POLYMER BINDERS

EPOXY CONCRETES

By

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Advantageous properties recommend epoxy concretes for repairing minor damages of roads, runways, hydraulic structures, for abrasion resistant surfacing of industrial concrete floors, bridge decks, etc. In any case, inexpensiveness is striven to, leading to layer thicknesses possibly below 8 to 10 mm, and max. aggregate particle sizes of 2 to 4 mm.

The reported research aimed at examining epoxy concrete properties of importance for *structural uses.*

1. Epoxy concrete materials

Research was made on a *modified epoxy resin* EB-14 made at the Research Institute for Plastics, and on cross-linking agent types *amine* (diethylenetriamine T2) and *amide* (poly-amino-amide T6).

Gelation times (in a *Höppler* rheoviscosimeter):

— Silica flour-charged EB-14 + T2: 140 to 150 min.
— Silica flour-charged EB-14 + T6: 230 to 240 min.

The *aggregate* was graded and washed Danube silica gravel (Fig. 1). Preliminary tests were made to choose mixing proportion of sand fractions 0 to 1 mm (1) and 1 to 4 mm (2) of minimum voids ratio, leading to the grading shown in thick-line curve (3) in Fig. 1. Before use, aggregates got dried at 105 °C.

Resin compositions:

— Resin EB-14: cross-linking agent T2 = 100 : 10,
— Resin EB-14: cross-linking agent T6 = 100 : 60.

These two resins were made to mortar with resin to sand ratios of 1 : 4, 1 : 6, 1 : 9.

Also to make a mortar of proportion 1 : 2 was attempted, but sand subsided and excess resin aggregated.

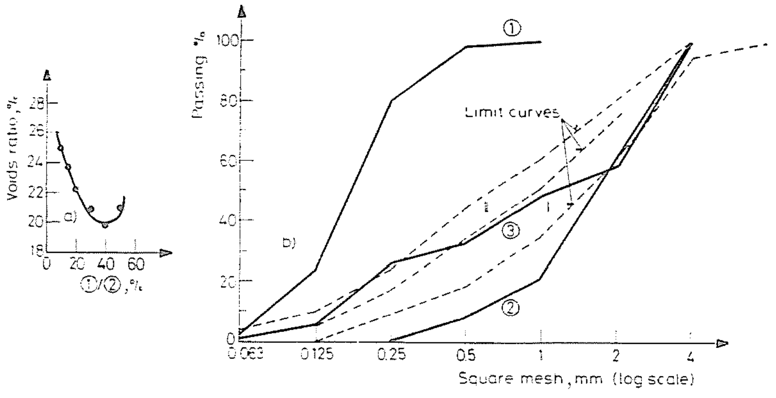

Fig. 1. Aggregate. *a)* Variation of the voids ratio with the proportion of both fractions; *b)* grading curve ③ experimentally determined from limit curves, initial aggregate fractions ① and ② and from the voids minimum

2. Mortar properties

2.1 *Bending-tensile and compressive strengths* of the mortar were determined on standard cement test specimens, by standard methods.

According to test results (Figs 2 and 3), mortar made with amine-type cross-linking agent T2 achieved 85 to 90% of its 28-day strength at 24 h of age, the same was achieved only at 7 days with an amide-type cross-linking agent T6.

1 : 4 mortars made with an amide-type cross-linking agent almost behaved like rubber.

Variation of resin to sand proportion between 1 : 4 and 1 : 6 little affected strength values, while a proportion of 1 : 9 reduced the strength by 20 to 30%. Namely, a proportion of 1 : 9 was accompanied by a high pore volume. A ratio of 1 : 4 resulted in an oversaturated mortar, with resin segregating on the surface in a thin layer, while a proportion of 1 : 6 exhibited some unsaturation.

Hardening of epoxy resin mortars at +5 °C and +10 °C was tested by cooling both the moulds and the mortar components to the test temperature before casting the specimens, somewhat hampering mortar mixing and placing. Prisms were air cured in moulds up to 24 h of age, then placed into tightly closing polythene bags and immersed in water to keep constant temperature.

Mortars made with amine-type cross-linking agent developed no strength at 5 °C at 1 day of age.

Bending-tensile strength is seen in Fig. 4 to be less affected by temperature changes than is compressive strength, and after 7 days, strengths of mortars stored at 10 °C and at 20 °C little differed. At the same time, mortars made with amine-type cross-linking agent are sensitive to temperature, con-

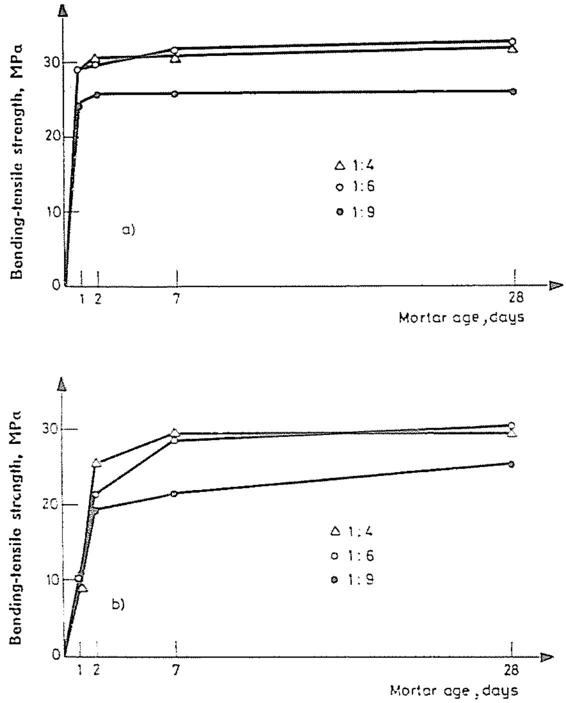

Fig. 2. Bending-tensile strength of epoxy resin vs. time at ambient temperature *a)* with T2; *b)* with T6

firming the observation that below 10 °C, epoxy resins made with amine-type cross-linking agent and no setting accelerator are missing their main advantage, the high early strength.

At last, mortars stored at 5° C tend to the same strength as those stored at 20 °C, only that it is achieved later, and the bending-tensile strength sooner than the compressive strength.

Bending-tensile vs. compressive strength has been plotted in Fig. 5 for different storage temperatures.

2.2 *Shrinkage*

Shrinkage was measured by means of a *Leitz* optical micrometer, of a reading accuracy of 0.001 mm, and its one-tenth still could be estimated. Measurements as early as possible were striven to. Therefore the glass scale containing the hair cross was stuck on mortar made with T2 and T6 at 6 and 20 hours of age, respectively. The first measurement was made directly after the adhesive hardened, hence at 8, and 22 hours of age, respectively. Initially, readings followed each 4 to 8 hours, then daily up to 7 days, thereafter weekly.

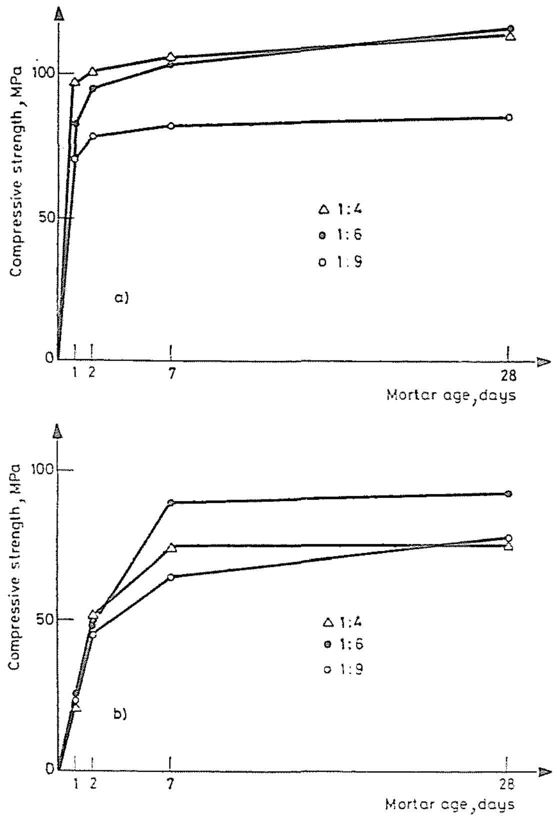

Fig. 3. Compressive strength of epoxy resin vs. time at ambient temperature *a)* with T2; *b)* with T6

Measurement results on mortar made with T2 are seen in Fig. 6. Shrinkage curves indicated most of the shrinkage to occur in the first days. It is largely dependent on the proportion of components but it is no linear function of the resin content (Fig. 7). It is little dependent on the kind of cross-linking agent.

Shortening due to cooling was omitted, since the mortar made with T2 and a mixing ratio of 1 : 4 was only heated by 3.5 °C over the ambience.

2.3 *Abrasion resistance*

Abrasion tests were made in an abrasion equipment system *Bauschinger-Böhme.*

Specimens 7.07 by 7.07 by 1.0 cm were tested at 45 days of age by using *Naxos* grinding powder, in original condition, on the moulded face of the specimen.

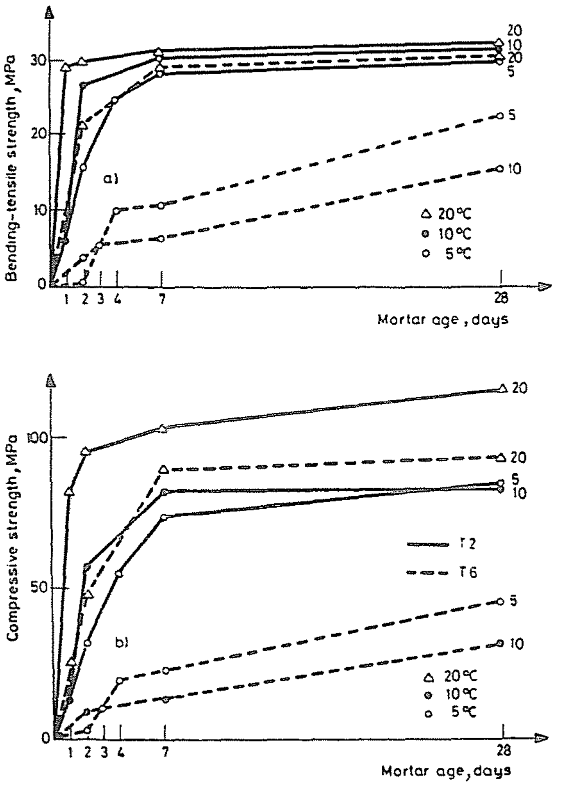

Fig. 4. Effect of temperature on the hardening process of epoxy mortar at 1 : 6 resin to sand ratio; *a)* bending-tensile strength; *b)* compressive strength

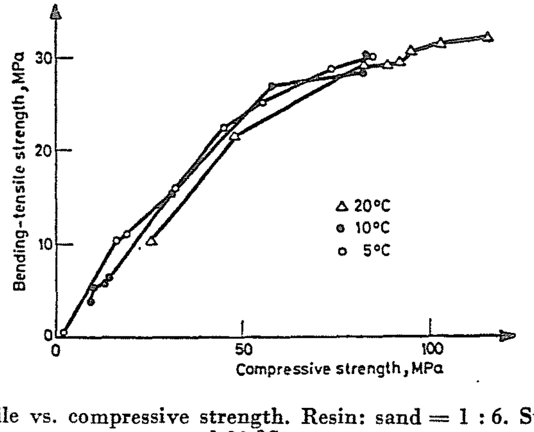

Fig. 5. **Bending-tensile vs. compressive strength. Resin: sand = 1 : 6. Stored at 5 °C, 10 °C and 20 °C, resp.**

The height loss was uniform during abrasion. Abrasion rate vs. resin content is seen in Fig. 8.

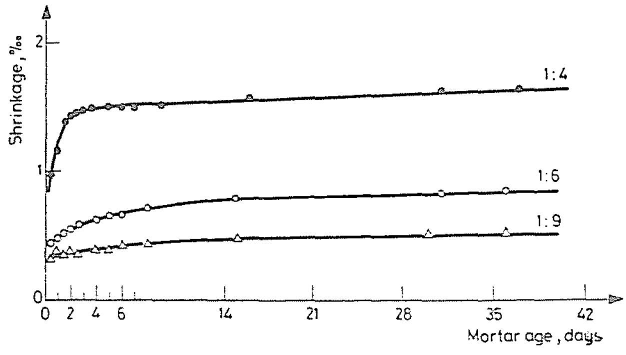

Fig. 6. Shrinkage vs. time for amine-type cross-linking agent T2

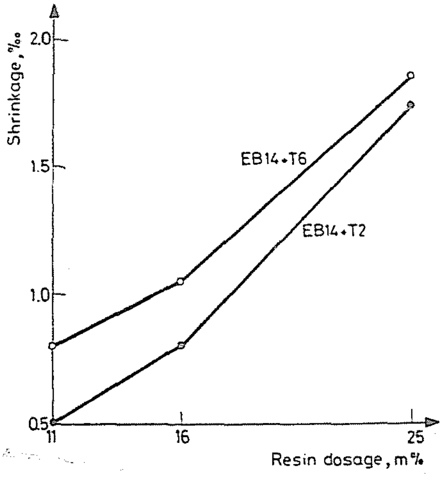

Fig. 7. Final shrinkage vs. resin dosage

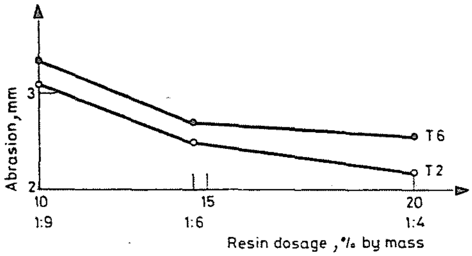

Fig. 8. Abrasion rate vs. resin dosage

2.4 *Examination of the failure mechanism*

The failure mechanism was examined on 7 by 7 by 25 cm prisms. Deformations were determined in compressive testers with measuring ranges of 400 and 500 kN, inductive strain gauge type D-32, *Honeywell* measuring bridge kWS/T-6, *Honeywell* X—Y—Y' plotter and dynamometer cell. At the instant of failure, the loading velocity was 400 ± 100 kN/s.

Curves $\sigma - \varepsilon_y$ and $\sigma - \varepsilon_x$ traced by the plotters yielded Poisson's ratios for increasing σ/R_p values, using formula:

$$\nu = \frac{\varepsilon_y}{\varepsilon_x}$$

and the volume change diagram as a function of σ/R_p has been determined by means of the volume change due to the elastic deformation method.

To construct the volume change function $\Delta\Theta$, functions $\sigma_x - \varepsilon_x$ and $\sigma_x - \varepsilon_p$ have been divided to intervals corresponding to 0.1 R_p. Within the interval 0.8 to 0.9 σ/R_p three divisions have been made to permit a straight line to replace the function. Section-wise volume change values have been calculated from:

$$\Delta\Theta = \Delta\varepsilon_x - 2\Delta\varepsilon_y$$

and represented in the midline of the section. Connecting the calculated values by a continuous line delivered function $\Delta\Theta - \sigma/R_p$ (Figs 9 through 12).

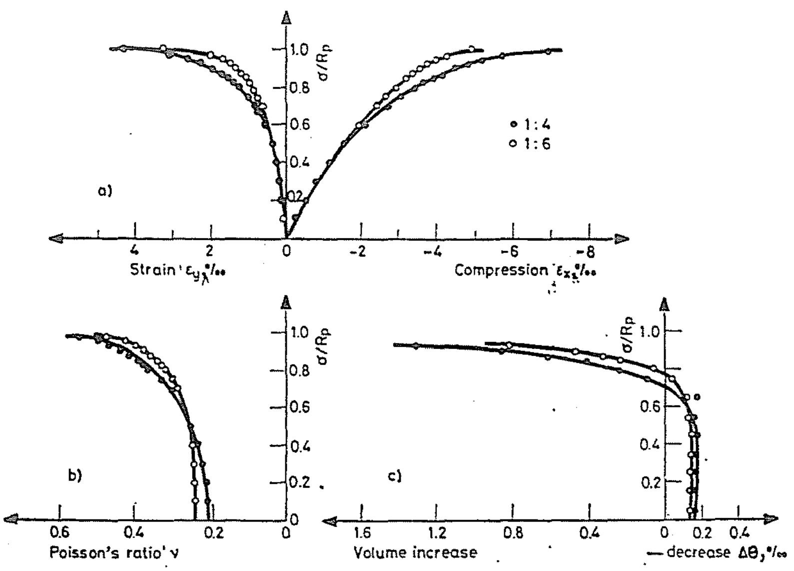

Fig. 9. Deformation, volume change and Poisson's ratio of 1-day prisms made with T2 vs. σ/R_p

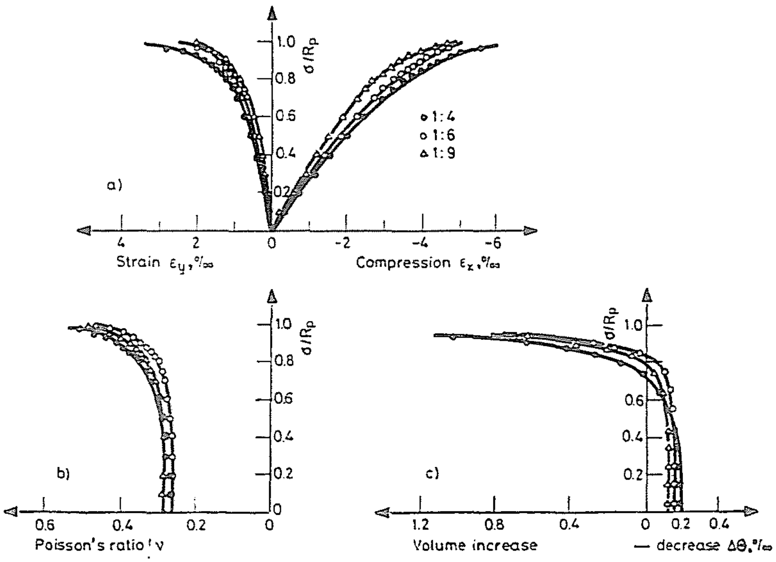

Fig. 10. Deformation, volume change and Poisson's ratio of 7-day prisms made with T2 vs. σ/R_p

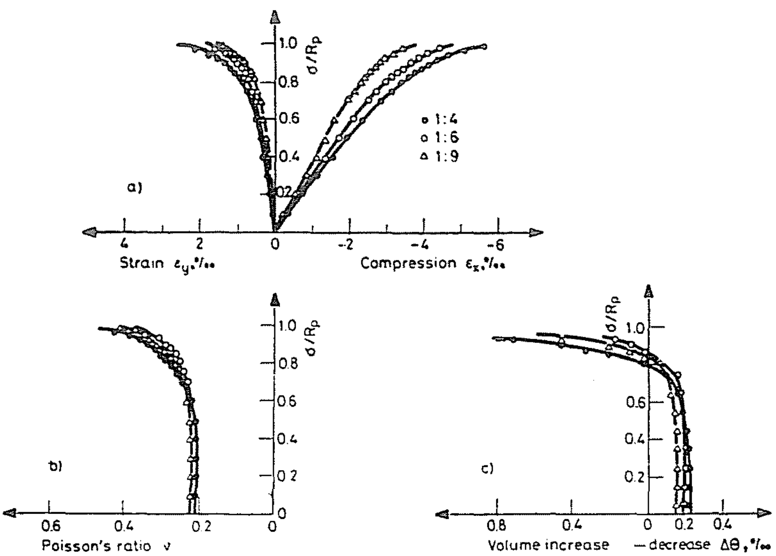

Fig. 11. Deformation, volume change and Poisson's ratio of 39-day prisms made with T2 vs. σ/R_p

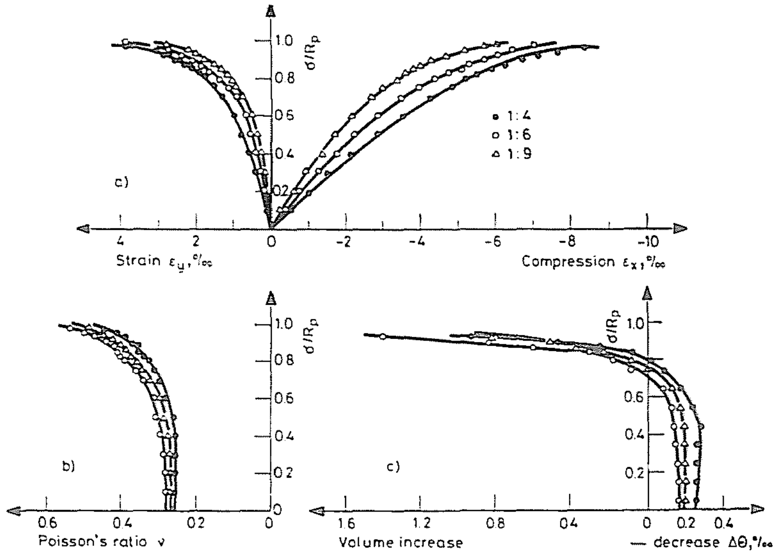

Fig. 12. Deformation, volume change and Poisson's ratio of 28-day prisms made with T6 vs. σ/R_p

Tests involved determination of prism strength R_p and initial moduli of elasticity in compression E_0 as well as those belonging to 0.3 σ/R_p.

3. Conclusions

a) The ultimate deformation could only be approximated, namely prisms failed abruptly as in an explosion. In particular, sloping limb of curves $\sigma - \varepsilon$ is uncertain. Nevertheless, ultimate deformation unambiguously grows with

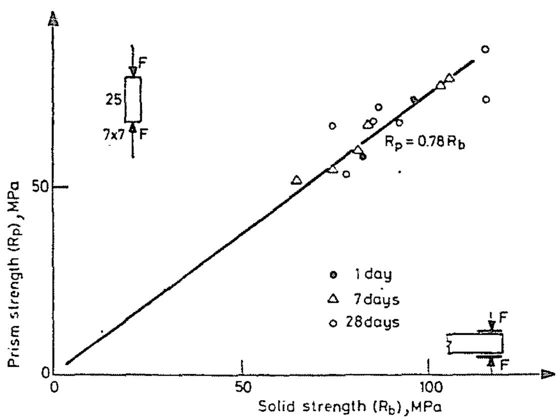

Fig. 13. Prism strength vs. solid strength

increasing resin content, and is higher for amide (T6) than for amine (T2) cross-linking agent. The resin with amine-type cross-linking agent behaved elastically almost up to failure, while that made with an amide-type one exhibited properties of an elastic-viscous material.

b) Timely development of prism strengths R_p is similar to that of solid strengths R_b. The relationship between both compressive strengths has been plotted in Fig. 13.

c) Small axial loads caused only elastic deformations, the concrete got compacted. This compaction remained constant until the slopes of curves $\sigma_x - \varepsilon_x$ and $\sigma_x - \varepsilon_y$ changed. If curve $\sigma_x - \varepsilon_x$ begins warping before curve $\sigma_x - \varepsilon_y$ then the linear volume decrease is followed by a more than linear one. This phenomenon has only been observed for green mortar prisms (e.g. Fig. 9) and it is other than typical. If, however, function $\sigma_x - \varepsilon_y$ starts warping the first, then the linear volume decrease is followed by one tending to decrease, then, after sign reversal, by volume increase. This is a typical behaviour.

At the time of change of function $\Delta\Theta - \sigma/R_p$, the structure starts to yield in form of microcracks. With increasing load, these microcracks multiply, widen, and the mortar starts rapid yielding. Also curves $\nu - \sigma/R_p$ are constant as long as functions $\Delta\Theta - \sigma/R_p$ are.

Limit of the constant section was in the range of 0.4 to 0.6 σ/R_p, and it got lower with increasing resin content. It was little affected by mortar age and type of cross-linking agent. Characteristic point of function $\Delta\Theta - \sigma/R_p$ is its intersection with the ordinate, usually between 0.8 and 0.9 σ/R_p. A lower value was only obtained with amine-type cross-linking agent, a ratio of 1 : 4 of resin to aggregate, up to 7 days.

d) Poisson's ratios can be assessed at 0.2 to 0.25, and at 0.25 to 0.30 for cross-linking agents T2 and T6, respectively, under a load of max. 0.4 R_p,

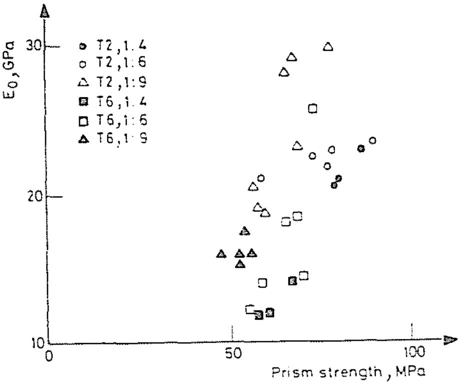

Fig. 14. Initial modulus of elasticity in compression vs. prism strength

occurring in practice, irrespective of the mortar age and of the resin content within the tested range. After the mortar starts yielding, it grows and near failure it may be as high as 0.6.

e) Tests showed the initial modulus of elasticity in compression to be taken as identical to $E_{0,3}$.

Initial modulus of elasticity in compression vs. prism strength (Fig. 14) shows them to be about linearly related. The modulus of elasticity in compression is about 65% of the dynamic modulus of elasticity determined in the *Kretz* apparatus.

Summary

Tests have been made with modified epoxy resin and cross-linking agent to determine properties of epoxy concrete of structural importance. Silica sand was applied as concrete aggregate.

Epoxy mortars soon achieved 85 to 95% of the 28-day strength.

Resins made with a cross-linking agent are sensitive to cold storage.

Most of the shrinkage is completed in the first three days, and it is the greater, the higher the resin content.

Abrasion amounted to 2—3 mm, decreasing with increasing resin content.

Both compression and transversal strain under load increased with increasing resin dosage.

Initial modulus of elasticity in compression is about 65% of the dynamic modulus of elasticity.

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