CONCRETE WITH FOAMED POLYSTYRENE AGGREGATE

by

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1. Introduction

The latest development in lightweight concrete is that with polystyrene beads as aggregate. The light weight of the concrete is due to polystyrene beads of very low density. Polystyrene beads are produced by a prefoaming equipment from polystyrene globules as raw material.

Polystyrene concrete is a recent development [1], [2], [3]. In this country, industrial use preceded research work, namely the Agricultural Producer's Co-operative "March 15" in Hernád started to manufacture wall slabs of polystyrene concrete for agricultural buildings some years ago.

The Department of Building Materials, commissioned by the National Building Enterprise No. 22, begun the research work in 1971. The scope was to produce heat-insulating wall slabs and partitions of polystyrene concrete for living houses. This study is summing up experience obtained with polystyrene concrete.

2. Materials used in the tests

Polystyrene beads are produced in different particle sizes. In the described tests, beads of 4 to 6 mm diameter, 18 kg/m^3 density, 2% water absorption have generally been used. Some tests served to control the effect of the bead size on the concrete properties, using polystyrene beads of about 2 mm diameter, 30 kg/m^3 density.

The *cement* was of grade 600 tested in earth-moist mortar.

Occasionally river silica sand was added, as shown in Fig. 1.

3. Strength of polystyrene concrete

In the test, polystyrene beads were dosed by volume, the other components by weight. Composition, consistency, method of mixing, method of curing and mode of surface treatment of polystyrene beads were varied.

In general, 3 prisms of 7,07×7,07×25 cm size were made of each mix. These were tested at 7 days to failure by a bending load applied at third-point over a span of 24 cm. Four of the six specimens obtained in this way were tested for compressive strength, using a platen of 50 cm^2 area, the other two were used to determine the density of the dry concrete.

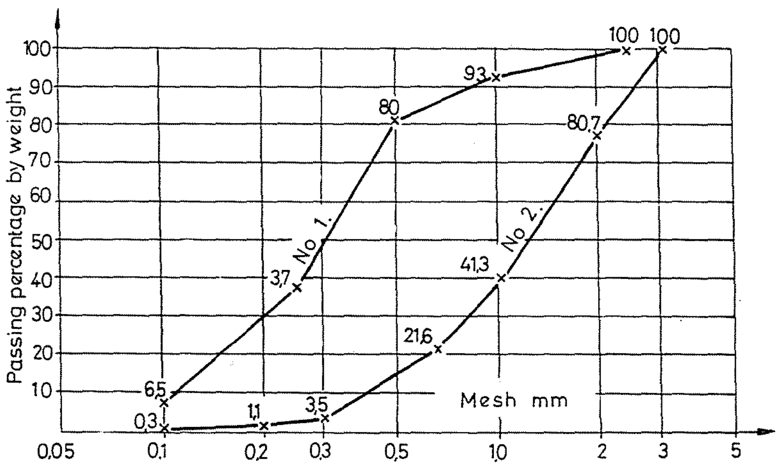

Fig. 1. Sand grading curves

Test results

a) There exists a linear relationship between the density and the compressive strength and modulus of rupture of polystyrene concrete, apart of the initial period. This linear equation depends, however, markedly on the composition of the concrete, as shown in Figs 2 and 3, for a concrete prepared with 4 to 6 mm polystyrene beads. The highest strength for the lowest density is obtained if the gaps between the polystyrene beads are filled out by cement paste alone. This is, however, no cement saving solution. Therefore in practice, the concrete contains also 0 to 3 or 0 to 5 mm sand. In this case the strength is lower for the same density. In practice it is not worth-while to make this kind of concrete with less than 750 kg/m^3 density. Strength diminishes even more with sand lacking fines under 1 mm. There is no space for sand grains of 1 to 3 mm in the gaps between the polystyrene beads, therefore the density of the concrete increases. In Figs 2 and 3, triangles indicate the 28-day strength of a 20 cm control cube and of a 15×15×50 cm control prism (span 45 cm, third-point loading) both prepared with 0 to 3 mm size sand and cement grade 500. As the modulus of rupture changes but slightly between 7 and 28 days, the control strengths deviate hardly from the equalizing line of the concretes of nearly identical composition.

b) Ratio of modulus of rupture to compressive strength of polystyrene concrete is essentially different from that of ordinary concretes (Fig. 4). Here the ratio ranges from 0.33 to 0.5.

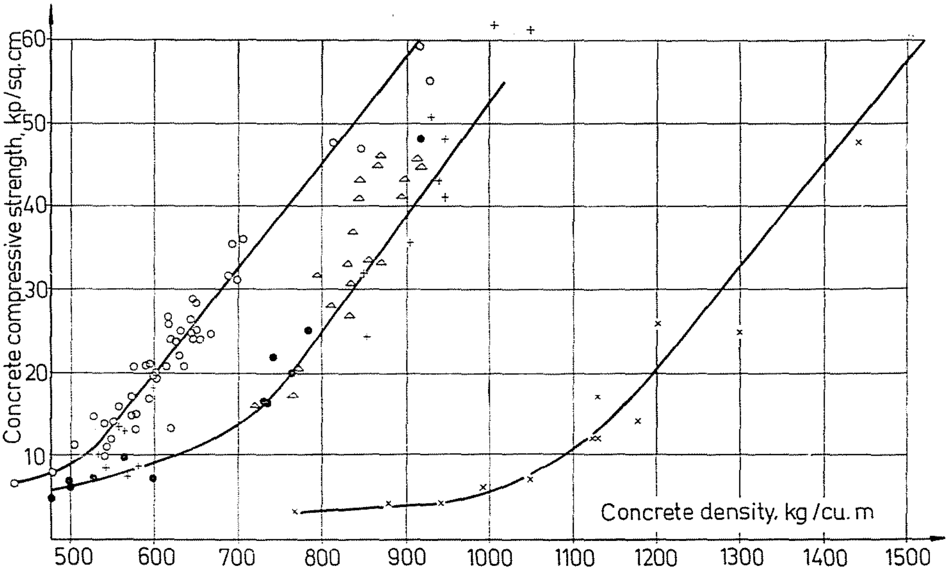

Fig. 2. Compressive strength of 7-day concrete vs. density of concrete dried to constant weight (Cement gr. 500 according to earth-moist mortar test)

Legend valid to Figs. 2 to 4:
Prisms 15 by 15 by 70 cm made of
○ cement paste (neat)
● " " + sand HO/1
+ " " + ,,HO/1 + H1/3
× " " + ,,H1/3
△ " " + ,,HO/3

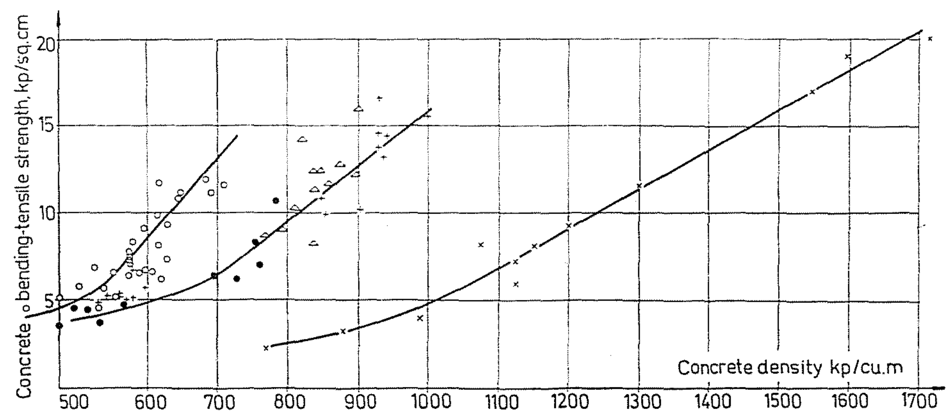

Fig. 3. **Bending-tensile** strength of 7-day concrete, vs. density of concrete dried to constant weight. (Cement gr. 500 according to earth-moist mortar test)

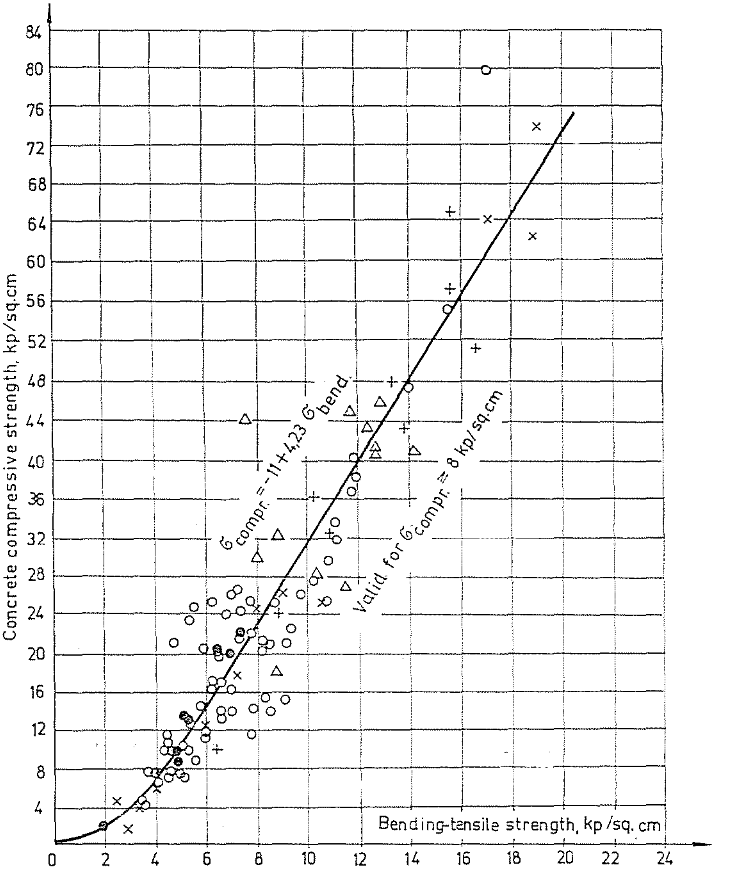

Fig. 4. Concrete compressive vs. bending-tensile strength (with the same notations of the composition as in Figs 2 and 3)

Table 1

Composition and

No.	Components in 1 cu.m concrete					Density (at casting) kg/litre
	Cement type „500", kg	water kg	sand 0/1 mm kg	polystyrene litre	polystyrene grain size mm	
4	324	145	532	850	4—6	1015
5	334	151	552	900	about 2	1063
6	520	152	—	1050	4—6	693
7	500	147	—	1000	about 2	667
8	326	147	539	850	4—6	1028
9	342	154	566	900	about 2	1080
10	510	150	—	1000	4—6	680
11	540	150	—	1100	about 2	680

c) The size of the polystyrene beads has some effect on the concrete strength. No specified difference could be established between concretes made with neat cement paste and made with cement paste containing aggregate of 0 to 1 mm, either in tests shown in Table 1 or in other tests. In general, the concrete with smaller polystyrene bead aggregate showed a slightly higher density and somewhat higher strength. Such a concrete is easier to place. For concretes made with cement paste and sand No. 2 according to Fig. 1, strength of concretes made with smaller polystyrene bead aggregate was invariably lower and more scattered. Namely, the increased space demand of the sand made uniform development of the mortar skeleton uncertain.

d) The time-dependent *natural hardening* of polystyrene concrete is determined by the cement, just as for ordinary concretes (Table 1).

e) Polystyrene concrete can be *steam cured*. However, it must be taken into account that polystyrene is a thermal insulating material and the temperature gradient in the concrete differs from that in ordinary concrete. For a 20 cm cube the temperature slope is shown in Fig. 5. It should also be taken into consideration that polystyrene is not resistant to heat. Control specimens of hardened concrete were kept in an exsiccator at 70, 80 and 90 °C for 24 h. At 90 °C the polystyrene decomposed; it left the specimen in gas form and the spongy concrete structure remained. At 70 °C no alteration was observed. At 80 °C decomposition was beginning on the exterior of the concrete. Probably there is no decomposition at 80 °C in a humid atmosphere but no steam-curing without a proper regulation is permitted.

f) The polystyrene concrete was *mixed* either manually, or in two different positive type mixers. Cement and sand were mixed dry for 20 sec, then with water for 1 minute. Now the polystyrene was added, to be mixed with the mortar for 30 sec. All the time the mix seemed to be uniform.

strength of the concrete

Curing	Modulus of rupture at compressive strength					
	1	7	28	1	7	28 days
	kg/sqcm					
steam	4.9	9.0	12.8	14.3	23.7	27.9
steam	4.9	9.2	12.6	14.5	23.0	31.5
steam	4.7	7.2	8.9	12.4	16.9	20.3
steam	5.7	6.5	7.5	15.2	18.0	20.2
air	4.6	10.0	14.0	11.6	30.7	43.7
air	4.6	11.2	15.8	10.5	26.0	38.4
air	4.5	9.0	10.0	7.8	18.8	23.2
air	4,6	6.8	9.4	8.4	17.6	23.5

In the Agricultural Producer's Co-operative "March 15" polystyrene concrete wall slabs have been produced for years. The concrete is mixed for 5 minutes in a rotary drum mixer. First, water is mixed with cement, then half of the polystyrene beads is added, followed by the sand, finally the other half of the polystyrene beads. The consistency is plastic (10 cm slump).

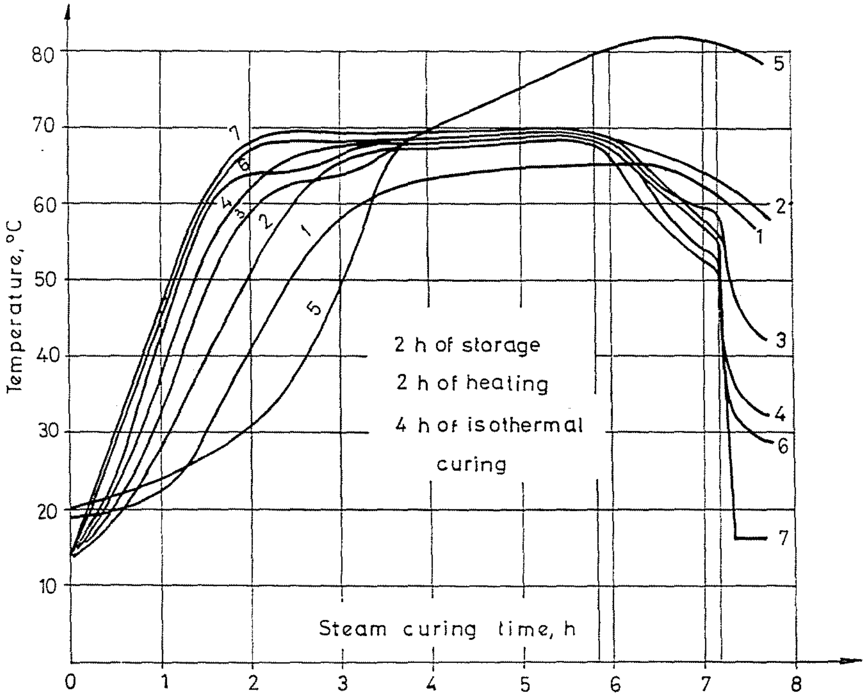

Fig. 5. Development of temperature during steam-curing inside a 20 cm concrete cube for 2 h of storage, 2 h of heating, 4 h of isothermal curing

Concrete cube No. 6 in Table 1: interior marked 5
exterior marked 6
Concrete cube No. 4 in Table 1: interior marked 1
exterior marked 4
Concrete of 2200 kg/cu·m density: interior marked 2
exterior marked 3
Chamber temperature marked 7

The mixer must be set up shielded from the wind, because even a mild air motion blows the polystyrene beads away. From the mixed paste the polystyrene aggregate cannot be blown away any more, therefore the concrete is transportable.

The scatter of polystyrene concrete strength is found to be high, mostly attributed to a non-uniform mixing, but placing has also a major role.

g) At the Agricultural Co-operative, the concrete is only spread and finished with a trowel.

It has been observed that this concrete cannot be compacted by pressing because it is resilient. On a vibrating table it could be well compacted when a small pressure was simultaneously applied on its surface. Large-size wall slabs were well compacted horizontally by a pan vibrator. For compacting the heat insulating layer of an experimental road section, the steam-roller seemed adequate.

h) According to literature, favourable results were achieved if the polystyrene was *engineered*, applying usually PVAc-dispersion to this aim. Our relevant tests brought no results. The concrete strength did not increase (neither was it expected to) nor did the uniformity of mixing of the polystyrene beads.

4. Shrinkage of polystyrene concrete

Two prisms of $10 \times 10 \times 50$ cm size were made of each mix composed according to Table 2, at 15 hours of age they were put in a climatization chamber and at 24 hours, determination of shrinkage began with the Amsler shrinkage gauge, in an atmosphere kept at 20 to 22 °C, and 64 to 66% r.h.

Table 2

Composition of shrinkage specimens

No.	Components in 1 cu.m concrete						Initial density kg/cu.m
	Cement kg	Water kg	Aggregate marked 2 in Fig. 1	Polystyrene		PVAc admixture	
				litre	Grain size mm		
22	580	153	—	1180	4—6	—	750
23	216	97	653	700	4—6	7	991
24	274	123	827	650	4—6	—	1240
25	600	173	—	1180	about 2	—	794
26	292	121	822	650	about 2	—	1255

a) In the first days, shrinkage of the concretes was rather rapid and even at 100 days it did not tend to an asymptote, as against ordinary concretes.

b) Shrinkage of these concretes — especially below 1000 kg/m^3 density — exceeds essentially that of the ordinary concretes and this must be reckoned with in designing large-size elements.

c) A linear relationship was observed between shrinkage and density of the concretes (Fig. 6). Straight lines connecting shrinkage values for 50 days and 100 days intersect on the abscissa. The 10-day shrinkage line connecting concretes No. 22, 25 and 23 joins also the intersection point. Subsequent shrinkage values show whether this conclusion is a rule and where the limit straight lays.

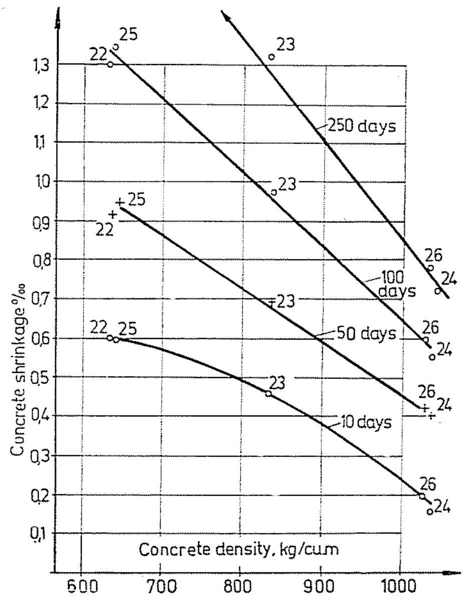

Fig. 6. Relation between density and shrinkage of polystyrene concrete

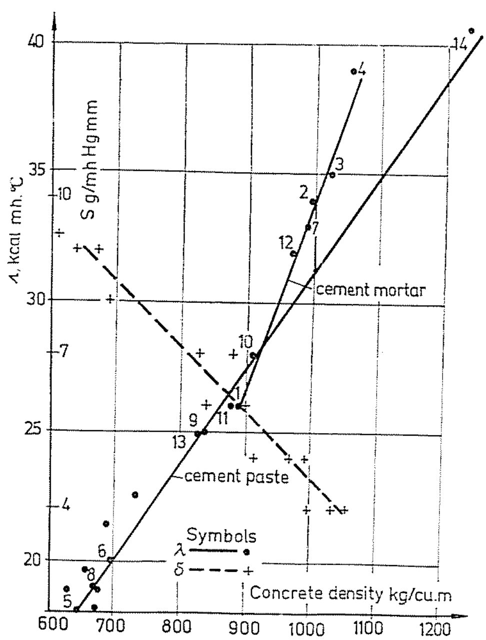

Fig. 7. Heat conductivity and vapour diffusion factor vs. dry concrete density

d) The shrinkage was not influenced by differential polystyrene bead sizes (6 mm instead of 2 mm) in concretes of the same density.

5. Heat conductivity of polystyrene concrete

Heat conductivity and vapour diffusion factors of dry slabs of thickness and composition shown in Table 3 were tested in a steady thermal flux. Some slabs were provided on both faces with a glass-fibre reinforced cement paste layer 1 or 2 cm thick. Test results are plotted vs. average density of the slabs in Fig. 7. Earlier results obtained with concretes of other than sandwich structure are indicated by empty circles.

Table 3

Composition of the tested concrete slabs

No.	Composition				Polystyrene litre/cu.m	Glass reinf. cement layer	Thickness cm
	Cement kg/cu.m	W/C	Sand, kg/cu.m				
			No. 1	No. 2			
1	375	0.455	425	205	1000	—	15
2	375	0.45	412	200	1000	—	15
3	375	0.45	412	200	1000	1 cm	15
4	375	0.45	412	200	1000	2 cm	15
5	500	0.288	—	—	1000	—	16
6	500	0.288	—	—	1000	1 cm	16
7	500	0.288	—	—	1000	2 cm	16
8	500	0.288	—	—	1000	—	14.7
9	500	0.288	—	—	1000	1 cm	14.3
10	500	0.288	—	—	1000	2 cm	15.5
11	375	0.45	412	200	1000	—	11
12	375	0.45	412	200	1000	—	8
13	500	0.275	—	—	1000	1 cm	7.5
14	500	0.275	—	—	1000	2 cm	8

Evaluation of the results

a) The heat conductivity varied linearily as a function of the hardened concrete density — in conformity with available experience. Slope of the straight differed, however, for cement paste or cement mortar filling out gaps between the polystyrene beads.

b) Also the vapour diffusion factor changed linearily with the density but reversely to the conductivity.

Summary

Light-weight concrete with polystyrene bead aggregate is suitable for manufacturing non-load-bearing, thermal insulating large-size slabs.

Reliability of mixing and placing is decisive for the uniform concrete quality, much more than for ordinary concretes.

The batching order of materials during mixing must be strictly followed.

Compressive strength, modulus of rupture, thermal conductivity and vapour diffusion factor, shrinkage and density of the concrete are linearily related. The ratio of modulus of rupture to compressive strength is about 0.33 to 0.50. The relationship between strength and density depends on whether the skeleton responsible for the strength consists of cement paste or cement mortar.

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