Polyester Mortar

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Synopsis

The basic properties of polyester resin mortar have been studied. These properties included compressive strength, flexural strength, modulus of elasticity, shrinkage, and resistance to sulfuric acid. The main variables were the polymer content, the ratio of coarse sand to filler, the method of curing, and the age. The properties of Portland cement mortar were also studied for comparison.

Polyester mortar shows a higher rate of hardening, higher strength, and higher resistance to sulfuric acid than cement mortar. On the other hand, polyester mortar shows lower modulus of elasticity and higher shrinkage than cement mortar.

INTRODUCTION

Polymer concrete is a composite material consisting of polymers incorporated in concrete. Its behavior depends mainly on the method of incorporation and, hence, the type of the produced polymer concrete.[1] The family of polymer concrete generally includes three types: polymer cement concrete (PCC), polymer-impregnated concrete (PIC), and polymer concrete (PC), which is some times called plastic concrete or resin concrete.[2-4] The term "resin concrete" is used to describe materials in which resin rather than Portland cement is used as the binder for aggregate particles.[5,6]

Polyester resin and epoxy resin mortars have been widely used in repair and strengthening reinforced concrete structures around the world.[7-9] During the last few years polyester resin mortar has been used in repair works in Egypt. However, before it becomes more widely used it is necessary to investigate its properties especially in the hot climate.

EXPERIMENTAL

Polyester resin is commercially available in the market in Egypt and is imported by different companies that deal with chemicals used in the repair of concrete. In the near future this resin could be produced locally when the Egyptian petrochemical project is completed.

The polyester resin used consists of a liquid and a filler blend containing a catalyst. Polyester resin mortar mixes were prepared by mixing the liquid

Journal of Applied Polymer Science, Vol. 33, 1609–1622 (1987)
 CCC 0021-8995/87/051609-14$04.00

TABLE I
Scheme of Mortar Testing[a]

Type of mortar	Cement-Sand-w/c	PFS (polymer-filler-sand)	Age of test	Test property
Cement mortar	1:3:0.5	—	3,7, and 28 days	1. Compressive strength
Polyester mortar	—	1:3:0 1:4:0 1:3:1 1:3:3	2 h, 4 h, and 1, 3, 7, and 28 days	2. Flexural strength 3. Modulus of elasticity[b] 4. Acid resistance[b]

[a]Method of curing: air and oven at 60 °C.
[b]Tested at 28 days only.

resin and the filler blend containing the catalyst. Sand was added to some mixes. Table I shows a schedule of the different mixes used in this investigation.

Polyester resin mortar constituents were mixed and compacted manually. Tests were carried out on 40-mm cubes for the compression test, beams 40 × 40 × 160 mm for the flexural test, and cylinders of 75 mm diameter and 150 mm height for the modulus of elasticity tests. The shrinkage test was carried out on 20 × 20 × 280 mm prisms. Polyester resin test specimens were cured either in air or in an oven at 60 °C until the testing date.

For the acid resistance test a solution of 1 *N* sulfuric acid was prepared as recommended in the ASTM Standards.[(10)] The test specimens were soaked in the solution at the age of 28 days for 48 h. The specimens were then taken out of the solution and left in air to dry for 48 h and compression and flexure strength tests were carried out on the different test specimens.

TEST RESULTS

Table II represents the effect of age, polymer content, and method of curing on the compressive and flexural strengths of the polyester mortar mixes studied in this research work.

It is indicated that the compressive strength of polyester mortar is much higher than that of the standard cement mortar mix at all ages. Polyester mortar shows more rapid development of compressive strength than standard cement mortar. It gains most of its compressive strength within 2 h at a temperature of 20 °C or more. Polyester mortar shows compressive strength 425–717% higher than that of cement mortar at 3 days of age. At 28 days of age, polyester mortar compressive strength is higher than that of cement mortar at the same age by a range varying from 263 to 380%.

Compressive strength of polyester mortar is generally affected by the polymer-aggregate ratio, filler content, and curing condition.

Within the range of polymer-aggregate ratio considered in this investigation, the compressive strength of polyester mortar increased as the polymer content increased. The rate of increase of compressive strength decreased as the polymer content decreased. This observation is more evident for ages of 7 and 28 days (Fig. 1).

TABLE II
Compressive and Flexural Strength of Polyester Mortar

Tested property	Method of curing	Age	Cement mortar	Polyester mortar (PFS)[a] 1:3:0	1:4:0	1:3:1	1:3:3
Compressive strength (kg/cm^2)	Air (20° C)	2 h	—	1000	813	738	606
		4 h	—	1013	850	750	625
		1 day	—	1081	938	813	688
		3 days	140	1144	1000	875	738
		7 days	210	1150	1013	894	750
		28 days	240	1150	1013	900	760
	Oven (60° C)	2 h	—	925	825	763	588
		4 h	—	950	850	788	500
		1 day	—	1025	925	863	575
		3 days	140	1075	950	900	588
		7 days	210	1088	963	925	613
		28 days	240	1100	967	925	615
Flexural strength (kg/cm^2)	Air (20° C)	2 h	—	295	263	243	210
		4 h	—	302	269	249	230
		1 day	—	315	289	263	236
		3 days	21	318	295	269	240
		7 days	32	328	302	275	245
		28 days	38	339	312	280	250
	Oven (60° C)	2 h	—	312	233	203	184
		4 h	—	322	236	210	190
		1 day	—	348	276	256	223
		3 day	21	248	282	262	230
		7 days	32	348	290	270	236
		28 days	38	348	290	270	243

[a] P = polymer content, F = filler content; S = sand content.

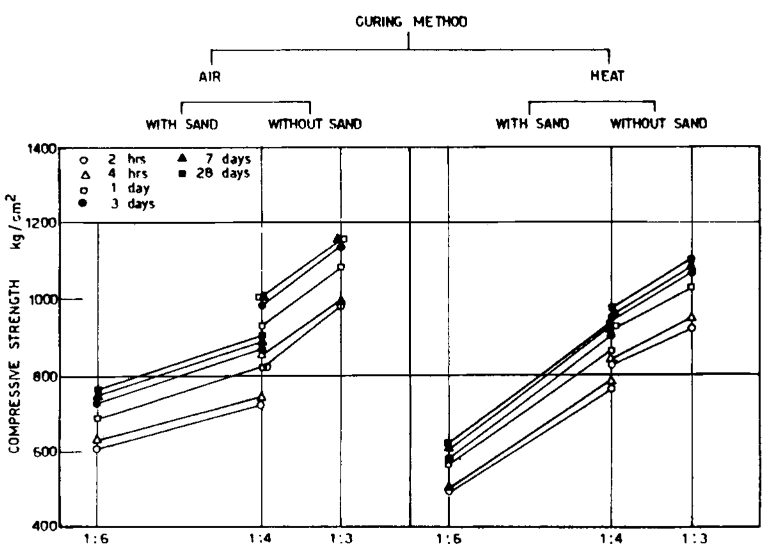

Fig. 1. Effect of polymer content on compressive strength of polyester mortar.

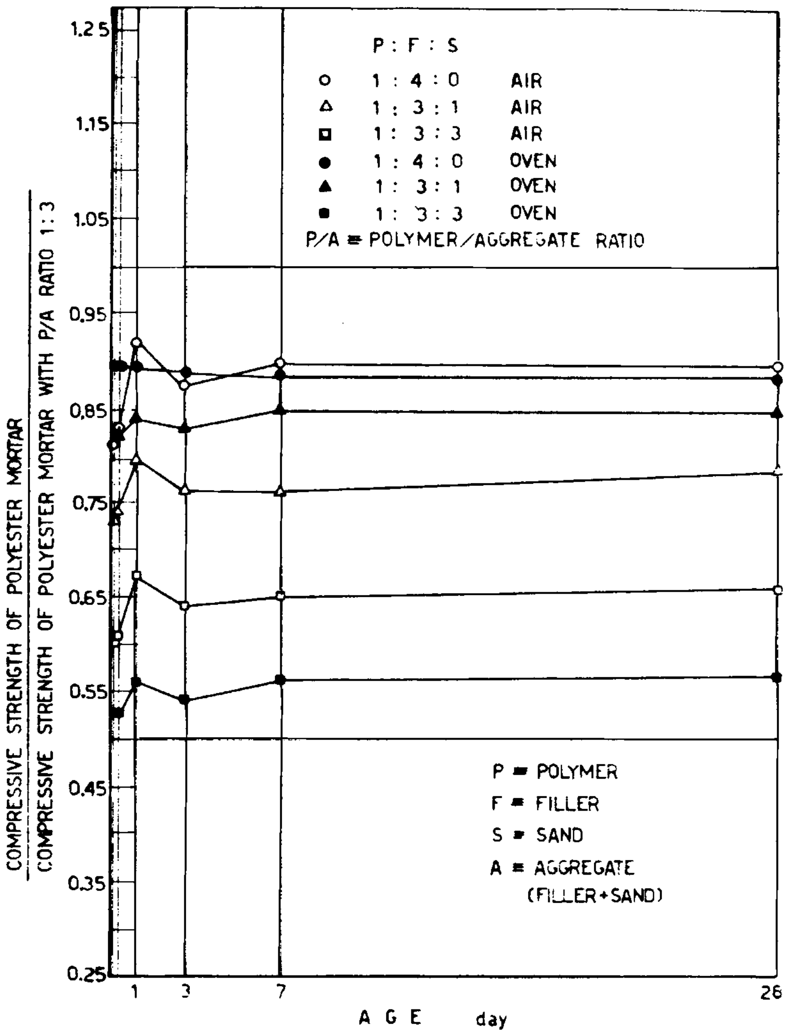

Fig. 2. Effect of sand content on compressive strength of polyester mortar.

Replacement of a part of the filler with coarse sand decreases the compressive strength of polyester mortar. The reduction increased with oven-treated specimens and with the increase in coarse sand content (Fig. 2).

Figure 3 indicates that the compressive strength of polyester mortar increases with age for all polymer-aggregate ratios considered in this study. Most of the gain in the strength of polyester mortar was attained at the earlier ages and up to 2 h. Very little gain in strength is observed after this age and up to 28 days. This observation is valid for all the specimens having the different polymer-aggregate ratios used in this investigation and either cured in air or heated in an oven. The ratio of compressive strength of polyester mortar at different ages to that at 28 days age is represented in Table III.

Heat-treated polyester mortar specimens at 60°C have shown a slight variation of ±6% in compressive strength in comparison with those cured in air at 20°C, as shown in Figure 4. This observation was found at high

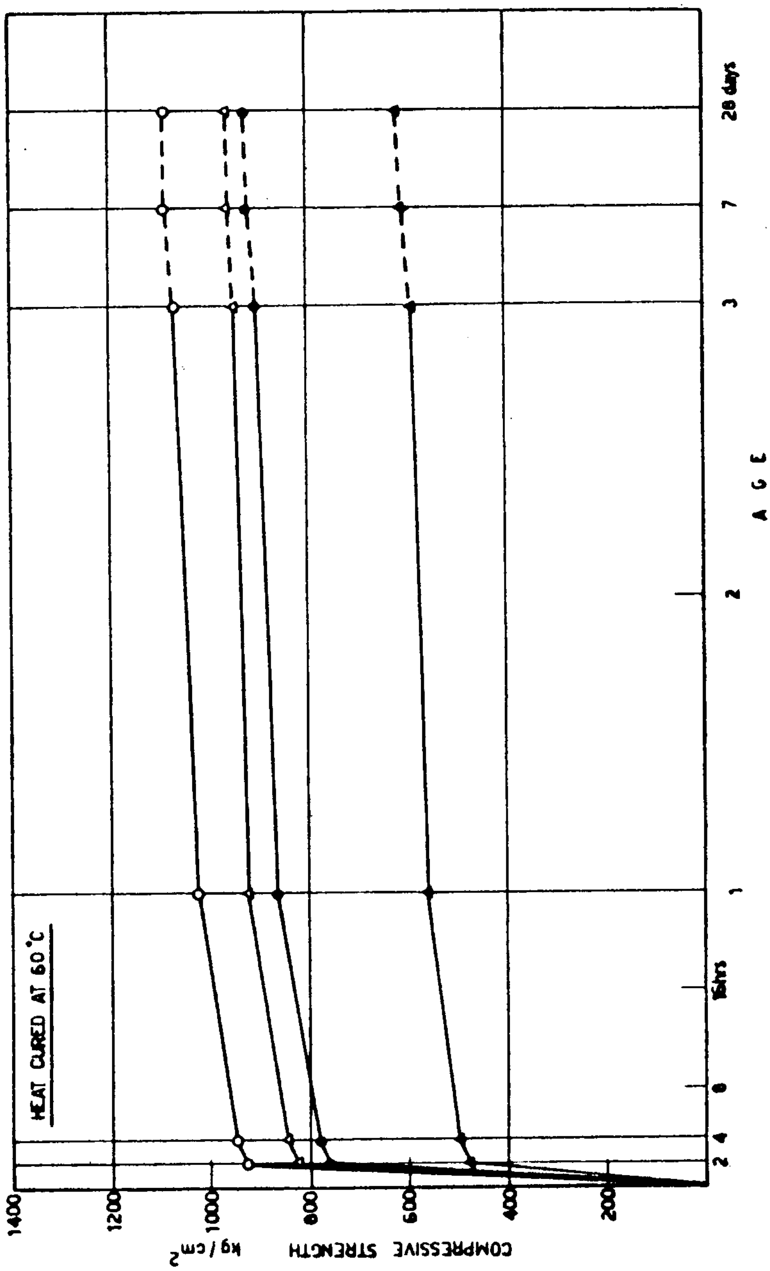

Fig. 3. Compressive strength of polyester mortar.

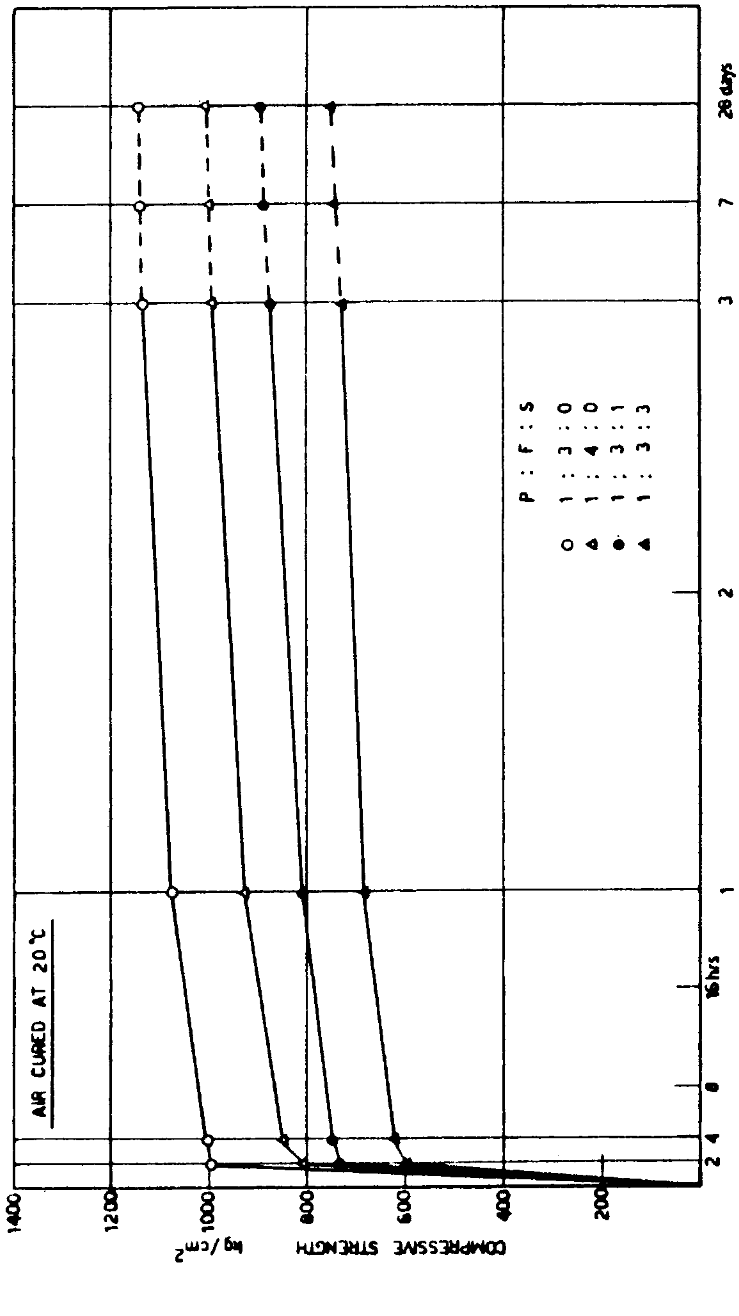

Fig. 3. *(Continued from the previous page.)*

TABLE III
Effect of Age on Compressive Strength of Polyester Mortar

Method of curing	PFS[a] Ratio	2 h/28 days (%)	4 h/28 days (%)	1 day/28 days (%)	3 days/28 days (%)	7 days/28 days (%)
Air	1:3:0	86.96	88.09	94.00	99.48	100
	1:4:0	80.26	83.91	92.60	98.72	100
	1:3:1	82.0	83.37	90.33	97.22	99.33
	1:3:3	79.74	82.24	90.53	97.11	98.68
Oven	1:3:0	84.09	86.36	93.18	97.73	98.91
(60 °C)	1:4:0	85.31	87.90	95.66	98.24	99.59
	1:3:1	82.49	85.19	93.30	97.30	100
	1:3:3	79.35	81.3	93.50	95.61	99.67

[a] Polymer-filler-sand.

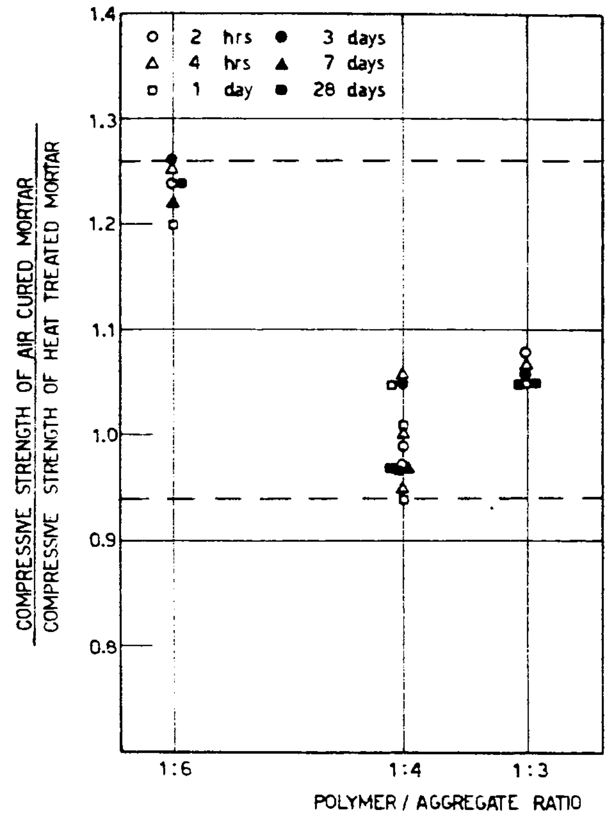

Fig. 4. Comparison between compressive strength of air-cured and heat-treated polyester mortar.

polymer-aggregate ratios. However, a reduction of about 23% was determined at the low polymer-aggregate ratio of 1 : 6.

The flexural strength of polyester mortar at 28 days of age varied from 639 to 916% times that of the standard cement mortar, as shown in Table II. Figure 5 indicates that flexural strength of polyester mortar increases as resin

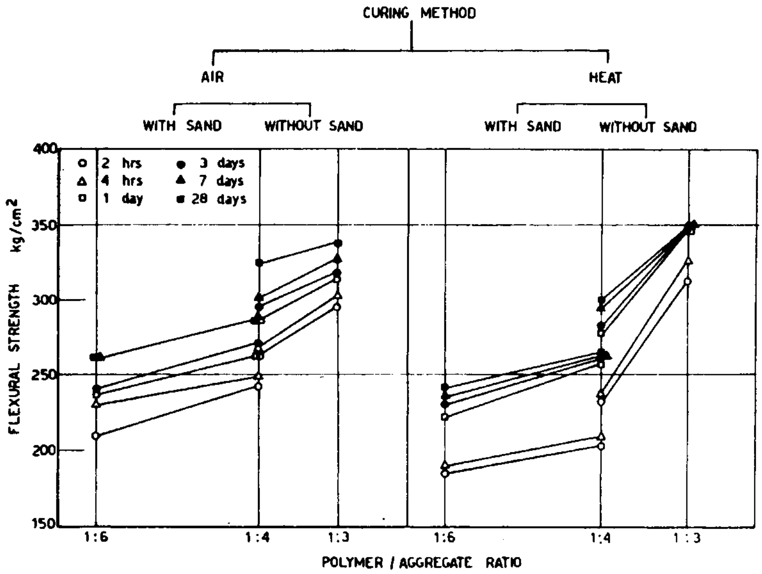

Fig. 5. Effect of polymer content on flexural strength of polyester mortar.

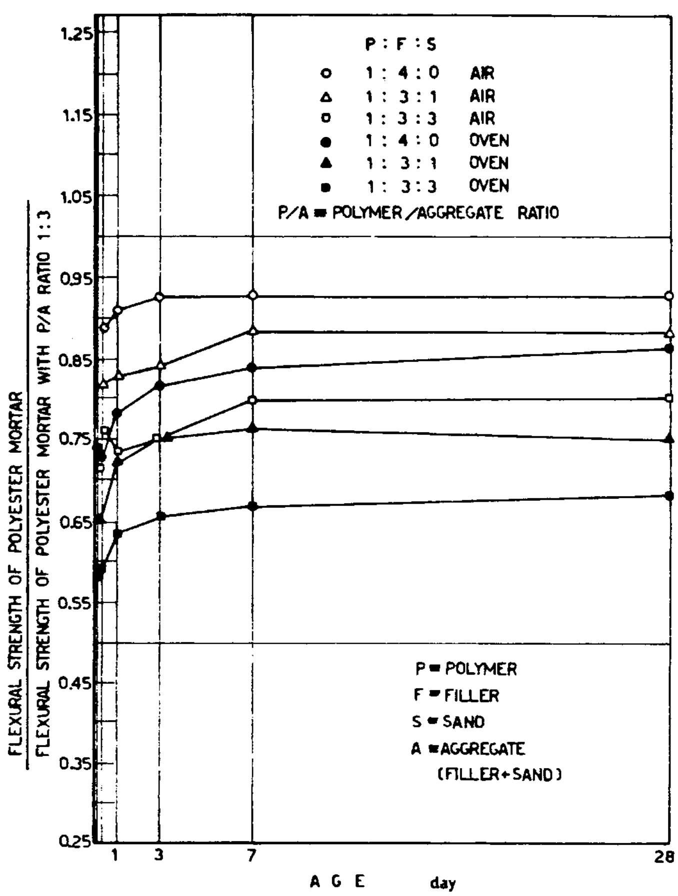

Fig. 6. Effect of sand content on flexural strength of polyester concrete.

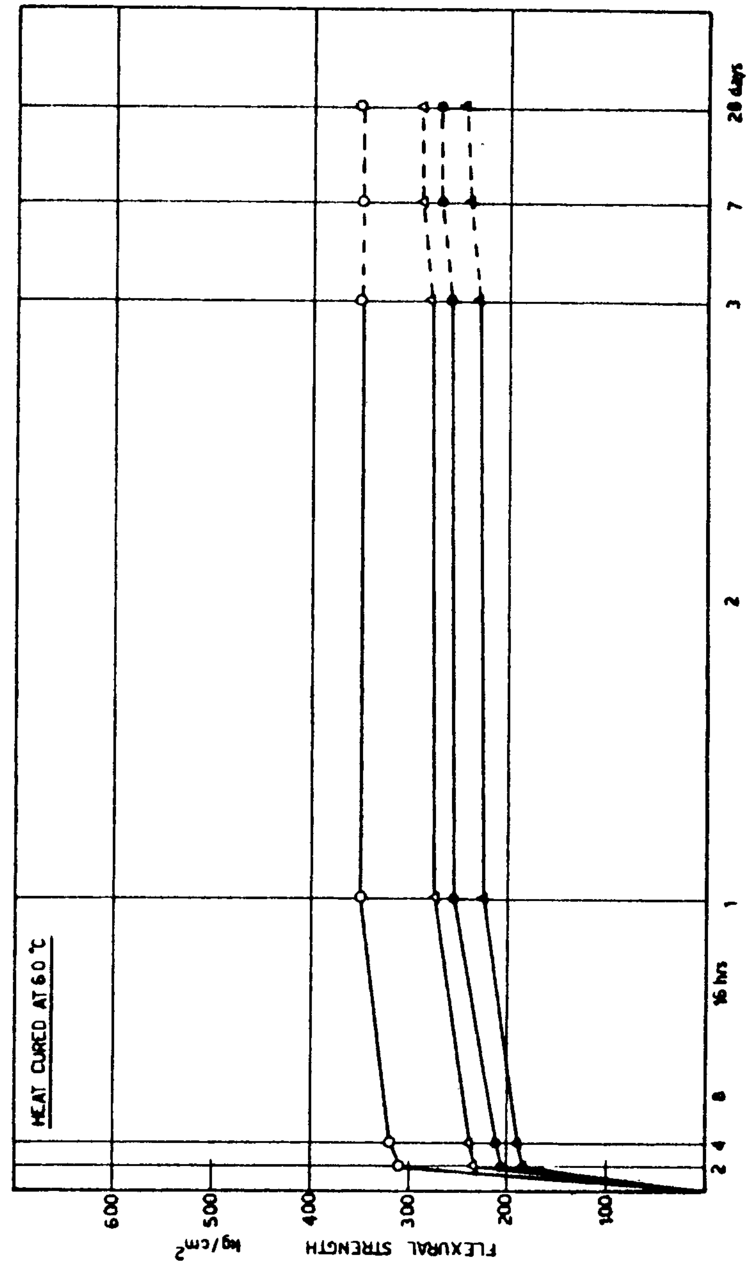

Fig. 7. Flexural strength of polyester mortar.

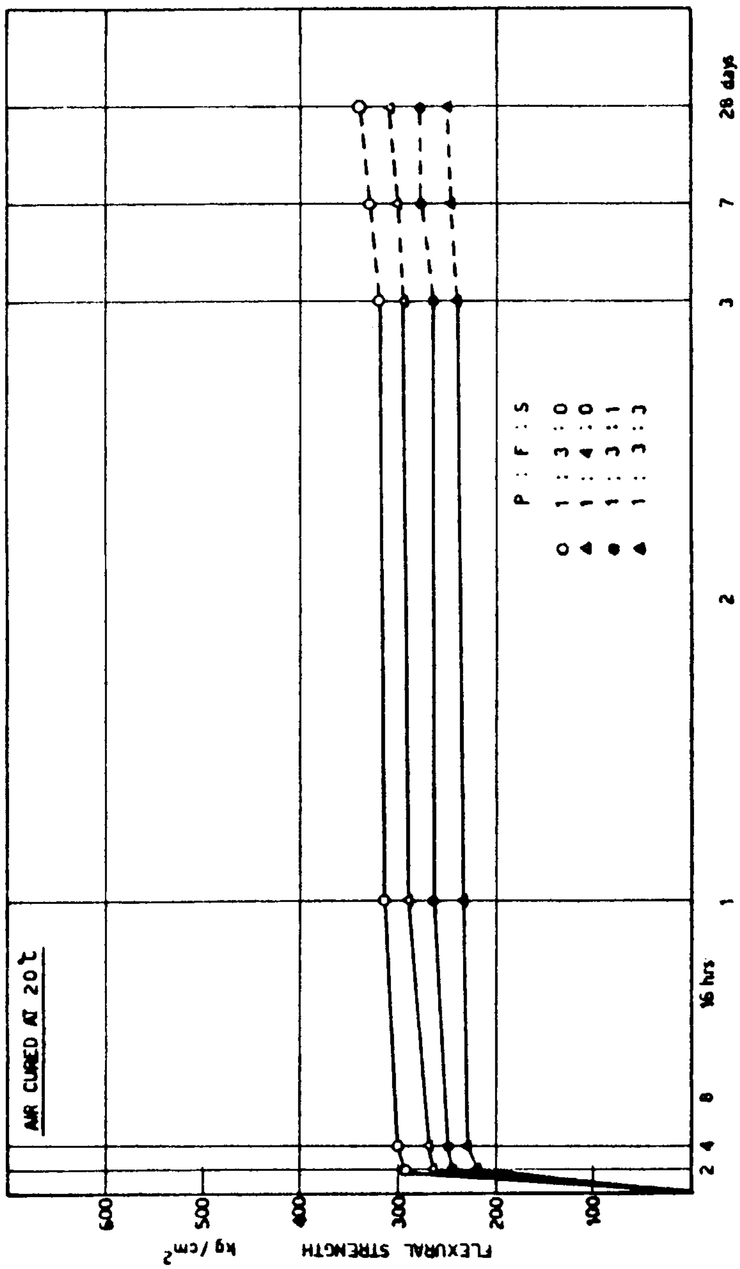

Fig. 7. (*Continued from the previous page.*)

TABLE IV
Effect of Age on Flexural Strength of Polyester Mortar

Method of curing	PFS	2 h/28 days	4 h/28 days	1 day/28 days	3 days/28 days	7 days/28 days
Air	1:3:0	87.02	89.09	92.92	93.81	96.76
	1:4:0	84.3	86.2	91.35	94.55	97.0
	1:3:1	86.78	89.0	94.0	96.0	98.0
	1:3:3	84.0	92.0	94.4	96.0	92.0
Oven	1:3:0	89.66	92.53	100	100	100
(60° C)	1:4:0	80.34	81.38	95.17	97.24	100
	1:3:1	75.19	77.8	94.8	97.0	100
	1:3:3	75.72	78.19	91.77	94.64	97.12

content increases. For heat-treated polyester mortar, the rate of increase in flexural strength with the increase of resin content is relatively higher than that recorded for air-cured specimens.

The use of coarse sand to replace a part of the filler in the polyester mortar decreases the flexural strength, as shown in Figure 6. The flexural strength of polyester mortar increases with age, as shown in Figure 7. The rate of gain in flexural strength with age is relatively high at the early ages compared with that at later ages. For age up to 2 h, the gain in the flexural strength of the investigated polyester mortar mixes represented about 81% of that recorded at 28 days age, as shown in Table IV.

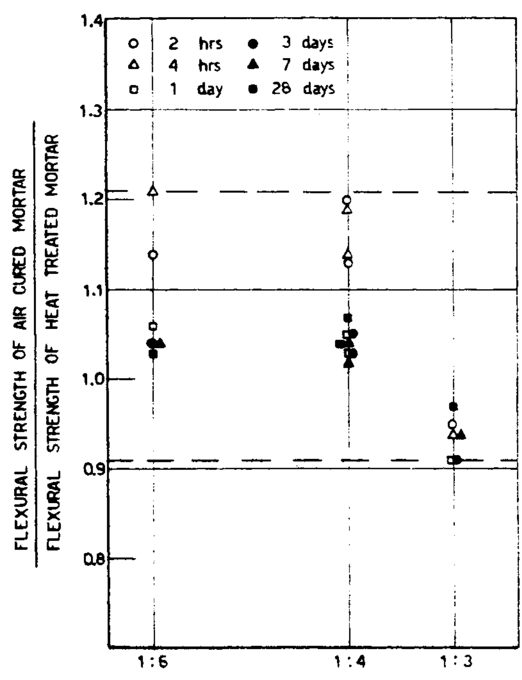

Fig. 8. Comparison between flexural strength of air-cured and heat-treated polyester mortar.

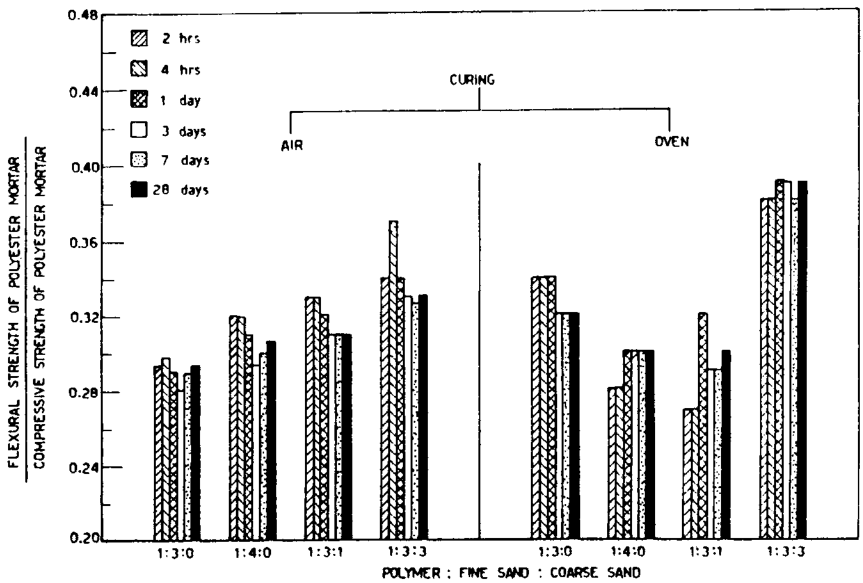

Fig. 9. Relation between flexural strength and compressive strength of polyester mortar.

Heat treating of polyester mortar slightly affected its flexural strength. In comparison with air-cured specimens, the flexural strength of heat-treated samples varied in the range of ±10% (Figure 8).

The ratio of flexural strength to compressive strength of polyester mortar is relatively higher than that of standard cement mortar, as can be found from Table II. This observation is valid for all mixes investigated in this study. At 28 days of age, the ratio of flexural strength to compressive strength of polyester mortar mixes averages about 30%, as shown in Figure 9. However, this ratio is about 16% for standard cement concrete specimens.

The modulus of elasticity and the shrinkage characteristics of polyester mortar mixes in comparison with cement mortar are shown in Table V. In general, polyester mortar has a lower modulus of elasticity and higher shrinkage than cement mortar. The modulus of elasticity of polyester mortar ranges between 46 and 54% of that of cement mortar. A lower modulus of elasticity was found with polyester mortar mixes with higher aggregate-polymer ratios.

TABLE V
Modulus of Elasticity and Shrinkage of Polyester Mortars at 28 Days Age

Tested property	Method of drying	Age	Cement mortar	Polyester mortar 1:3:0	1:4:0	1:3:1	1:3:3
E	Air	At	28	15	14	14	13
(kg/mm^2)	Oven (60 °C)	28 days	28	13	12	12	11
Shrinkage	Air	After	0.05	0.8	0.75	0.76	0.6
(%)	Oven (60 °C)	28 days from casting	0.06	0.75	0.73	0.7	0.58

TABLE VI
Effect of Sulfuric Acid on the Mechanical Properties of Resin Mortar

Type of mortar	Property	Cured in laboratory atmosphere for 28 days	Cured in laboratory atmosphere for 28 days then immersed in H_2SO_4 for 28 h
Cement mortar	Compressive strength (kg/cm^2)	240	170
	Flexural 38 strength (kg/cm^2)	33	
Polyester mortar (PSF, 1 : 4 : 0)	Compressive strength (kg/cm^2)	367	953
	Flexural strength (kg/cm^2)	300	296

Polyester mortar specimens treated in oven at 60°C for 28 days showed a reduction between 13 and 15% of those cured in air. The shrinkage of polyester mortar specimens cured in air for 28 days after casting ranged between 12 and 16 times that of cement mortar. However, the shrinkage of polyester mortar specimens cured in oven at 60°C for 28 days after casting ranged between 9.7 and 12.5 times that of cement mortar.

Effect of Sulfuric Acid Solution on Resin Mortar

Negligible reduction in either compressive or flexural strength was found with resin mortars after immersion in H_2SO_4 solution for 48 h, as shown in Table VI. However, a reduction of 30 and 20% was found in the compressive strength and flexural strength, respectively, when cement mortar specimens were subjected to the same conditions as resin mortars.

CONCLUSIONS

Polyester mortar has a considerably higher rate of hardening and gaining strength compared with that of ordinary portland cement mortar. It has gained most of its strength within 2 h after casting.

Within the limits considered in this work, resin mortar strength—compression and flexure—increased as polymer content in the mix increased.

For all polymer-aggregate ratios considered in this research, the corresponding resin mortar mix strength compression and flexure are higher than those recorded for the control standard cement mortar (cement-sand, 1 : 3 by weight) mix specimens. Higher differences are for resin mortar mixes with higher polymer content.

The strength of polyester mortar decreased as part of the filler in the mix was replaced by coarse sand. The reduction increased with the increase in sand content.

A slight variation in the polyester mortar strength was found as it was cured in oven at 60°C.

Polyester mortar has shown excellent resistance to sulfuric acid in comparison to cement mortar, which shows a great reduction in strength.

Although polyester mortar develops its strength at a very rapid rate, it suffers from very high shrinkage characteristics and a relatively lower modulus of elasticity than cement mortar. Consequently, the use of polyester mortar is recommended to be confined to nonstructural repairs.

References

1. RILEM, Working Group Admixtures, Classifications and Definitions of Admixtures, International RILEM Symposium on Admixtures for Mortar and Concrete, Brussels, 1967.
2. M. Steinbery, Concrete Polymer Materials and Its Worldwide Development, AC2, SP-40, 1974.
3. J. T. Dikeow, Review of Worldwide Development and Use of Polymers in Concrete, Proceedings of the First International Congress on Polymer Concrete, 1976.
4. W. G. Potter, *Use of Epoxy Resin*, Butterworths, London, 1975.
5. D. Jejcis, General Report, RILEM, September 1965.
6. L. Rechner, Concrete and Mortars Without Cement, RILEM, May-June 1968.
7. R. L. Holdsworth, Chemicals and Their Use in Repairs to Concrete, First Egyptian Structural Engineering Conference, Cairo University, April 1985.
8. L. J. Tabor, Effective use of epoxy and Polyester Resins in Civil Engineering Structures, CIRIA Report 69, Construction Industry Research and Information Association, London, January 1978.
9. A. F. Cusens, and D. W. Smith, A study of epoxy resin adhesive joints in shear, *Structural Engineering*, **58A**, January 1980.
10. ASTM Standards, Masonry Products, Ceramics, Thermal Insulation, Acoustical Materials, Sandwich and Building Constructions, Fire Tests, Part 5, ASTM Designation C279-54, 1958.

Received March 18, 1986
Accepted May 12, 1986