

# POLYMER-IMPREGNATED CONCRETE

By

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Research — sponsored by the *Section of Technical Development of the Ministry of Building and Urban Development* — has been made on the strength of impregnated concrete as a function of the impregnating monomer, the impregnation method and the concrete porosity.

The concrete strength is much influenced by the porosity of hardened cement or concrete. Any reduction of the concrete porosity adds to its strength. This has been at the origin of the idea of filling out pores by ulterior impregnation to improve concrete strength, watertightness, corrosion resistance, durability, abrasion resistance. Research made abroad on impregnated concrete had important achievements, adequately described in publications (e.g. [1 through 13]). In this country, pioneering work has been done by *János Koós*, research officer at the *Central Research Institute of the Silicate Industry* [14].

Our tests had been concerned with the effect of impregnation on the concrete strength and deformation characteristics.

## 1. Experimental

At the *Department of Building Materials*,  $70 \times 70 \times 250$  mm prisms were cast from concretes of different porosities (Table 1). Concrete No. 8 was admixed with 0.6% of *Biberol LP* air entraining agent. Concretes were made with portland cement C 450 (28-day strength of 45 MPa). Aggregate fineness modulus was 5.6 determined on a square mesh sieve set beginning with 0.063 mm. 90% of the aggregate was below 8 mm. Specimens were stored in lime-saturated water for a week, then in laboratory until impregnated.

Strength of the untreated prisms was determined on specimens used for water absorption tests. First, the bending-tensile strength  $R_{t,f}$  was determined by third-point loading over a span of 210 mm, then the modified cube strength on broken halves  $R_c$  with a load applied on a 5000 mm<sup>2</sup> pressure plate.

The specimens to be impregnated were dried at 150 °C for 24 h, then

Table 1

Composition and properties of green concrete, water absorption of concrete before drying, solid density of dry concrete

Symbol	Solid density of green concrete kg/m <sup>3</sup>	Cement dosage kg/m <sup>3</sup>	W/C	Glanville compacting factor	Solid density of dry concrete kg/m <sup>3</sup>	Water absorption by gradual immersion %
1	2180	164	0.81	0.875	2025	5.75
2	2290	218	0.66	0.85	2185	4.85
3	2345	264	0.54	0.85	2220	4.62
4	2390	312	0.56	0.84	2225	4.52
5	2380	353	0.42	0.765	2235	3.94
6	2380	400	0.38	0.75	2295	3.95
7	2375	500	0.345	0.71	2270	3.77
8	2410	358	0.42	0.835	2200	5.43

the dry concrete was stored in a sealed polythene bag until impregnated. Impregnation materials were selected from the following aspects:

- a) Described or at least mentioned in literature.
- b) Made in Hungary.
- c) Unexpensive.
- d) Operations possible under laboratory conditions.
- e) Technology fit to industrial application.
- f) Beside strength increase, improvement of other properties.
- g) Environmentally harmless material or technology.

Selected materials were *methyl-methacrylate monomer MMA* and a *polyester product UP* under the commercial name *Polikon 210*, both made by *Nitrokémia Industries, Fűzfő*, as well as *furfuryl-alcohol FA* made by *Nitrogen Works, Pé.* Major properties of impregnants and the applied catalysts have been compiled in Table 2.

In the first series, impregnation was made with methyl-methacrylate. First, vacuum of 270 to 400 Pa was created, followed by monomer supply onto the specimens. Meanwhile pressure grew to 2700 to 4000 Pa. After monomer supply, cocks were opened to make the vacuum in the recipient off in five minutes. Thereafter the specimens were kept in the monomer at atmospheric pressure for 30 min, then taken out, let dripping, weighed and immediately immersed in tap water, then heated to 80 to 90 °C to accomplish polymerization. Heat polymerization lasted 3 hours (also in series 2 to 4).

The second series differed from the first one by immersing the specimens before polymerization in boiling water cooled by the specimens to 80 °C.

**Table 2**  
*Impregnant properties and auxiliary materials*

Impregnant					Catalyst-primer		
Trade mark	Chemical denomination or formula	Foreign matter %	Density at 20 °C kg/m <sup>3</sup>	Viscosity at 20 °C Pa.S	Trade mark	Chemical denomination	Dosage as % of impr.
Plexy	$\text{CH}_2=\text{CCH}_3-\text{COOCH}_3$ methyl-methacrylate	—	950	$8.8 \cdot 10^{-4}$	—	—	—
Polikon 210	$\text{R}-\text{OOC}-\text{C}_6\text{H}_4-\text{COO}-\text{R}$ polyester based on isophthalic acid	40% of styrene	1110	0.45	Finox M50L Beschleuniger	50% methyl ethyl-ketone-peroxide CW Co-naphthenate	0.5 0.5
—	$\begin{array}{c} \text{HC}-\text{CH} \\ \parallel \quad \parallel \\ \text{HC} \quad \text{C}-\text{CH}_2-\text{OH} \\ \diagdown \quad \diagup \\ \text{O} \end{array}$ furfuryl-alcohol	—	1130	$1.1 \cdot 10^{-3}$	—	HCl diluted to 1 : 1	0.1

Further heating raised the temperature to 85 to 90 °C. This series was selected because it was observed that upon heating the water, part of the monomer was released from macropores of specimens deficient in paste, assessed macroscopically from the whitish froth or spongy sediment produced by the monomer polymerizing in water.

Dried specimens of the third series were immersed in MMA monomer at atmospheric pressure for a day, then left to polymerize in water at 80 °C.

Specimens in the fourth series were impregnated in a precondensate of furfuryl-alcohol FA similar to series 2, and condensed in boiling water.

Furfuryl-alcohol precondensate was produced with hydrochloric acid diluted to 1 : 1 by adding 1 ml of HCl to 1 litre of FA, reaction was started by immersion in lukewarm water, then the transparent furfuryl-alcohol was awaited to grow dark greenish-brown. Insofar as the compound got warmed, it was cooled in water. Viscosity of the precondensate about equalled that of water.

The fifth series was vacuum impregnated with a 60 : 40 mix of UP-resin and styrene monomer. Polymerization was accelerated by heat from an IR lamp applied on specimens clad in polythene sheets.

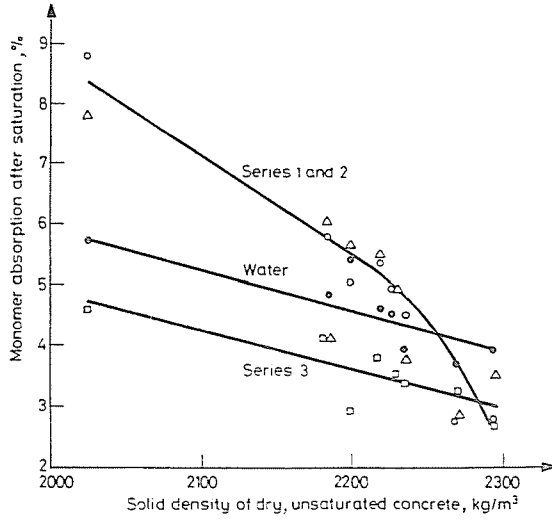


Fig. 1. Solid density vs. monomer absorption

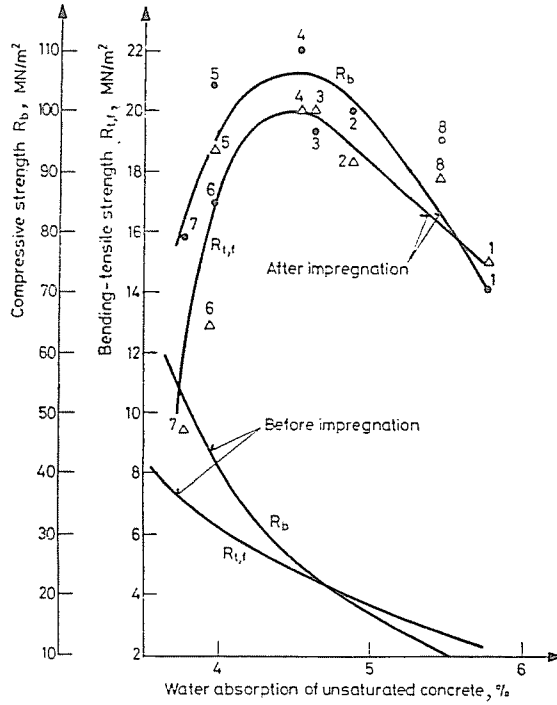


Fig. 2. Water absorption vs. strength

## 2. Evaluation of test results

Only experiments made with MMA monomer were successful. Polyester-styrene resin penetrated only to a depth of 2–3 mm. FA monomer though got imbued into the concrete but without strength improvement. Acid catalytic formation of furan resin is assumed to be hampered by concrete basicity.

Therefore in the following, only MMA impregnation will be evaluated.

Broken pieces of the impregnated specimens demonstrated their cross section to be completely penetrated by MMA.

Also, large (0.5 to 2 mm or over) air voids were clearly seen to remain empty. Furthermore, specimens impregnated by soaking (without vacuum) absorbed less monomer than did those saturated in vacuum.

Monomer absorption (directly after saturation but before polymerization) vs. dry concrete solid density has been plotted in Fig. 1, together with the water absorption. Vacuum treatment is seen to significantly forward impregnation (series 1 and 2). Very compact (high-density) concretes would, however, require pressure during impregnation.

Again, water saturation does not correspond to monomer saturation, since saturation also depends on the capillary activity of the impregnant. Also, gradual monomer immersion at atmospheric pressure (series 3) did not result in satisfactory impregnation during 24 hours.

Strength values in series 1 and 2 have been plotted as a function of water absorption (apparent porosity) in Fig. 2. Both compressive and bending-tensile strengths of impregnated concretes were optimum for about 4.5% of water absorption. For a higher than optimum water absorption, the strength increase was about constant. For a lower water absorption, however, the effect of impregnation abruptly decreased.

Strength gain vs. impregnant percentage by mass is seen in Figs 3 and 4. Both compressive and bending-tensile strengths tend to about linearly increase with the absorbed impregnant. Concretes rather deviating from the fitting curve are those rather unsaturated (No. 1), unable to hold the impregnated monomer, and aerated concretes No. 8, a priori with 4.5% of entrained air.

The strength development of impregnated concretes is also affected by the inherent concrete characteristics. Figs 5 and 6 refer to the initial solid density for a given grading, resulting in maximum strength increase. Taking only strength into consideration, — in the given case — maximum was at 2240 to 2280 kg/m<sup>3</sup>, for vacuum impregnated concretes (series 1 and 2). No such maximum could be demonstrated for specimens impregnated by gradual monomer immersion.

Impregnation was irrelevant to the ratio of bending-tensile to compressive strength (Fig. 7). It should be noticed here that the bending-tensile strength of non-impregnated concrete was determined in water saturated state. Impreg-

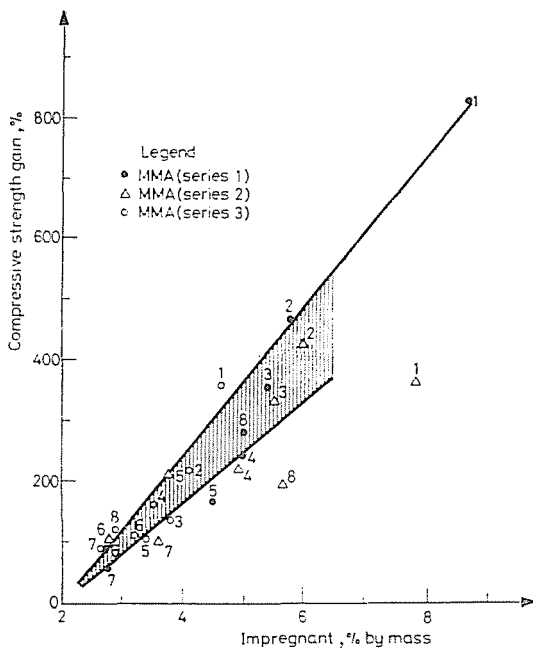


Fig. 3. Compressive strength vs. impregnant percentage by mass absorbed (numbers beside marks identify the concrete)

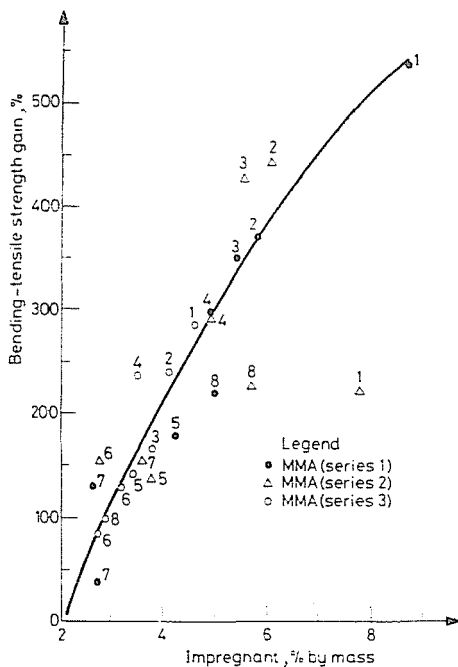


Fig. 4. Bending-tensile strength vs. impregnant absorption (numbers beside marks identify the concrete)

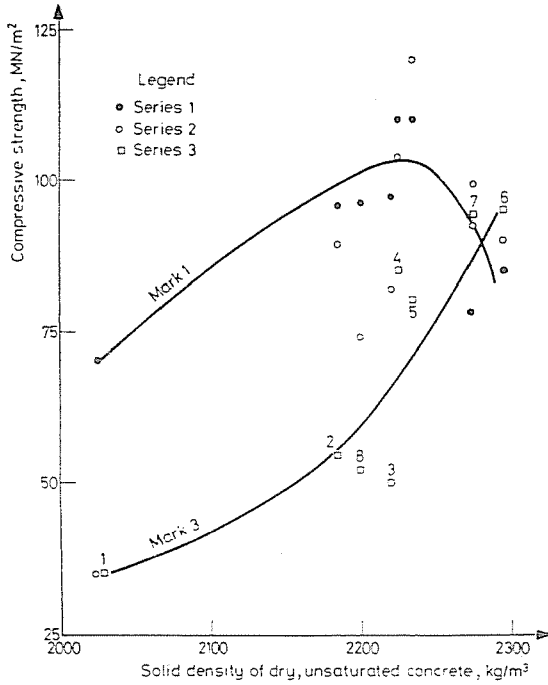


Fig. 5. Compressive strength of impregnated concrete vs. solid density of concrete before impregnation

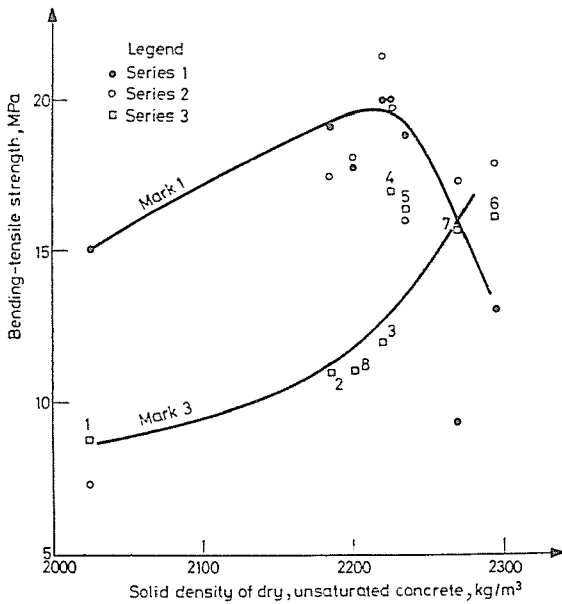


Fig. 6. Bending-tensile strength of impregnated concrete vs. solid density of concrete before impregnation

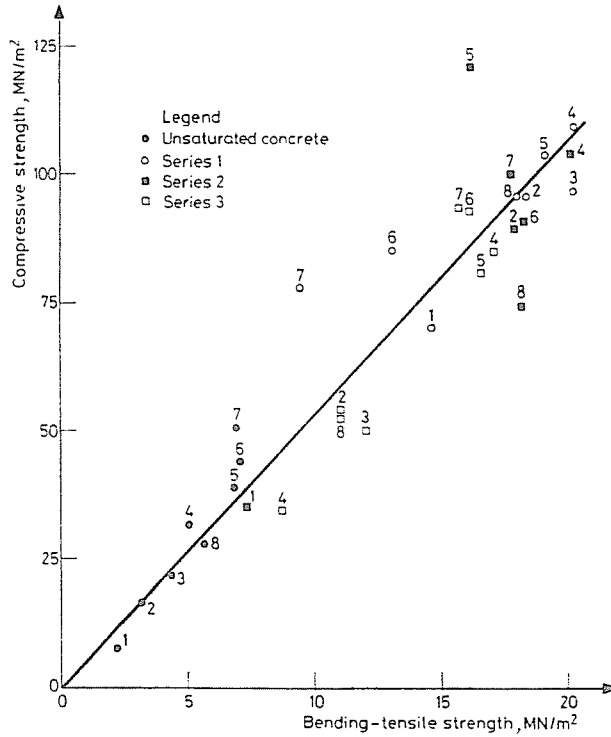


Fig. 7. Compressive vs. bending-tensile strength of a given concrete

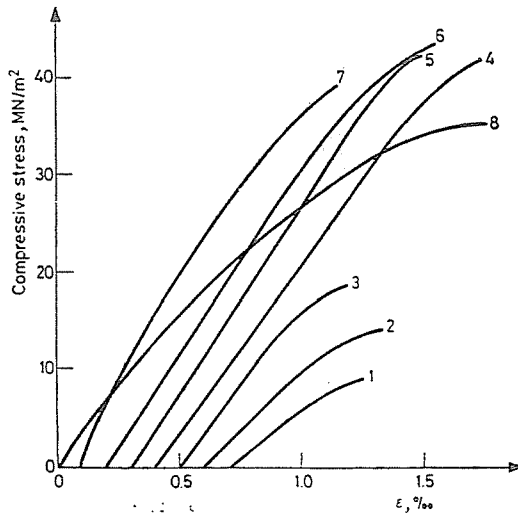


Fig. 8.  $\sigma - \epsilon$  diagrams for air-dry non-impregnated concretes



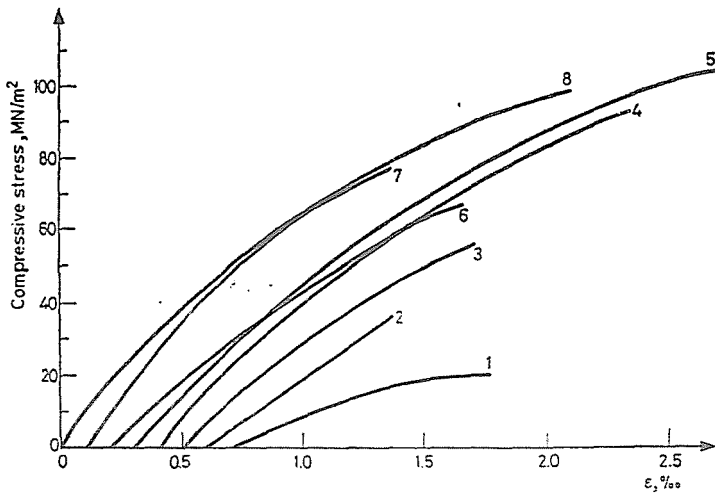


Fig. 9.  $\sigma - \varepsilon$  diagrams for impregnated concretes

nated concretes were, however, not water saturated before testing. Thus, the ratio does not depend on whether capillaries are water or polymer saturated.

Finally, comparison of Figs 8 and 9 shows that, although impregnation increases the concrete ultimate deformation and initial modulus of elasticity, but much less than its strength.

### Summary

Research was concerned with the interdependence between impregnating monomer, impregnation method and concrete porosity and strength.

Concrete porosity was controlled by the cement dosage, before impregnating the concrete, it was dried at 150 °C for 24 hours, then monomer impregnated and heat polymerized.

Strength was the highest for a concrete with 4.5% of water absorption, corresponding to paste saturated concretes. Methyl-methacrylate is the most suitable monomer for saturation. Vacuum saturation was better than saturation at atmospheric pressure by gradual monomer immersion. Relative strength gain was the higher, the more the concrete porosity hence the absorption, in extreme cases more than 500%. Impregnation though raised the initial modulus of elasticity and the ultimate deformation but less than strength. Impregnations with furfuryl-alcohol and polyester-styrene failed.

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