EFFECT OF PASTE SATURATION ON CONCRETE STRENGTH AND DEFORMATION CHARACTERISTICS

By

Gy. BALÁZS

Department of Building Materials, Technical University, Budapest

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1. Introduction

By the end of the past century, concretes have already been designed to have voids between coarse aggregate particles just filled out with mortar. These are termed paste saturated concretes. As early as 90 years ago, a method has been developed for determining cement dosage needed for paste saturation. FERET, author of the first concrete design formula, took residual voids in the concrete into consideration. Also introduction of ideal grading curves and actual concrete design formulae strive to paste saturated concretes.

Hungarian — otherwise excellent — silica gravel aggregates are featured by an almost complete lack of below 0.25 mm size particles — especially after washing. The established practice of adding Portland cements grade 350 and 450 in dosages of 300 to 500 kg/cu.m tends to offset deficiencies in aggregate grading and concrete manufacture.

The described tests referred to the variation of concrete strength and deformation characteristics for varying paste contents, consistency being kept about constant.

2. Experiments

Applying Portland cement grade 450 from DCW* in dosages varying from 120 to 480 kg/cu.m, graded and washed aggregate approaching both limit curves (Fig. 1), fresh concrete composition and characteristics have been compiled in Table 1. Concrete consistency was nearly constant, the w/c ratio being altered only in tests I/4 and I/5.

The tests involved the following characteristics:

a) Concrete bending-tensile strength on $7\times7\times25$ cm prisms with 21 cm spans, under third-point loading. Compressive strength was tested on portions of prisms broken in bending, with 50 sq. cm compressive surfaces.

b) Concrete cube strength on 20 cm cubes.

* Danube Cement Works

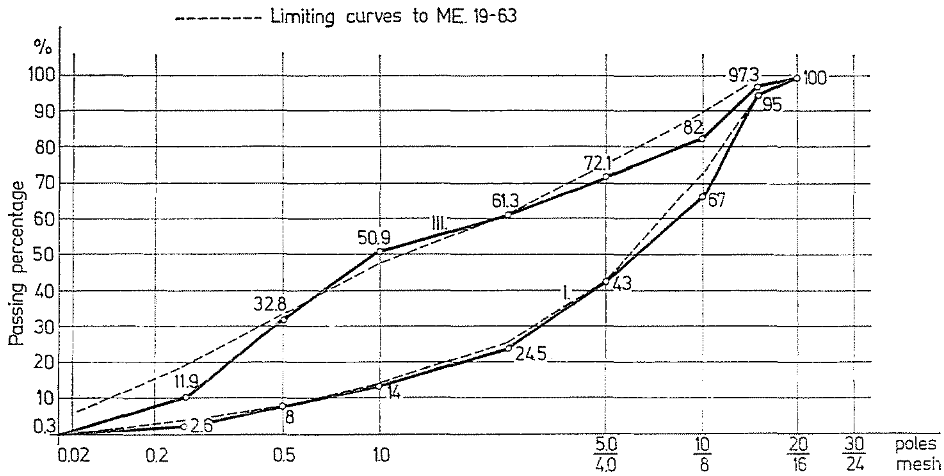

Fig. 1. Grading curves and limiting curves - - - Limiting curves according to ME 19—63

c) Axial tensile strength on special 8-shaped tensile specimens 50 cm long, 12×12 cm mid-span cross section also used for recording stress-strain diagrams by means of induction strain gauges of 40 mm basis length.

Table I

Compositions and consistencies of freshly mixed concretes

Symbol	Real cement dosage, kg/cu.m	Aggregate type	Concrete cube density, kg/cu.m	w/c	Glanville Compacting Factor, CF
I/1	345	I	2430	0.387	—
I/2	417	I	2424	0.406	0.704
I/3	475	I	2386	0.40	0.74
I/4	344	I	2432	0.445	0.77
I/5	350	I	2462	0.494	0.86
I/6	260	I	2466	0.50	0.71
I/7	155	I	2334	0.74	0.755
I/8	119	I	2234	0.80	0.75
I/9	332	I	2436	0.43	0.71
I/10	480	I	2403	0.39	0.75
I/11	151	I	2375	0.75	0.77
III/1	477	III	2300	0.47	0.77
III/2	346	III	2300	0.50	0.765
III/3	155	III	2220	1.05	0.82
III/4	418	III	2330	0.49	0.76
III/5	256	III	2297	0.64	0.77
III/6	129	III	2178	1.29	0.80

3. Test results and evaluation

a) The concrete hardening procedure is seen in Figs 2 and 3 to be considered as linear vs. log. concrete age from 1 to 90 days. Concretes with cement dosages of 350 to 470 kg/cum are seen to exhibit a slight nonlinearity of bending-tensile strength, and those with 470 kg/cu. m, of compressive strength.

b) Irrespective of age, compressive strength of $7 \times 7 \times 25$ cm prisms decidedly depended on the w/c ratio, differences increasing with age (Fig. 4). Bending-tensile strength depended less on w/c ratio. Bending-tensile strength of concretes with w/c = 0.4 increased with age, while the relative compressive strength was practically independent of age (Fig. 5).

c) Concrete compressive strength varied as a function of cement dosage according to a curve exhibiting an optimum (Figs 6 and 7). Strength optima pertained at 1 day to a cement dosage of about 350 kg/cu.m, at 7 days to about 380 kg/cu.m, while at 90 days to about 420 kg/cu.m. Also bending-tensile strengths exhibited a marked optimum at 1 day for about 370 kg/cu.m of cement dosage. At 7 days this optimum was rather faint, while at 90 days the tested range exhibited no optimum at all.

Results confirm the earlier observation that increasing the cement dosage beyond a certain limit results in no strength increase any more, especially as concerns the compressive strength.

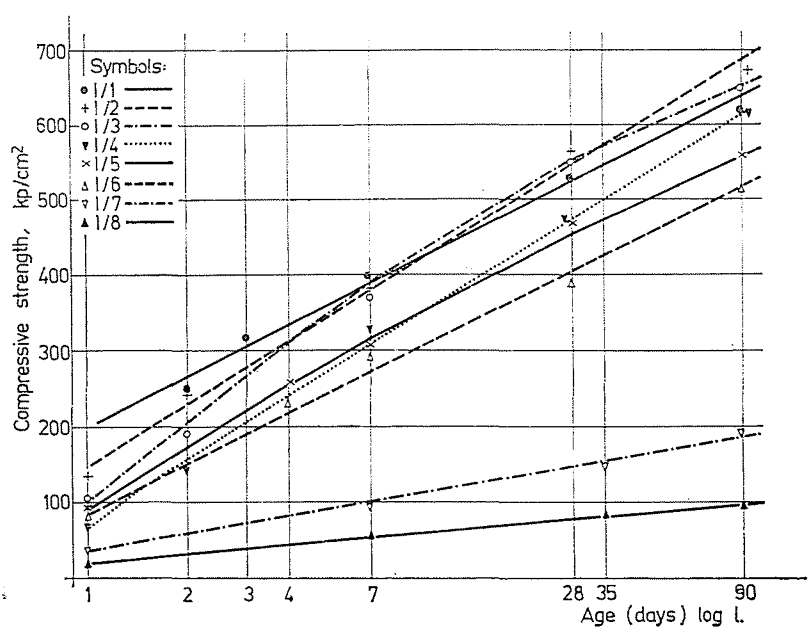

Fig. 2. Concrete compressive strength vs. age

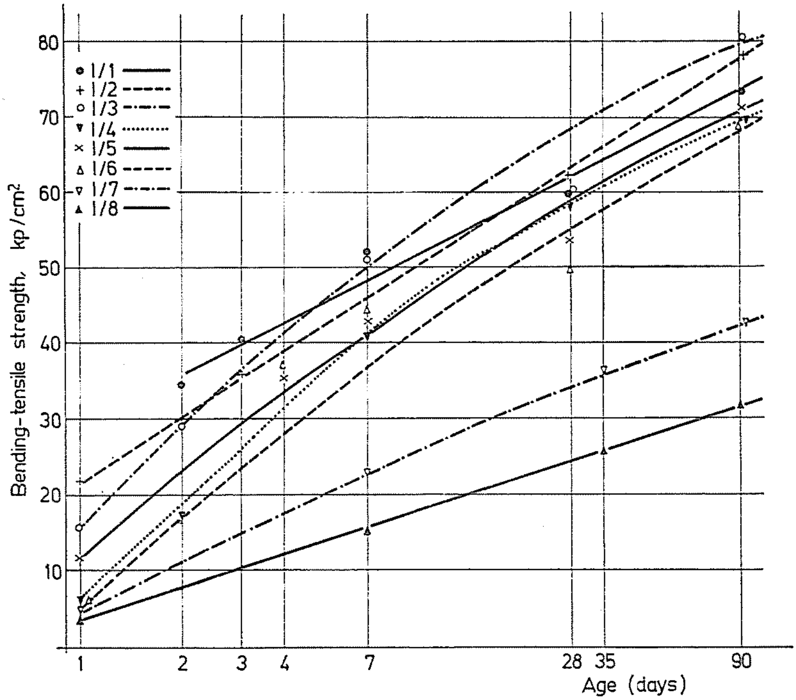

Fig. 3. Concrete bending-tensile strength vs. age

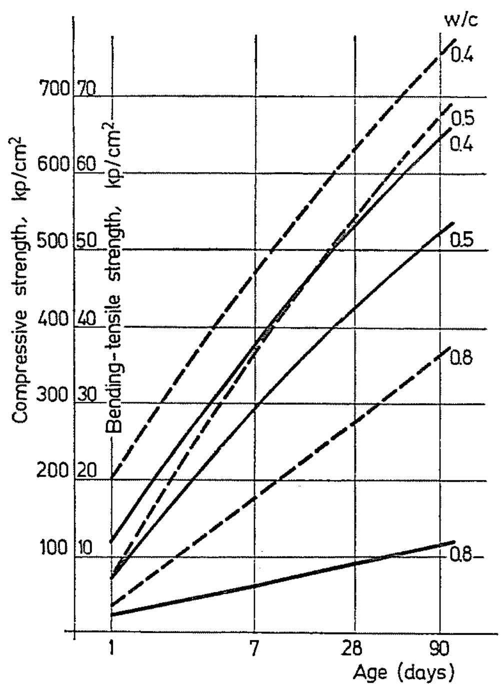

Fig. 4. Strength vs. age of concretes made with different w/c ratios
Legend: ——— compressive strength, - - - - bending-tensile strength

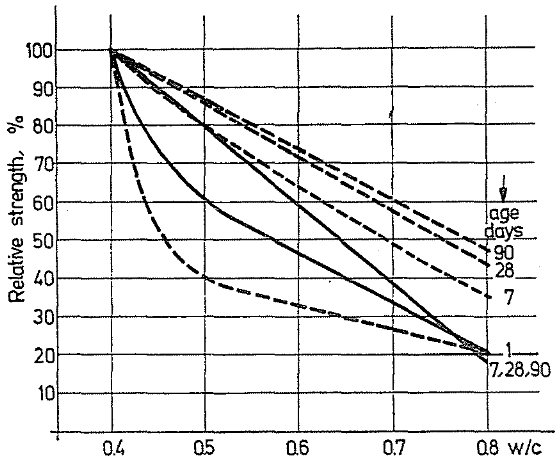

Fig. 5. Relative strengths vs. w/c and age of concrete
Legend: ——— compressive strength, - - - bending-tensile strength

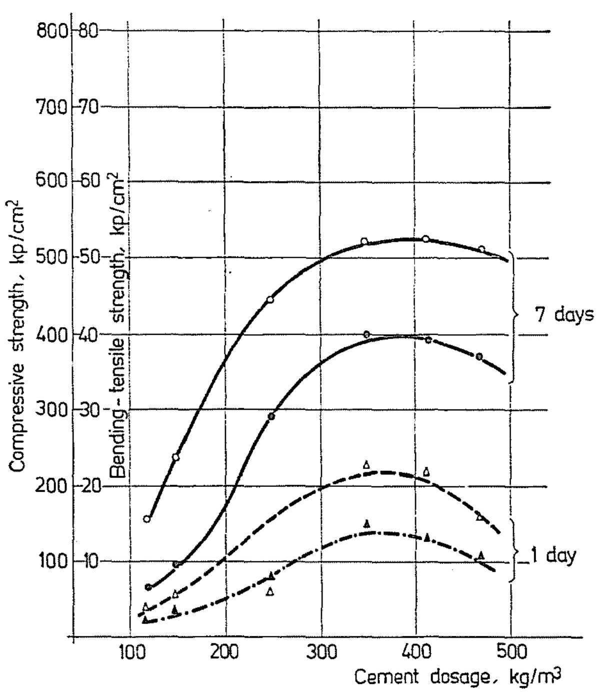

Fig. 6. 1 and 7-day concrete strengths vs. cement dosage
Legend: ●▲ compressive strength; □△ bending-tensile strength

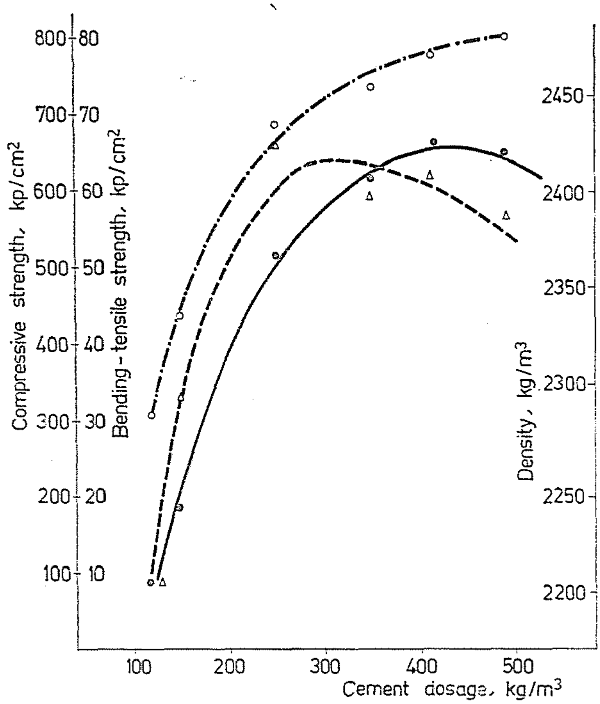

Fig. 7. 90-day concrete strength and density vs. cement dosage
Legend: — . — . — .o bending-tensile strength, ——— ⊙ compressive strength, - - - - - - △ density

This tendency of strength development is in virtual contradiction to the expected increase of binding force with increasing cement dosage. This contradiction is virtual because of the importance of voids percentage in strength development. Nevertheless, concrete compactness can only be increased with cement dosage to a given limit, beyond that the voids content grows hence compactness decreases. The resulting strength optimum is somewhat shifted with respect to the compactness optimum.

d) Concrete cube strength (on 20 cm cubes) and cement dosage (Fig. 8) showed a relation similar to that in Fig. 7. Fig. 8 demonstrates a cement excess over about 300 kg/cu.m for the given aggregate to be useless from the aspect of compressive strength. Also here, concrete compactness had its maximum at about 250 kg/cu.m.

e) Also curves relating cement dosage and bending-tensile strength gave optima with aggregates both III and I, but the optimum was at a cement dosage of 400 to 500 kg/cu.m, referring to a higher paste demand.

f) From the aspect of saturation, a great importance is attributed to the total volume of cement and sand below 0.25 mm.

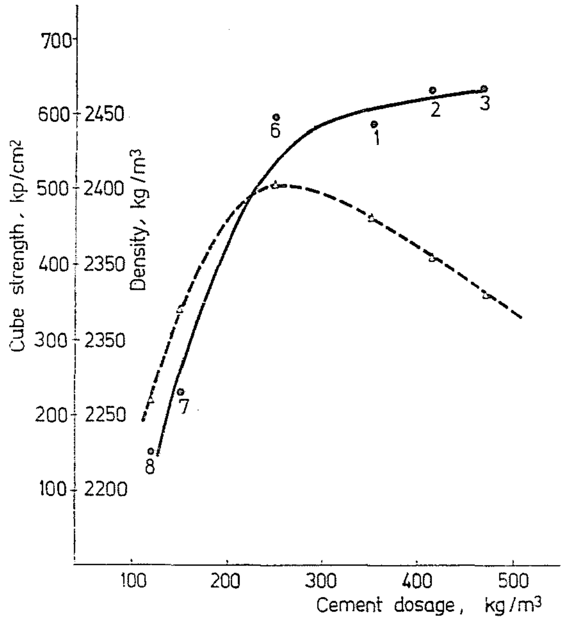

Fig. 8. Concrete cube strength vs. cement dosage. Legend: ⊚ compressive strength; △ density

Cube strengths of concretes I/1 through I/11 have been plotted as a function of concrete fines understood as above (Fig. 9). Strengths of concretes of identical consistencies are on two straight sections intersecting at a point considered as optimum fines content. The intersection point depends on the concrete age. At 28 days the intersection corresponds to a dosage of about 400 kg/cu. m, and at 120 days to about 300 kg/cu. m. It is likely to be dependent also on the concrete consistency, namely strengths of concretes I/5 and I/1 are outside the straight line. Tests I/9, I/10 and I/11 are essentially the same as tests I/4, I/3 and I/7, leaving the tendency inaffected.

Bending-tensile and compressive strengths of prisms $7 \times 7 \times 25$ cm made of concretes I/1 through I/11 have been plotted in Figs 10 and 11, respectively, as a function of the fines content in the concrete. Fig. 10 shows an optimum fines content for the bending-tensile strength to exist, decreasing from 390 kg/cu. m for 7-day concretes to 315 kg/cu.m for 90-day concretes. Slopes of both sections of the straight line connecting the strengths are seen to increase with concrete age. Compressive strengths exhibited a similar tendency (Figs 11, 12).

g) The curve for the relation between tensile strength and cement dosage of concrete gave an optimum (Fig. 13), just as did those between other strength types and cement dosages.

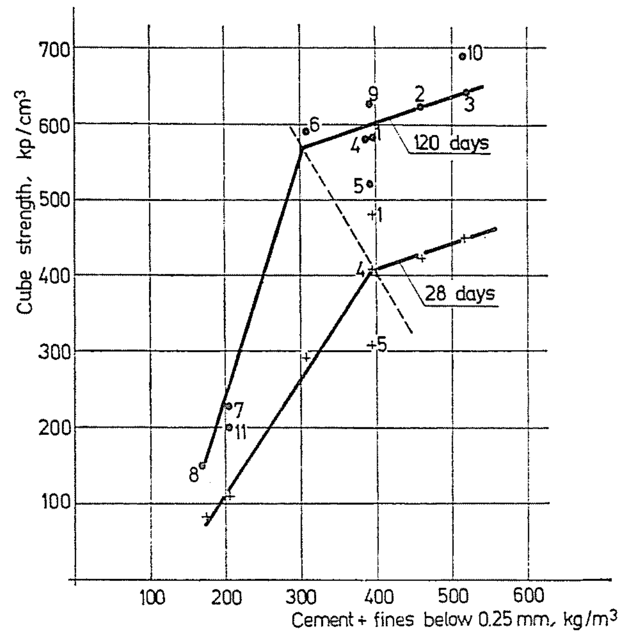

Fig. 9. Concrete cube strength vs. fines percentage

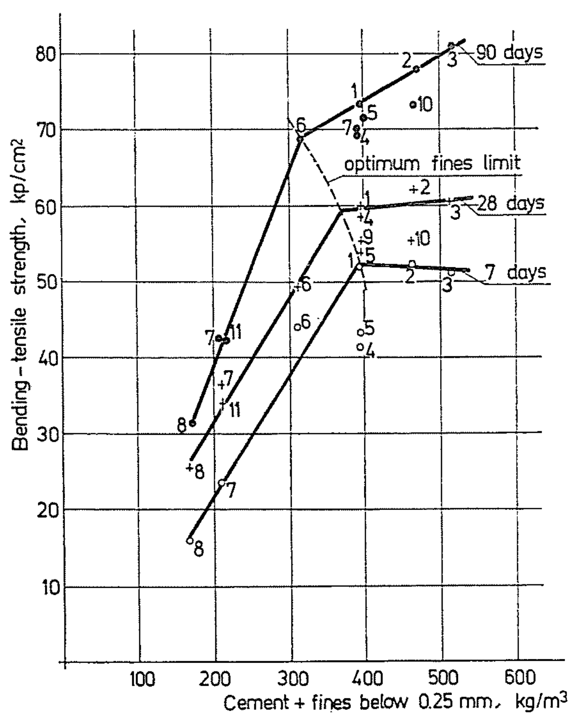

Fig. 10. Concrete bending-tensile strength vs. fines percentage

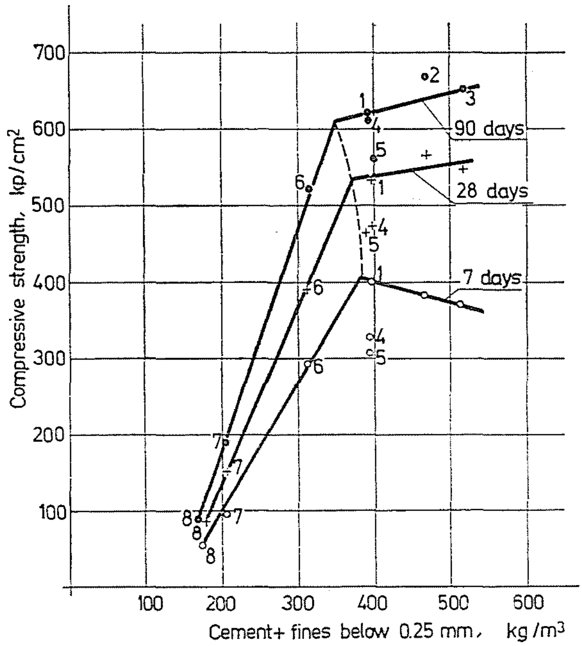

Fig. 11. Concrete compressive strength vs. fines percentage

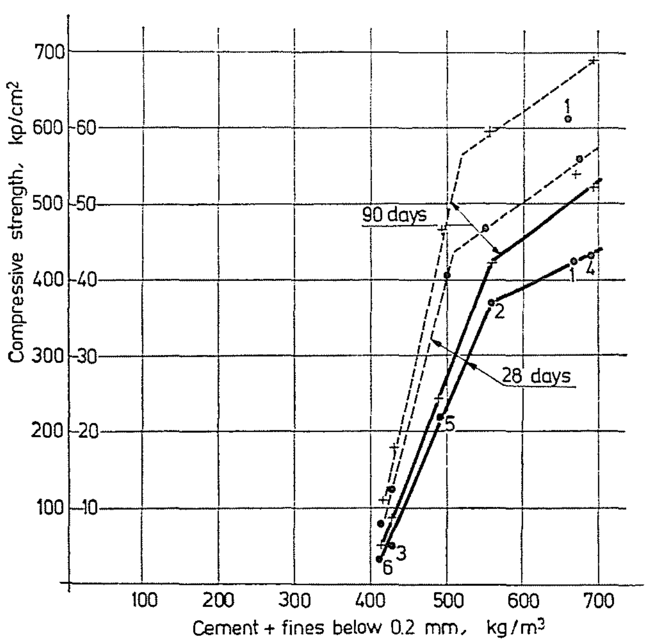

Fig. 12. Concrete bending-tensile and compressive strength vs. fines percentage
Legend: ——— compressive strength, - - - - - bending-tensile strength

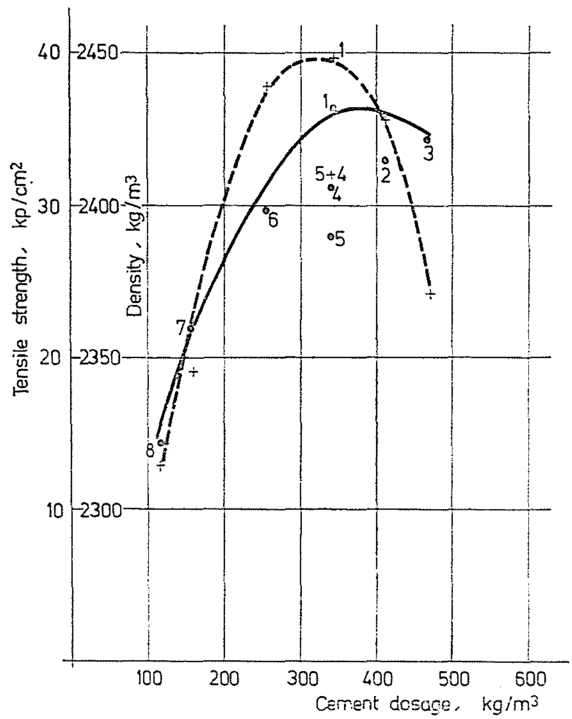

Fig. 13. Tensile strength and density of 115-day concretes made with aggregate type I vs. cement dosage
Legend: ◉ ——— tensile strength,
+ - - - - - density

h) With increasing cement dosage, the ultimate strain of concrete (Fig. 14) hence the extensibility of concrete increased about linearily. Thus, extensibility may be increased by higher cement dosages. On the other hand, extensibility of concrete I/5 showed a decrease beyond a given w/c for identical cement dosage.

i) For cement dosages of 120 to 350 kg/cu. m the tensile strength was about proportional to the initial tensile modulus of elasticity (Fig. 15) but thereover not. The tensile modulus of elasticity was understood as the asymptote of the initial tangent to the "virgin diagram".

j) In the cement dosages ranging from 350 to 500 kg/cu. m, the ratio of tensile-bending to compressive strength was about constant, and abruptly increased with decreasing cement content (Fig. 16). Hence to assume this ratio as constant seems only justified for paste-saturated and oversaturated concretes.

k) Also the ratio of compressive strengths found on 20-cm cubes and on $7\times7\times25$ cm prisms is function of paste saturation rather than to be constant (Fig. 17).

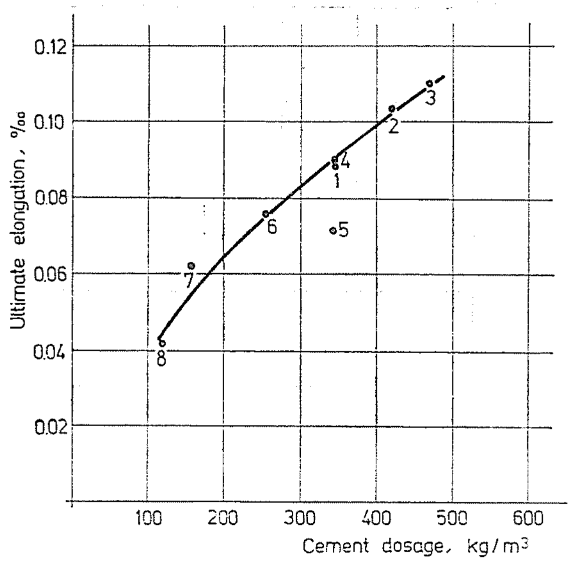

Fig. 14. Ultimate elongation of 115-day concretes made with aggregate type I vs. cement dosage

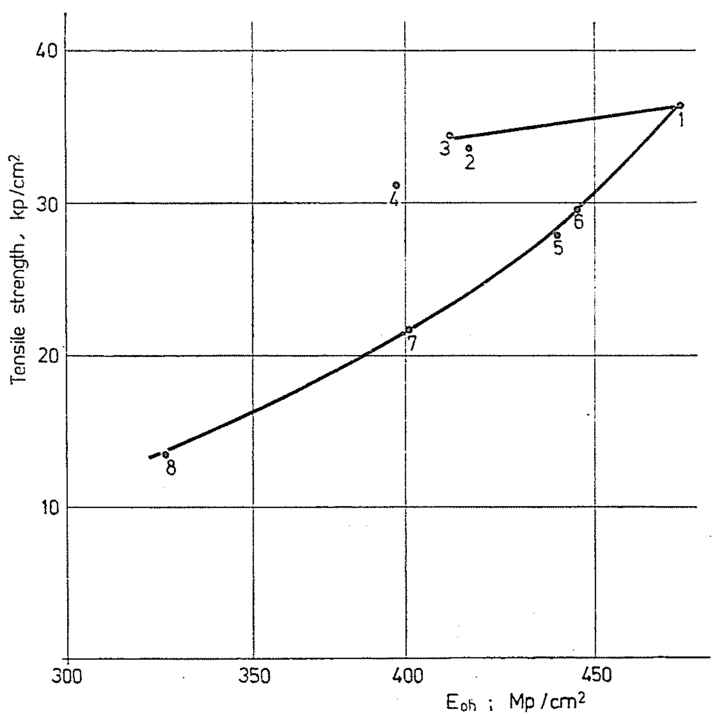

Fig. 15. Tensile strength vs. modulus of elasticity in tension (aggregate type I)

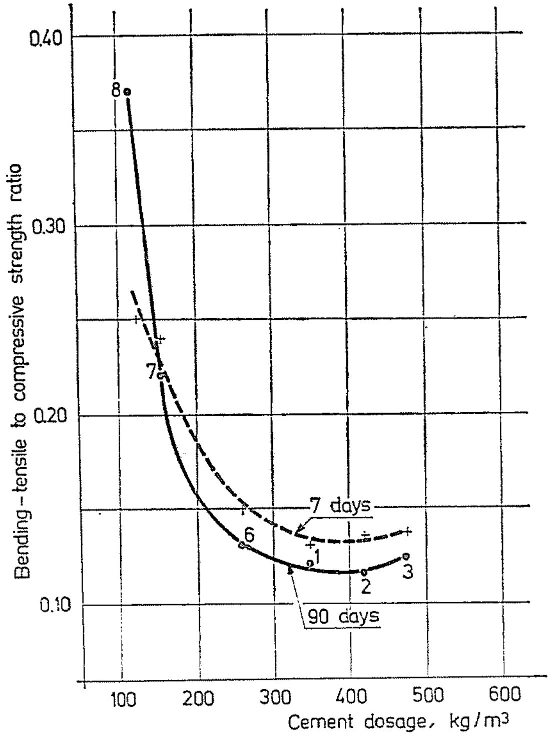

Fig. 16. Bending-tensile to compressive strength ratio (aggregate type I)

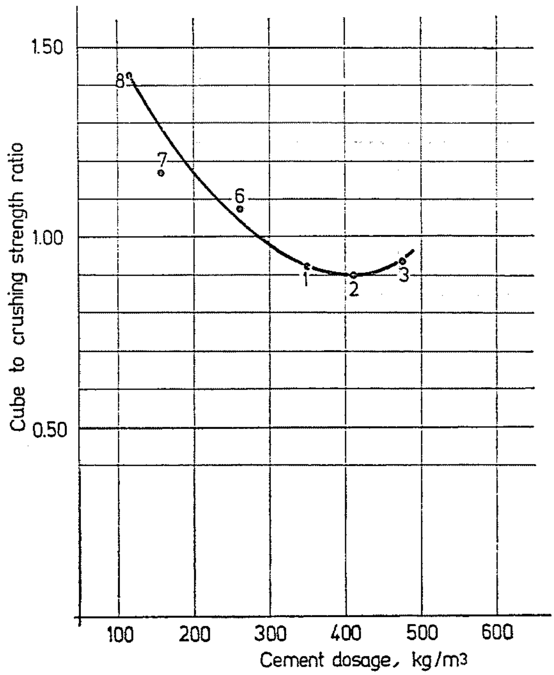

Fig. 17. Cube to modified cube strength (ASTM C 119-65T) ratio vs. cement dosage

Summary

The hardening process of 1 to 90-day concretes immersed in water has been investigated. The concrete was made with standard aggregate and a cement dosage varying in wide ranges. Compressive strength was found to depend on the w/c ratio at any age but the tensile strength was found to be little dependent. Higher w/c ratios reducing concrete density caused a strength loss. Given grading curves had an optimum cement dosage from the aspect of compressive strength, little manifest in respect to the tensile strength. The density optimum pertained to a somewhat lower cement dosage than did compressive strength optimum. Both unsaturation and oversaturation increase the voids ratio in the concrete. An increased percentage of fines demanded more cement for optimum strength and compactness. Optimum can be assessed from the density of freshly mixed concrete. Extensibility grew with cement dosage. The bending-tensile to compressive strength ratio increased for unsaturated concretes but for saturated and oversaturated concretes it was nearly constant. Also the cube to prism strength ratio depended on paste saturation.

Ass. Prof. Dr. György BALÁZS, head of dept., H-1521 Budapest