immediately after the fire exposure, the specimens were removed from the furnace and subjected to the compression load until failure in the case of "hot strength" tests. The depth of epoxy burnout was determined for each specimen immediately after the specimen had been failed under compression loading.

DISCUSSION OF TEST RESULTS

The experimental data is provided in detail in Ref. 3 and partially summarized in Figs. 3 to 13. This data represents the average test results for the small-scale, intermediate scale and large-scale specimens. Due to careful preparation of the specimens and the primary one-dimensional nature of heat flow, the test results for the three specimen sizes were very similar.

The test results in Figs. 3 and 4 pertain to two-hour ASTM E119 fire exposure as "hot strength" compression tests without fire surface coatings and for low viscosity epoxy adhesives. The strength levels for crack widths of 0.05 in. or larger are very low even for 10 in. thick shear walls. As indicated in Fig. 4, the depth of epoxy burnout is approximately 3 inches regardless of crack width.

Figs. 5 and 6 provide test results for one-hour SDHI fire exposure as "hot-strength" compression tests without fire surface coatings and for low viscosity epoxy adhesives. The differences in the nature and severity of the ASTM E119 and SDHI fire exposures are clearly illustrated by Figs. 3 through 6. Note that the compressive strength values for SDHI fire exposures are only about 50% higher than those for ASTM fire exposures. However, the depth of burnout is approximately three times more in the ASTM fire exposure as compared to SDHI fire exposure.

Figs. 7 through 10 summarize the effects of crack width on epoxy repaired shear walls. All four figures refer to 6 in. thick wall specimens subjected to a two-hour ASTM E119 fire exposure. Figures 7 and 8 pertain to a 1 inch thick plastic coating and Figure 9 and 10 pertain to 3/8 in. thick plaster coating. Although the thickness of the plaster coating does not appreciably affect the compressive strengths, the depth of epoxy burnout is significantly reduced with increasing plaster thicknesses.

Figs. 11 and 12 provide test results for a two-hour ASTM E119 fire exposure as "residual strength" compression tests without fire surface coatings. Comparison of Figs. 3 and 11 illustrates the differences in the heat input of the two different fire exposures namely the ASTM E119 and the SDHI. Fig. 13 provides the depth of epoxy burnout as a function of wall thickness for SDHI fire exposure.

CONCLUSION

The conclusions from the above test results and other experimental data provided in Ref. 3 are summarized below.

1. Shear walls of 6 inch thickness or less repaired with epoxy adhesives will have negligible shear "hot strength" either during SDHI or E119 fire exposures. For 8 in. and 10 in. wall thicknesses, the strength values are also reduced extensively.

2. Epoxy adhesive in cracks which was not burned out during fire exposure regains full strength after cooling down to room temperatures.
3. The depth of epoxy burnout is relatively independent of crack width as shown in Figs. 4, 6, 12 and 13.
4. Epoxy repaired concrete after fire exposure can be effectively re-repaired with epoxy adhesives and/or epoxy grout (Ref. 3).
5. Epoxy adhesives have negligible strengths at temperatures above 400°F.

Additional data and conclusions are provided in Ref. 3.

ACKNOWLEDGMENTS

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3. Plecnik, J. M. and M. G. Pham, "Final Report to NSF on Fire Testings of Epoxy Repaired Shear Walls", CSULB Structures Lab Report, SL 80-4, 1980.

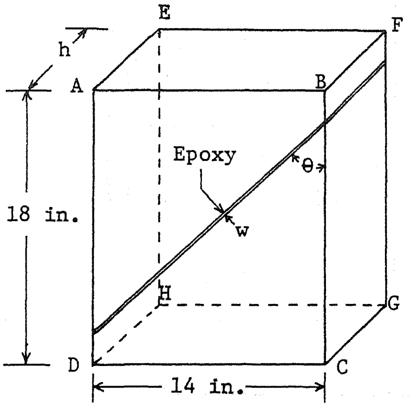

Fig. 1 : General Specimen Configuration

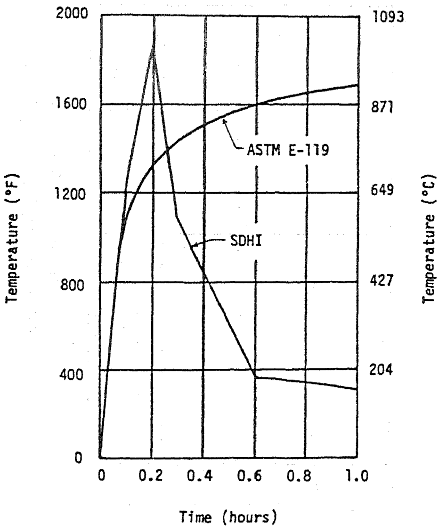

Fig. 2 : ASTM E119 and SDHI Time-Temperature Fire Curves.

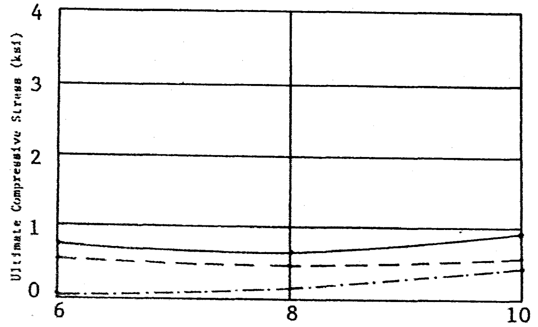

Fig. 3 : Average Ultimate Compressive Stress as a Function of Wall Thickness.

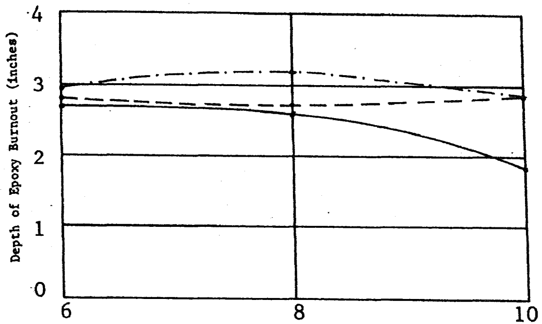

Fig. 4 : Average Depth of Epoxy Burnout as a Function of Wall Thickness.

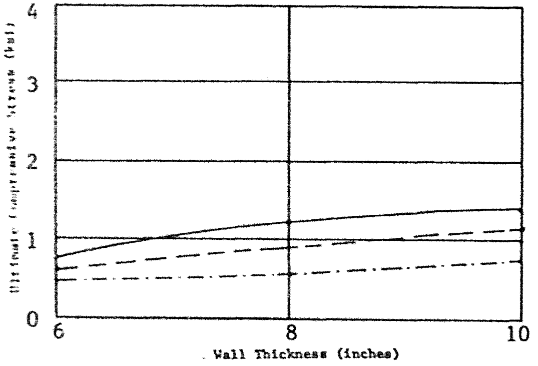

Fig. 5 : Average Ultimate Compressive Stress as a Function of Wall Thickness.

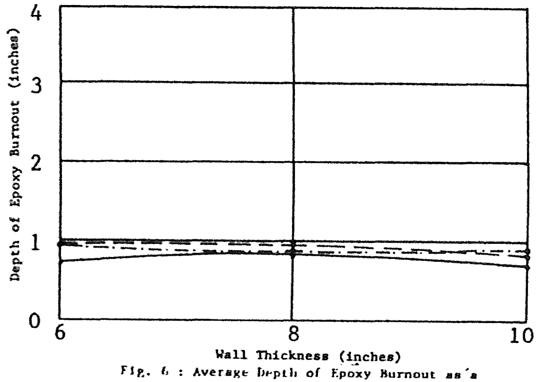

Fig. 6 : Average Depth of Epoxy Burnout as a Function of Wall Thickness.

NOMENCLATURE
0.05 in. crack width ———
0.10 in. crack width - - - -
0.25 in. crack width —·—·—

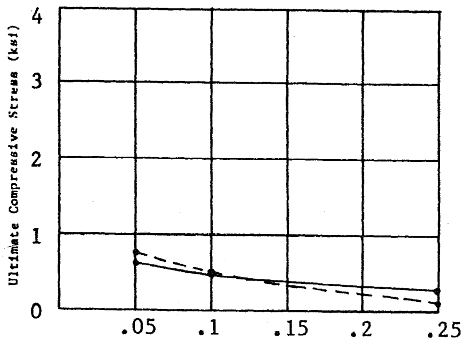

Fig. 7 : Average Ultimate Compressive Stress as a Function of Crack Width.

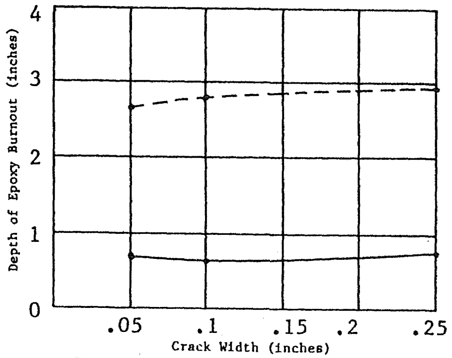

Fig. 8 : Average Depth of Epoxy Burnout as a Function of Crack Width.

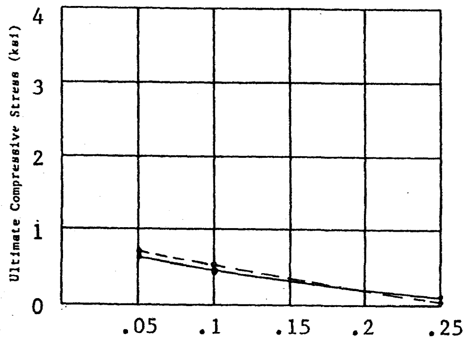

Fig. 9 : Average Ultimate Compressive Stress as a Function of Crack Width.

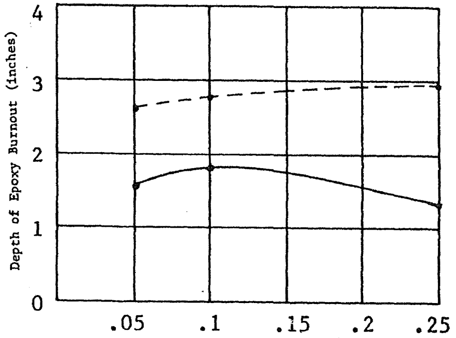

Fig. 10 : Average Depth of Epoxy Burnout as a Function of Crack Width.

NOMENCLATURE

plaster fire surface coating ————

No plaster fire surface coating - - - - - -

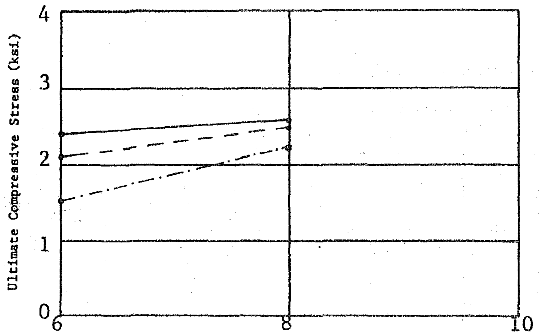

Fig. 11 : Average Ultimate Compressive Stress as a Function of Wall Thickness.

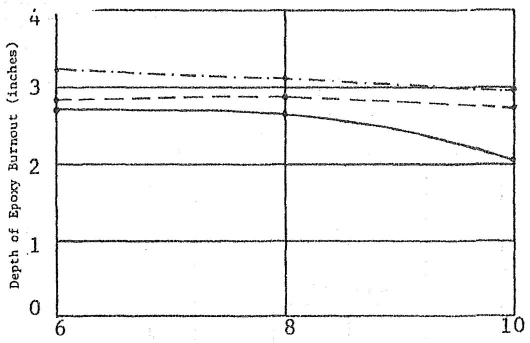

Fig. 12 : Average Depth of Epoxy Burnout as a Function of Wall Thickness.

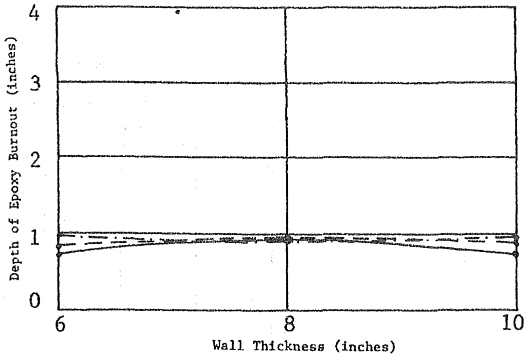

Fig. 13 : Average Depth of Epoxy Burnout as a Function of Wall Thickness.

NOMENCLATURE
0.05 in. crack width ————
0.10 in. crack width – – – – –
0.25 in. crack width –·–·–·–