# TENSILE BOND STRENGTH OF POLYMER MODIFIED MORTARS

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## ABSTRACT

An experimental program was performed to investigate ways of improving the bond strength of masonry mortars through the use polymer additives, so that more efficient use of masonry could be realized. Results from a clay brick masonry mortar bond strength testing program investigating mineral and chemical admixtures are presented. Various admixtures, including a plasticizer, silica fume, numerous latecies, and two epoxies were added to and compared against a type S cement-lime mortar. Crossed couplets, cubes and cylinders were cured under both dry and moist conditions. Relatively high adhesive bond strengths were obtained with several polymers. A few polymers actually improved adhesive bond enough for cohesive bond failure to occur in the mortar.

## INTRODUCTION

The weak link in masonry construction is the mortar joint. Masonry construction is the process of joining masonry units (either brick, tile, concrete masonry units, or stone) with mortar to create a wall or panel. The final product is a composite of masonry units bonded by mortar. However, normal mortar is weaker than masonry units in compressive and tensile strength, and more susceptible to deterioration. As a result, the composite strength of masonry is highly dependent upon a good bond between the mortar

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and unit, and unfortunately, this bond strength is normally only a fraction of the already low mortar tensile strength (Kampf, 1962; Ritchie and Davison, 1962).

Bond failure, which is typically due to excessive tensile stress perpendicular to the mortar joint, is evidenced by cracking along the mortar joints. Locations where excessive shear, differential settlement, or bending occur are typically cracked. These cracks normally run perpendicular to the direction of tensile stress in the panel, opening in the direction of tensile stress. To avoid extensive crack damage and control crack size, common engineering practice is to reinforce and grout masonry walls. However, cracking at the bond line may still occur, providing a location for water to penetrate, and deterioration to start.

Cracking of the mortar joint is the primary cause of serviceability problems associated with masonry. Moisture entering surface cracks will follow the bond line through capillary action and may lead to the occurrence of a progressive failure. Major causes of degradation result from exposure to freeze thaw cycles or as a result of the intrusion of sulfate ion from either ground water or as a byproduct of acid rain. In most cases, the mortar joint deteriorates first. By improving the durability of mortar joints, less maintenance would be required, and a wider range of structural applications would be possible. The logical first step in improving the durability of masonry is to minimize crack formation. To do this, bond strength must be improved.


## EXPERIMENTAL PROGRAM

The scope of the current research was limited to performing an initial screening of cement admixtures and recording their effect on the bond strength of a type S masonry mortar.

The primary bond strength investigation was broken down into two phases.

- o    Phase I:      Literature review, product survey, and initial testing program.

- o    Phase II:     Phase one data review, completion of the testing program, continued literature review, and report preparation.

The initial literature review and product survey was conducted as background for developing the testing program. Topics investigated included test procedures, variables which affect bond strength, and commercially available products. Table 1 lists the companies and admixtures which were included in the testing program. Tables 2 and 3 are the variable matrices for phase one and two respectively.

Upon review of the phase one results, it was apparent that variations in the control batch strength results required additional trials to better establish the expected direct tensile bond strength. It was also thought possible to establish a multiple regression equation

## Table 1 - Product Codes

| Company | Product Name | Generic Name | Batch Code |
|---|---|---|---|
| Air Products | Airbond CP-41 | EVA (or VAE) Emulsion<br>Vinyl Acetate/Ethylene Copolymer | EVA 1E |
| Air Products | Airbond CP-67 | Acrylic Emulsion | ACRYL 3E |
| Air Products | Airbond SP-330 | Styrene- Acrylate Powder | STY-ACRL |
| Air Products | Airflex RP-238 | EVA Powder | EVA 1P |
| Air Products | Airflex RP-245 | EVA Powder | EVA 2P |
| DOW Chemical | DOW460 | Styrene-Butadiene Emulsion | S-B |
| DuPont | Neoprene 571 | Polychloroprene Emulsion | CHLORO |
| Henkel Products | NOPCO NXZ | Liquid Defoamer Agent | DEFOAM |
| ICI Resins | Neocryl 1044 | Acrylic Emulsion | ACRYL 2E |
| Master Builders | MB Acrylset | PVAc Emulsion<br>Polyvinyl acetate | ACRYL 4E |
| Master Builders | MB-SF | Pelletized Microsilica (Silica Fume) | SF |
| Master Builders | Micro Air | Air Entraining Agent | AIR |
| Rhone-Poulenc | Epi-Rez WD-510 | Water Dispersible Epoxy Resin | EP |
| Rohm & Haas | Rhoplex CL-C100 | Epoxy Curable Latex | CURABL |
| Rohm & Haas | Rhoplex E-2903 | Acrylic Powder | ACRYL 2P |
| Rohm & Haas | Rhoplex DP-2605 | Acrylic Powder | ACRYL 1P |
| Rohm & Haas | Rhoplex MC-1834 | Acrylic Emulsion | ACRYL 1E |
| Shell Chemical | Epon 828 Resin | Bisphenol A - Epoxy Resin | EP |
| SKW/CORMIX | Melment L-10 | Superplasticizer<br>Sulfonated melamine formaldehyde | SP |
| Union Carbide | Elotex WS-45 | VeoVa Powder<br>Vinyl Ester of Versatic Acid | VeoVa |

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## Table 2 - Phase I Variable Matrix

| Batch | Primary Admixture | Flow [a] Low | Med. | High | Brick IRA 9.7 | 27 | Secondary Admixture Air | Defoam | Plast. |
|-------|-------------------|-----|------|------|-----|----|-----|--------|--------|
| A | Control | ● | | | ● | | | | |
| B | Control | ● | | | ● | ● | | | |
| C | Control | | | ● | ● | ● | | | |
| D | Control | | ● | | ● | ● | | | |
| E | AIR | | ● | | ● | | ● | | |
| F | DEFOAM | | ● | | ● | | | ● | |
| G | SP | | ● | | ● | ● | | | ● |
| H | SP | | | ● | ● | ● | | | ● |
| I | MB-SF | ● | | | ● | | | | |
| J | MB-SF | | ● | | ● | | | | ● |
| K | ACRYL 1E | | ● | | ● | | | ● | |
| L | ACRYL 1E | | ● | | ● | | | ● | ● |
| M | S-B | ● | | | ● | | | ● | |
| N | S-B | | | ● | ● | | | ● | ● |
| O | STY-ACRL | ● | | | ● | | | ● | |
| P | STY-ACRL | | ● | | ● | | | ● | ● |
| Q | EVA 1P | | ● | | ● | | | ● | |
| R | EVA 1P | | ● | | ● | | | ● | ● |
| S | ACRYL 1P | | ● | | ● | | | ● | |
| T | ACRYL 1P | | | ● | ● | | | ● | ● |
| U | AIR | | ● | | ● | | | | |
| V | S-B | ● | | | ● | | | | |

a - Low flow is less than 110%, medium flow is between 110 and 120% and high flow is greater than 120%

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## Table 3 - Phase II Variable Matrix

| Batch | Primary Admixture | Flow [a] | | | Brick IRA | | Admix. | | Sub-Topic | | |
|-------|-------------------|-----|-----|-----|-----|-----|-----|-----|------|------|------|
| | | Low | Med | Hi | 9.7 | 27 | Def | SP | Cube | Sand | Flex |
| W | Control | ● | | | ● | | | | ● | | |
| X | Control | ● | | | ● | | | | ● | | |
| Y | Control | ● | | | ● | | | | ● | | |
| Z | Control | | ● | | ● | | | | ● | | |
| AA | Control | ● | | | ● | | | | ● | | |
| AB | Control | | ● | | ● | | | | ● | | |
| AC | Control | | | ● | ● | | | | ● | | ● |
| AD | ACRYL 1E | | | ● | ● | | ● | ● | ● | | ● |
| AE | SP | | | ● | ● | | | ● | ● | | ● |
| AF | Control | | | ● | ● | | | | ● | | |
| AG | Control | | ● | | ● | | | | ● | | |
| AH | Control | | | ● | ● | | | | ● | | |
| AI | Control | ● | | | ● | | | | ● | ● | |
| AJ | Control | | | ● | ● | | | | ● | ● | |
| AK | Control | | | ● | ● | | | | ● | ● | |
| AL | SP | | | ● | ● | | | ● | ● | ● | |
| AM | ACRYL 1E | ● | | | ● | | ● | ● | ● | ● | |
| AN | ACRYL 2P | ● | | | ● | | ● | | ● | | |
| AO | ACRYL 3E | | ● | | ● | | ● | | ● | | |
| AP | ACRYL 2E | | ● | | ● | | ● | | ● | | |
| AQ | CURABL | ● | | | | ● | ● | | | Epox | |
| AR | CURABL + | ● | | | | ● | ● | | | Epox | Lime |
| AS | CHLORO | COAGULATION | | | | | | | | | |
| AT | ACRYL 4E | ● | | | ● | | ● | | | | |
| AU | VeoVa | ● | | | ● | | ● | | | | |
| AV | EVA 1E | ● | | | ● | | ● | | | | |
| AW | EVA 2P | ● | | | ● | | ● | | | | |
| AX | EP | ● | | | | ● | | | | Epox | |
| AY | EP + | ● | | | | ● | | | | Epox | Lime |
| BB | Control | | ● | | | ● | | | Cem. | Sand | Ctrl |

a - Low flow is less than 110%, medium flow is between 110 and 120% and high flow is greater than 120%

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to predict the bond strength of a type S mortar for comparison with modified mortars having similar initial properties.

Information on the basic masonry materials used in the experimental program is presented in Table 4.

*Testing*
All strength tests were performed twenty-eight days following preparation. For each batch, averages and standard errors were reported for the following:

Dry Cured
- o   3 cylinders in compression
- o   3 split cylinders
- o   6 crossed couplets

Moist Cured
- o   3 cylinders in compression
- o   3 split cylinders
- o   6 crossed couplets

All totaled, the following number of tests were performed:

- o   371 - 3" x 6" cylinders in compression
- o   306 - 3" x 6" split cylinder tests
- o   120 - 2" cubes in compression
- o   210 - joints in flexure
- o   636 - crossed couplets

## RESULTS

This paper discusses only data associated with the direct tensile bond strength tests. The bond strength data has been organized into sub-groups in the investigation. These groups are; control group, washed sand group, superplasticizer group, latex group, and the epoxy group. Due to the number of variables included in this research, combinations of admixtures were limited to phase one batches. The number of trials was also limited to one for most combinations, so that a wide variety of polymers could be tested. It was decided to keep the brick IRA, base mortar composition, admixture addition rate, and water: cement ratio (W/C) constant within each group for comparison. Holding W/C constant did not give reproducible flow or air content, so comparison of the mortars from one trial is not as exact as could be done in a program employing multiple trials, as was done for the control group.

Figures 1 and 2 show all of the recorded tensile bond strength results from moist and dry cured specimens respectively. The horizontal line splitting the graphs at 80 psi indicates the maximum bond strength expected from a type S mortar using the same materials.

## Table 4 - Experimental Program Materials

- **Cement:** Portland Type I
- **Lime:** Hydrated Type S
- **Sand:** Manufactured Mason's Sand
  - Absorption: .13% - .16%
  - Specific Gravity: 2.482
  - Fineness Modulus: 1.47 - 1.49 (very fine)
- **Brick:** Severe Weathering Solid, Face Brick
  - Extruded, Wire Cut
  - All brick came from two cubes, color varied within each cube
  - Initial Rate of Absorption
    - Dark red: 4-15 g/30in$^2$/min. (Avg. = 9.7)
    - Light red: 18-31 g/30in$^2$/min. (Avg. = 27)
  - Compressive Strength (n = 12) (not appreciably different)
    - Dark red: $\bar{x}$ = 12,466 psi; $s$ = 822 psi
    - Light red: $\bar{x}$ = 10,867 psi; $s$ = 895 psi

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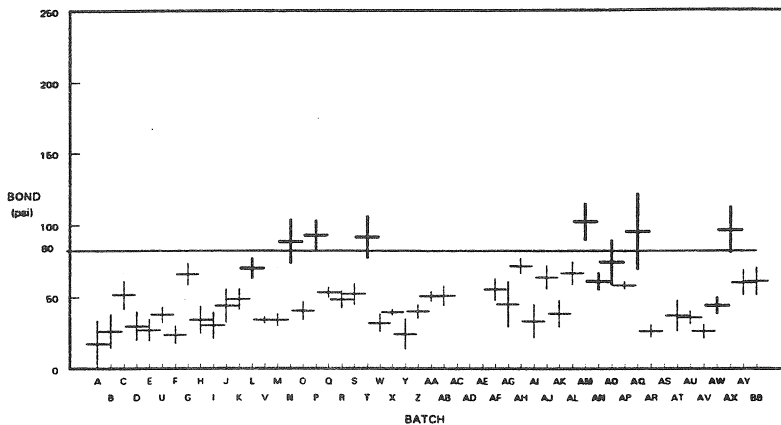
**Fig. 1 - Wet Cured Tensile Bond Strength At 90% Confidence Interval**
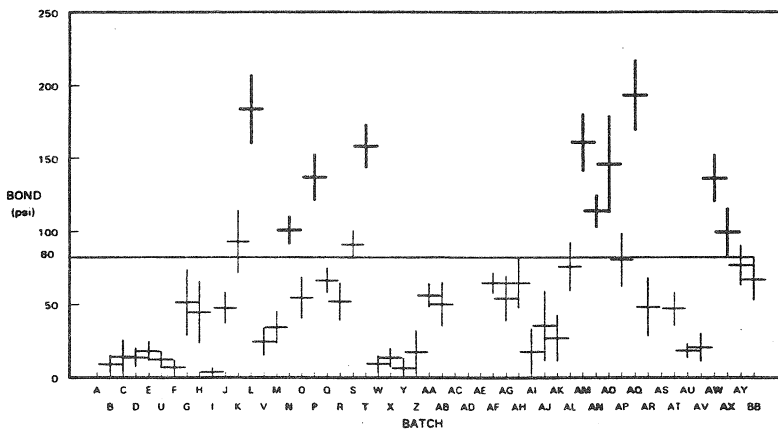


**Fig. 2 - Dry Cured Tensile Bond Strength At 90% Confidence Interval**

It appears that acrylic latencies consistently provide improved bond strength, except for ACRYL 4E. The surfactant used to prevent coagulation during storage of the latex emulsion could be incompatible with lime.

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The purpose of this investigation was to identify polymers which could be used in masonry mortars to improve the tensile bond strength. In light of the limited, but dramatic bond strength increases displayed in these results, the authors believe that acrylic latex polymers in general hold the best promise for structural applications. Acrylics are typically very durable and weather well, and are resistant to damage from ultra violet light. Individual polymers should be tested for compatibility with several plasticizers, and determine whether addition of plasticizer in the emulsion is stable for packaging purposes. The results indicate that EVA 2P is also a candidate for further investigation.

*Epoxy Group*
The epoxy group was the last series tested in this program. As a result, it was decided to try the polymers with and without lime in the mortar. The combinations with lime resulted in lower bond strengths, and reduced pot life of the mortar. The CURABL latex-epoxy combination with lime results are very low, due to the fact that the mortar had to be retempered to make couplets. Lime caused the potlife to be reduced to approximately twenty minutes, allowing only sufficient time for making cylinders and recording the flows and air content.

From the experience working with these mortars, the authors believe that epoxy modification should not be used for general structural applications, but could be a significant specialty application with structural benefits. The reasons for this opinion are that the precision required for batching and working with epoxy modified mortar would not be commonly found in practice, and that only an application requiring excellent durability and chemical resistance could justify the expense of incorporating the epoxy. Such an application would be structural glazed tile shearwalls in a chemical plant or food preparation facility.

## CONCLUSIONS

Polymer modified mortars hold great promise as a way of dramatically increasing the bond strength of masonry mortars. Several polymers have been identified as candidates for further investigation.

## REFERENCES

Kampf, Leo. (1962), "Factors Affecting Bond of Mortar to Brick." Symposium on Masonry Testing, ASTM Special Technical Publication (STP) No. 320 Philadelphia, PA: American Society for Testing and Materials, pp. 127-140.

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