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Testing for engineering and durability properties of an epoxy mortar system

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ABSTRACT

Epoxy mortar systems are becoming a more widely used method of repair for reinforced concrete structures due to their high strength, rapid hardening and ease of application. The durability of some of these systems, however, is still in some doubt.

In this paper the engineering properties and durability of a particular type of repair mortar consisting of a two component epoxy mortar system, available in the market and meeting ASTM C881 specifications for epoxy resins, was investigated. The effect of sulphuric acid, sodium hydroxide and sodium chloride solutions at 40°C and 70°C on compressive strength and weight of the epoxy mortar was investigated for time durations up to 100 days. The compressive strength, tensile strength, flexural strength, bond strength and modulus of elasticity were also determined at 23°C and 40°C along with the water absorption for this type of epoxy mortar.

An increase in weight was observed at all ages. The change in the durability and engineering properties for the investigated type of epoxy mortar was found to be tolerable, except for temperatures close to 70°C where about a 40% reduction in compressive strength was observed.

INTRODUCTION

Deficiencies in the behavior of reinforced concrete structures can occur as a result of deterioration which could be due to environmental conditions, chemical attack, freeze—thaw damage or water, or due to factors such as fatigue, overloading, fire damage or natural forces such as earthquakes, high winds, snow or rain. Deficiencies in structures could also occur due to design deficiencies such as calculation errors, mix design, concrete cover, thermal forces and reinforcing details or due to construction or material deficiencies. In all cases deficient structures require remedial attention or repair. The repair of structures using epoxy, is on the increase. Due to its low viscosity, epoxy could be used to repair small cracks by injection (Basunbul *et al.* 1990, Masonry 1987, Moriconi *et al.* 1991). For wider cracks, however, mortars are usually required. The use of cementitious mortars for repair is diminishing and it is being replaced by epoxy mortars due to their fast hardening, low viscosity and more importantly, controlled shrinkage (ACI Committee 503R 1993). Even in cases where cementitious mortar is used, an epoxy layer is commonly applied to bond mortar to old concrete. For the repair of honeycombing or large voids, batches of epoxy mortars or epoxy concrete could be used (Fowler 1989). Epoxy may also be used for coating rebars to limit steel corrosion (Treece 1989).

Due to the advances in the manufacture of different types of epoxies, to meet physical and mechanical properties such as viscosity, shrinkage, strength, ductility, time of hardening among others, the types of epoxies available in the market are increasing. There is a need to develop information on durability of different types of epoxies under various conditions (Al-Mandil 1990). In this paper the effect of sulphuric acid, sodium hydroxide and sodium chloride solutions at different temperatures and for different durations on the strength and weight of an epoxy mortar is investigated. Also studied are the tensile, flexural and bond strengths and modulus of elasticity at different temperatures.

MATERIALS AND SAMPLE PREPARATION

The tested mortar consisted of solvent-free epoxy resin, as a binding material, mixed with a blend of a well-graded fine siliceous aggregates. The epoxy resin meets with the ASTM C881 specifications for epoxy resin base bonding systems for concrete and the fine aggregates are prepacked by the manufacturer with maximum aggregate size of 0.5 mm. The epoxy resin consisted of a hardener and a base material. The hardener and the base were mixed together for 5 minutes. The aggregates were then added slowly during mixing which continued for 3 more minutes to assure homogeneity of the mix. The ratio of epoxy to aggregates is 1 : 7 by weight as recommended by the manufacturer.

Mortars were then poured into moulds to prepare the required specimens. For compressive strengths and chemical resistance tests, 50 mm × 50 mm × 50 mm cubes were cast. For the flexure test, beams of 25 mm × 25 mm × 300 mm were utilized. The beams were tested on a span of 229 mm. For the tensile strength test, briquette molds that comply with ASTM C 307-94 specification were used with specimen size (smallest cross-section) of 1 in. × 1 in. (25 mm × 25 mm) and for the water absorption test, test cylinders of 25 mm in diameter by 25 mm in height were used.

To examine the bond strength of the epoxy resin, the slant shear test was used. Halves of Portland cement concrete cylinders inclined at 30° and of dimensions 152.4 mm in height and 76.2 mm in diameter were cast. Specimens were cured in average temperature of 22° and average humidity of 30%.

PROCEDURE AND CALCULATIONS

Chemical resistance testing (ASTM C267-90)

Specimens were cured for 7 days before immersion in 17% sulphuric acid solution at 40°C and 70°C for time durations of 1, 7, 28, 56 and 100 days. Three replicate specimens were tested for each age and temperature. Specimens were weighed and then loaded to failure in compression. The change in weight, compressive strength and change in compressive strength at each test age and temperature were recorded. The same test procedure was used for specimens immersed in 20% sodium hydroxide and 70% sodium chloride solutions.

Compressive strength (ASTM C579-91)

Compressive strengths of specimens cured for 1, 7, 28 and 100 days at 23°C and 40°C were determined. For each test age and temperature, the average of three replicate specimens are reported in Table 1.

Tensile strength (ASTM C307-94)

Specimens were loaded in tension and the tensile strength was determined after 7 days of curing at 23°C and 40°C. For each temperature, the average of 6 replicate specimens are shown in Table 2.

Flexural strength and modulus of elasticity (ASTM C580-93)

Flexural strength and modulus of elasticity at 23°C and 40°C for specimens cured for 7 days were determined. Beams were loaded in simple bending using a central

Table 1. Chemical resistance test results.

	Age (days)				
Exposure condition	1	7	28	56	100
17% H_2SO_4 Solution					
Average strength at 70°C (MPa)	79.0	74.1	69.4	58.5	50.5
Average strength at 40°C (MPa)	84.3	87.1	84.0	81.9	80.6
Average change in strength at 70°C (%)	− 5.09%	− 11.00%	− 16.60%	− 29.70%	− 39.40%
Average change in strength at 40°C (%)	1.28%	4.61%	0.96%	− 1.60%	− 3.12%
Average change in weight at 70°C (%)	0.49%	1.93%	4.98%	5.24%	8.27%
Average change in weight at 40°C (%)	0.15%	0.40%	1.32%	2.37%	3.12%
20% NaOH Solution					
Average strength at 70°C (MPa)	97.1	91.9	89.8	66.9	51.7
Average strength at 40°C (MPa)	92.3	90.9	89.7	86.1	84.5
Average change in strength at 70°C (%)	16.62%	10.40%	7.89%	− 19.60%	− 37.90%
Average change in strength at 40°C (%)	10.89%	9.17%	7.73%	3.44%	1.52%
Average change in weight at 70°C (%)	0.14%	0.70%	1.42%	1.72%	3.11%
Average change in weight at 40°C (%)	0.04%	0.35%	1.12%	1.73%	2.26%
20% NaCl Solution					
Average strength at 70°C (MPa)	103.9	98.6	94.2	92.4	90.0
Average strength at 40°C (MPa)	95.1	94.6	100.4	89.2	87.3
Average change in strength at 70°C (%)	24.83%	18.46%	13.12%	11.01%	8.17%
Average change in strength at 40°C (%)	14.30%	13.62%	20.66%	7.21%	4.93%
Average change in weight at 70°C (%)	0.00%	0.00%	0.04%	0.07%	0.15%
Average change in weight at 40°C (%)	0.00%	0.01%	0.03%	0.01%	0.05%

Table 2. Mechanical properties at 7 days.

	Exposure Temperature	
Property	23°C	40°C
Compressive Strength (MPa)	83.2	94.9
Tensile Strength (MPa)	12.8	12.0
Flexural Strength (MPa)	29.2	28.9
Modulus of Elasticity (GPa)	13.36	13.83

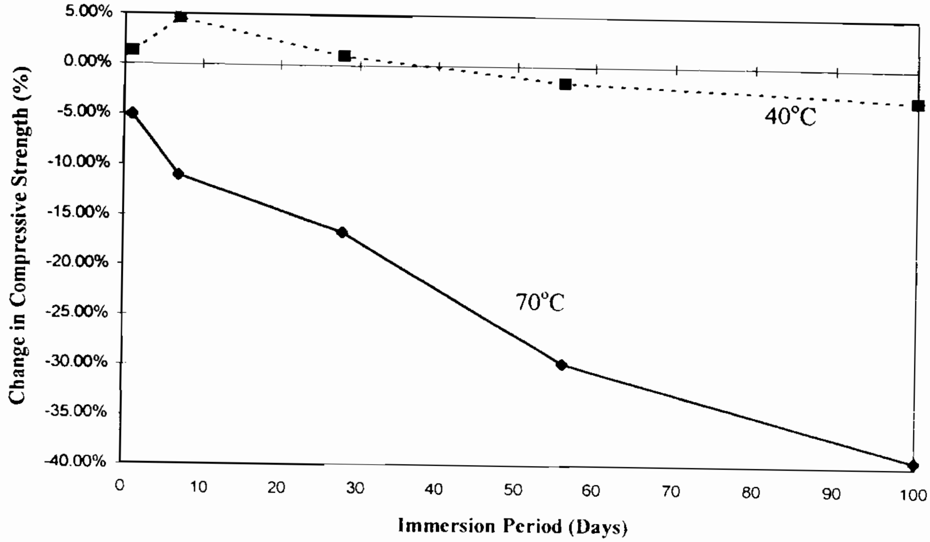

Fig. 1. Change in compressive strength with immersion period in H_2SO_4.

load at mid-span. The flexural strength and the tangent modulus of elasticity were determined using:

$$S = 3PL/2bd^2 \tag{1}$$

and

$$E = L^3M/4bd^2 \tag{2}$$

respectively, where:

S = flexural strength,
P = maximum load,
L = span (229 mm),
b = width (25 mm)
d = depth (25 mm)
E = tangent modulus of elasticity
M = slope of tangent to the initial straight line of the load-deflection curve.

For each temperature, the average of 6 replicate specimens are reported in Table 2. The method of calculating the modulus of elasticity is stated in ASTM C580-93.

Bond strength (ASTM C882-91)

The two halves of the cylinder were bonded together using a layer of the epoxy mortar of about 0.5 mm in thickness. A total of six specimens were prepared. Specimens were initially kept at room temperature for 7 days, and then three specimens were kept at 23°C and the other three at 40°C for an additional week. Specimens were then loaded to failure in compression. As failure did not occur along the bonded plane, the bond strength is higher than the recorded compressive strength at each temperature.

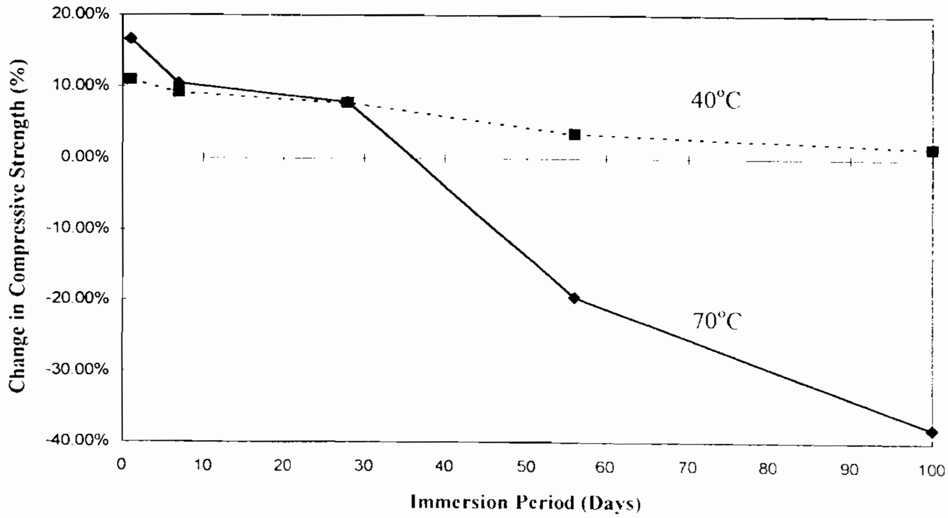

Fig. 2. Change in compressive strength with immersion period in NaOH.

Water absorption (ASTM C413-94)

Six replicate specimens were cured for 7 days. The result of the absorption test is presented as the average change in weight before and after boiling in water for two hours.

TEST RESULTS AND DISCUSSION

Chemical resistance results are shown in Table 1. The changes in average compressive strength at 40°C and 70°C due to immersion in sulphuric acid, sodium hydroxide and sodium chloride are shown against the immersion period in Figs. 1, 2 and 3

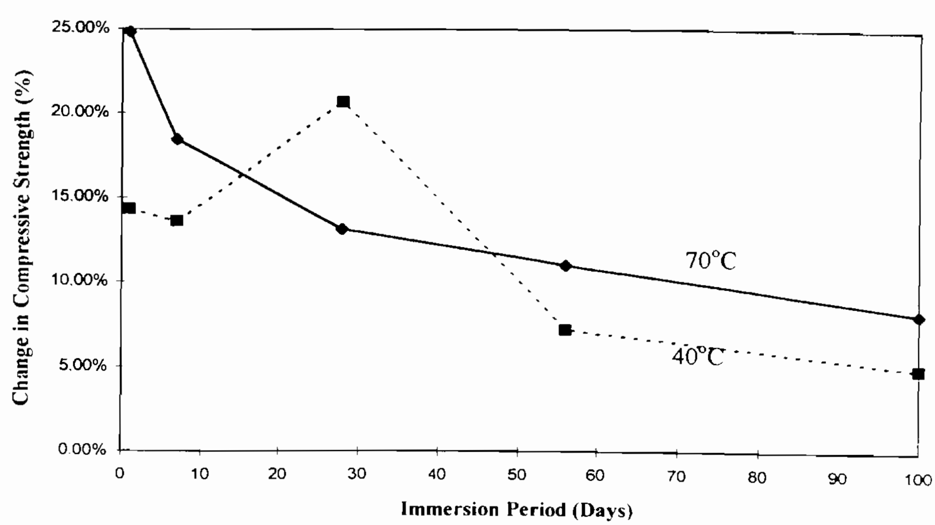

Fig. 3. Change in compressive strength with immersion period in NaCl.

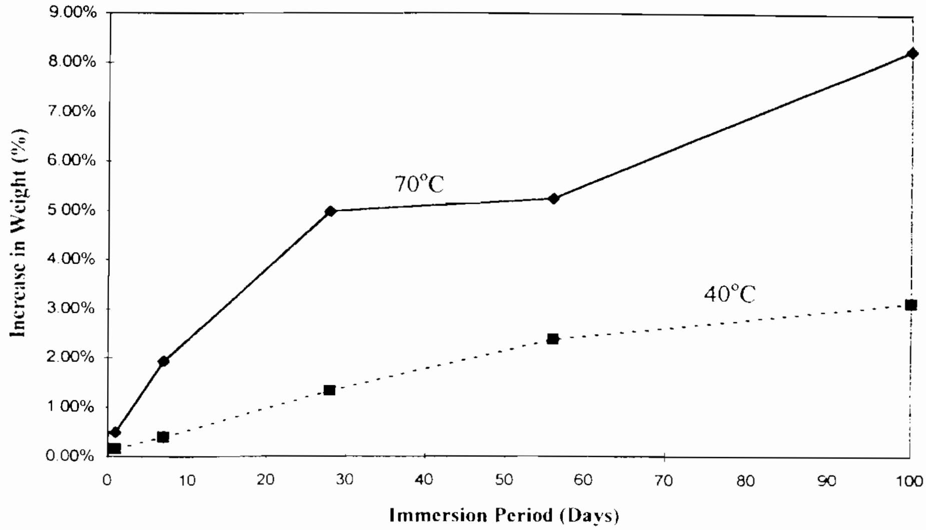

Fig. 4. Change in weight with immersion period in H_2SO_4.

respectively and the changes in average weight at 40°C and 70°C are shown for the same exposure conditions in Figs. 4, 5 and 6 respectively. The average compressive strength of the control specimens after 7 days at 23°C was found to be 83.22 N/mm^2. Due to H_2SO_4 solution at 70°C a gradual decrease in strength was observed with a maximum decrease of 39.37%, while at 40°C an increase in strength was observed for the first 28 days followed by a decrease in later ages. The maximum increase was 4.61% at 7 days and the maximum decrease was 3.12% at 100 days.

The NaOH solution at 70°C caused an increase in strength for the first 28 days followed by a reduction in strength. The maximum increase at the age of one day

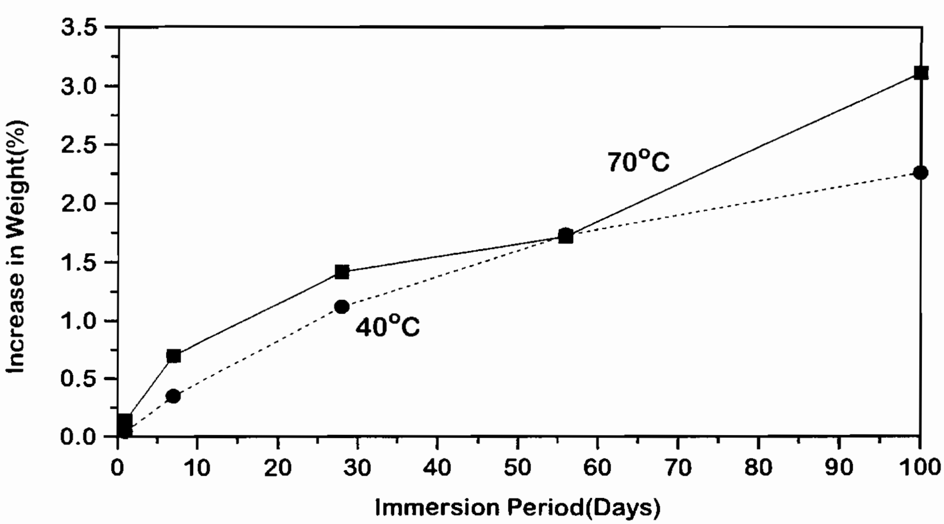

Fig. 5. Change in weight with immersion period in NaOH.

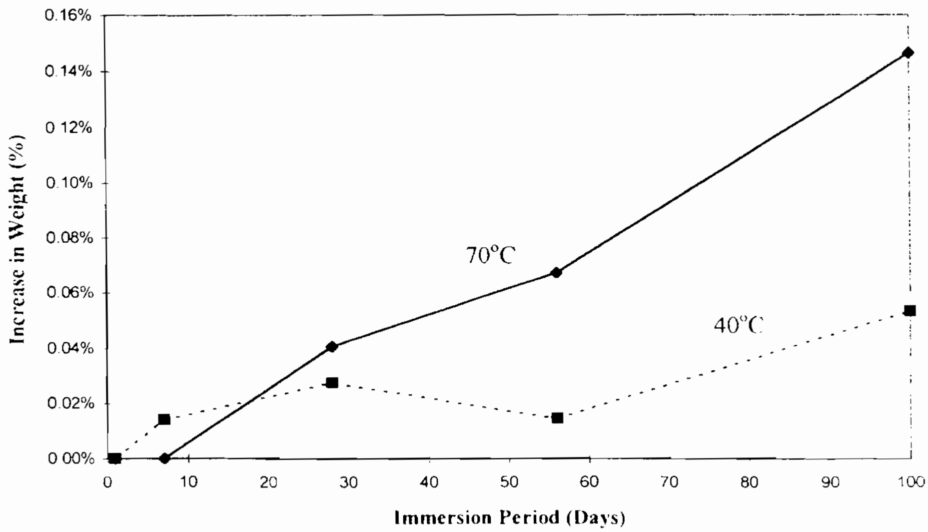

Fig. 6. Change in weight with immersion period in NaCl.

was 16.62% while the maximum decrease was 37.93% at the age of 100 days. However, at 40°C an increase in strength was observed at all ages. The maximum increase was 10.89% at age 1 day. The increase was reduced gradually with age to 1.52% at 100 days. Due to NaCl solution an increase in strength was observed at all ages and at both temperatures. The increase in strength was higher at 70°C. The maximum increase was 24.83% at day 1 due to exposure at 70°C.

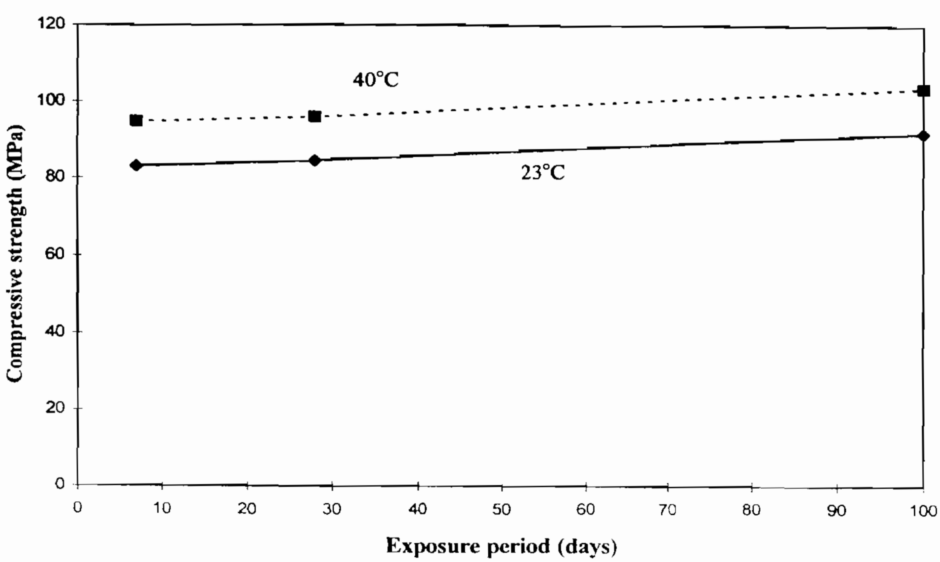

Fig. 7. Variation in compressive strength with time.

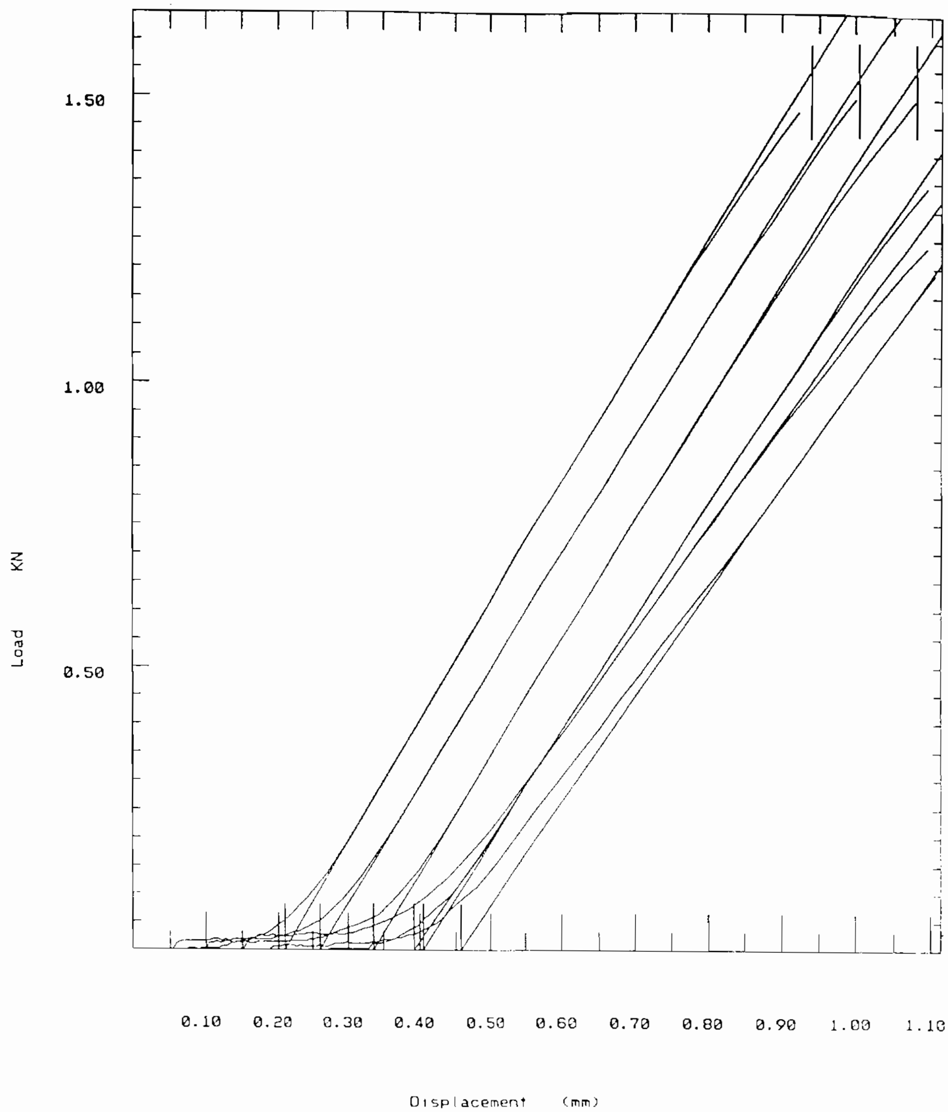

Fig. 8. Load-displacement curves at 23°C.

All three chemicals caused a gradual increase in weight of the specimens. The increase in weight was higher at the higher temperature and was higher for sulphuric acid than for sodium hydroxide, which was higher, in turn, than for sodium chloride. The maximum increase in weight was 8.27% for specimens immersed in sulphuric acid at 70°C for 100 days. The increase in weight for all specimens and the initial increase in strength for some specimens are possibly due to crystallization of salts in the concrete pores, which increases with the immersion period. With the increase of time, however, the chemical deterioration increases and hence a reduction in strength is noticed especially for specimens immersed in sulphuric acid at the higher temperature.

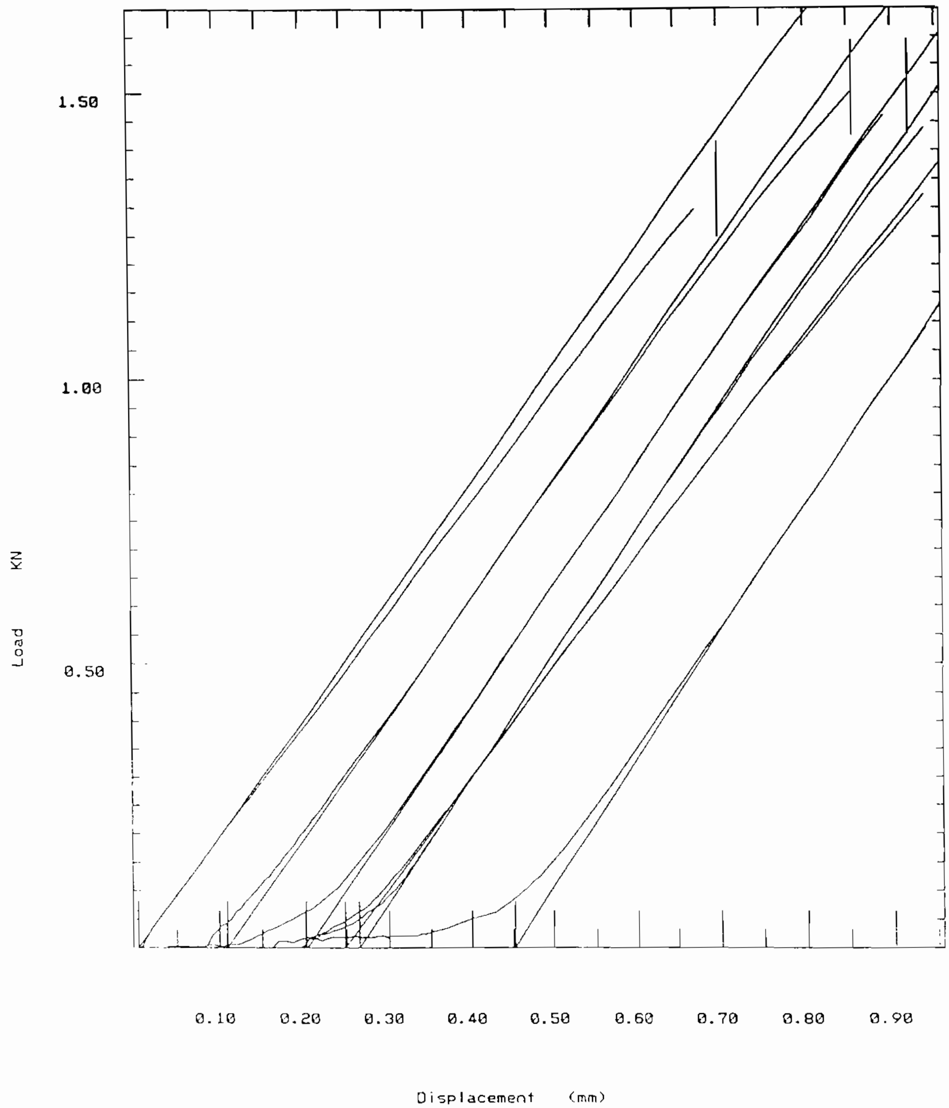

Fig. 9. Load-displacement curves at 40°C.

The change in compressive strength with time is shown for specimens cured at 23°C and 40°C in Fig. 7. The compressive strength was higher for specimens cured at 40°C than those cured at 23°C. The increase in strength due to the difference in curing temperature was 14.02%, 13.44% and 12.77% at the ages of 7, 28 and 100 days, respectively.

The average compressive strength, tensile strength, flexural strength and modulus of elasticity for specimens cured for 7 days at 23°C and 40°C are shown in Table 2. A slight decrease of 6.23% and 0.82% in tensile and flexural strength, respectively, due to the increase in curing temperature was noticed. To evaluate the modulus of elasticity, the load-deflection diagrams for the beams cured at 23°C and 40°C were plotted. The diagrams are shown in Figs. 8 and 9, respectively. The reason for the observed nonlinearities at low loads is probably the test technique adopted. This, however, did not affect the calculation of the modulus of elasticity. An increase in the average modulus of elasticity of 3.48% due to the increase in curing temperature was observed.

For the slant shear test, failure did not occur along the bond line, which means that the bond strength was higher than the observed failure stress. For the specimens cured at 23°C, the 7 day bond strength was higher than the compressive strength of 26.62 N/mm^2 and for the specimens cured at 40°C, the 7 day bond strength was higher than the compressive strength of 23.39 N/mm^2. The average water absorption for specimens cured at room temperature for 7 days was found to be 0.07%.

CONCLUSIONS

The durability of a class of epoxy mortar system was studied. The effect of exposure to sulphuric acid, sodium hydroxide and sodium chloride on the compressive strength and weight of specimens for time durations up to 100 days was evaluated. An increase in weight was observed for all specimens at all ages and exposure conditions. The critical exposure conditions were found to be the sulphuric acid and sodium hydroxide solutions at 70°C, where a reduction in compressive strength of about 40% was observed. At 40°C a maximum reduction of about 3% in compressive strength was observed for sulphuric acid exposure while an increase was observed at all ages for sodium hydroxide. An increase in compressive strength was also observed at all ages, and both temperatures, for specimens immersed in sodium chloride solution. The large difference in reduction in compressive strength due to temperature variation (39.37% to 3.12% for sulphuric acid and 37.93% to −1.52% for sodium hydroxide) emphasizes the sensitivity of the durability of epoxy mortars to variation in temperature. This fact should be considered for epoxy mortar systems exposed to chemicals at higher temperatures. The compressive strength was found to be higher for specimens cured at higher temperature. The effect of temperature on tensile and flexural strengths and the modulus of elasticity was found to be insignificant and may be ignored in design. The bond strength was found to be higher than the compressive strength due to failure not being along the bond line. The average water absorption at 7 days was found to be 0.07%.

In general, the type of epoxy mortar investigated was found to be durable and may be used in conditions comparable to those used in this investigation, except at temperatures close to 70°C, in which case an almost 40% reduction in the mortar compressive strength may occur.

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اختبار التحمل لنظام مونة ايبوكسية

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خلاصة

أصبح استعمال أنظمة المونة الايبوكسية الطريقة الأكثر انتشارا لإصلاح منشآت الخرسـانة المسلحة نظرا لمقاومتها العالية وسرعة تصلدها وسهولة استعمالها ، ولكن مازال مدى تحمـل بعض هذه الأنظمة محل دراسة.

في هذا البحث تمت دراسة تحمل نوع من مونة الاصلاح مكون من مركبين ومستخدم فـي السوق الكويتية ومطابق للمواصفات الأمريكية ASTM C881. وقد تمـت دراسـة تـأثير محاليل حمض الكبريتيك وهيدروكسيد الصوديوم وكلوريد الصوديوم عند درجات حـرارة 40 م و 70 م في مقاومة المونة ووزنها لمدد تصل إلى مئة يوم. كما تمت دراسة مقاومة كل مـن الضغط والشد والانحناء والتماسك إضافة إلى معامل المرونة عند درجتـي الحـرارة 23 م و 40 م وكذلك امتصاص الماء لهذا النوع من المونة الإيبوكسية.