

## Marine floating concrete made with polystyrene expanded beads\*

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Expanded-polystyrene concrete (EPS-concrete) is very suitable for use as marine floating concrete as has been shown by Mr Bagon and Professor Frondistou-Yannas in the above paper. Its suitability may be attributed to the low rate of water absorption, which is due to the closed structure of its pores. This attribute is obtained by using mixes with dry bulk densities exceeding  $700 \text{ kg/m}^3$ <sup>(1)</sup>.

For an improvement of the concrete properties, however, I would like to make some observations on the thermal stability of the polystyrene beads, which affects the closed structure of the concrete. Also, I would like to suggest some reasons why the strength of EPS-concrete develops differently from that of normal concrete.

During the hardening process of EPS-concrete, maximum temperatures of 90 to 110°C on average have been determined<sup>(1,2)</sup>. These high temperatures are due to the heat of hydration of the cement on the one hand and, on the other hand, to the low thermal conductivity of the expanded-polystyrene beads. At the same time, partial melting of the polystyrene beads could be observed. For this reason an investigation‡ of the thermal stability of the polystyrene beads at higher temperatures has been carried out in a controlled climate room. The results of these tests are represented in Figure I.

It can be clearly recognized that, for the polystyrene beads tested, the critical temperature range starts above 95°C where volumetric stability is no longer guaranteed.

Moreover, it is known that there will still be some residue of the gas-forming agent remaining in newly expanded polystyrene beads. This agent will be reactivated at temperatures exceeding 90°C, causing micro-cracks in the hardening cement paste.

For these reasons, temperatures exceeding 90°C should be avoided during the hardening process of EPS-concrete.

The closed structure of the EPS-concrete is of great importance for the protection of embedded steel members against corrosion<sup>(3)</sup>, since the alkalinity of the pore water will be maintained by the high diffusion resistance of the polystyrene beads<sup>(4)</sup>.

However, the diffusion resistance is decreasing considerably when the polystyrene beads are melting in the hardening concrete owing to the higher temperatures. This process produces EPS-concrete which, although it originally had a close-pore structure, finishes up similar to aerated concrete with open pores.

Even when EPS-concrete is being used as a marine floating concrete, the maximum temperature in the hardened concrete must be taken into consideration in order to maintain the closed structure. It is doubtful whether the test results reported by Bagon and Frondistou-Yannas are free from any such effect of

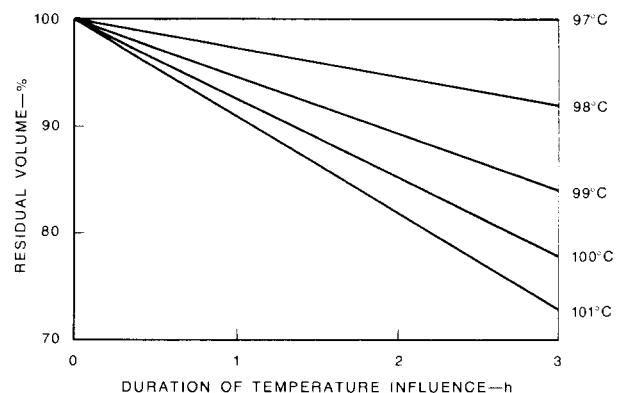
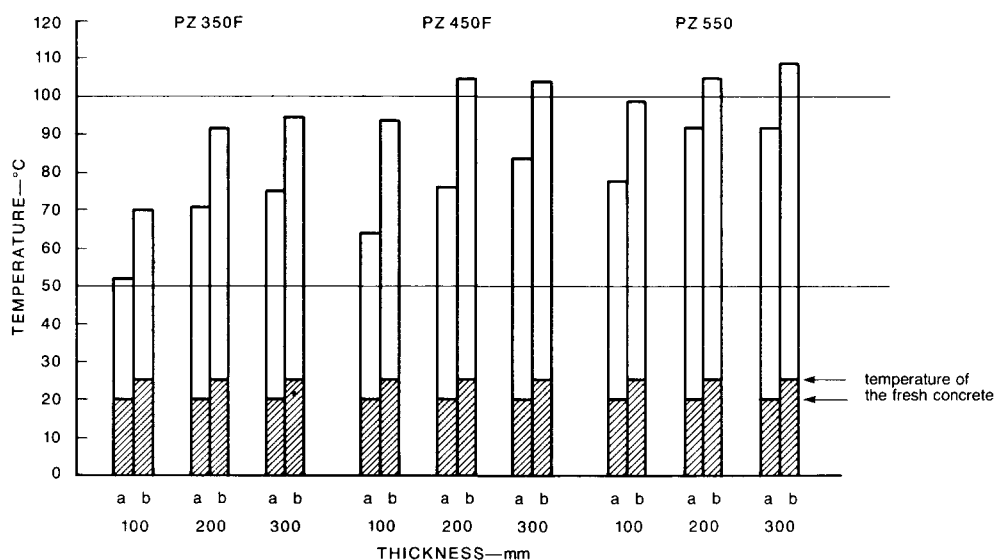


Figure I: Thermal stability of polystyrene beads.

\*Pages 225-229 of MCR 97.

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‡By Hoechst AG of Frankfurt-am-Main. Unpublished.



Concrete a: Density  $730 \text{ kg/m}^3$

Sand 0–2 mm

Cement content  $330 \text{ kg/m}^3$

Concrete b: Density  $770 \text{ kg/m}^3$

Pulverized-fuel ash

Cement content  $340 \text{ kg/m}^3$

Figure II: Maximum temperatures in hardening EPS (expanded-polystyrene) concretes:

partially melted beads, for instance, within the specimens for the determination of the water absorption (drying temperature  $105^\circ\text{C}$ ). This effect may be assumed from their high water absorption.

The calculations made for the estimation of the maximum temperatures are given in reference 5. The predominant influences upon the temperature level are the heat of hydration of the cement and the thickness of the concrete elements. These influences can be clearly seen in Figure II where, in addition, the influence of different filling materials is distinguishable.

Furthermore, in order to reduce the maximum temperature in thick concrete elements, considerably less cement should be used than is indicated by Mr Bagon and Professor Frondistou-Yannas. For good workability and to maintain a closed structure, the necessary quantity of fine components should be compensated by using such filling materials as fine sand, silicate flour or pulverized-fuel ash. In doing so, no great strength losses need be anticipated.<sup>(1)</sup>

In determining the strength development of EPS-concretes in comparison with normal concretes, the different mechanism of failure of the two types of concrete should be taken into consideration. The compressive strength of normal concrete is mainly influenced by the tensile strength of the matrix and by the bond strength between the matrix and the aggregate.

For lightweight concretes with ceramic lightweight aggregates, the stiffness of these aggregates is an additional influencing factor which, once a certain strength limit is exceeded, will only allow for a smaller further increase in the concrete strength. This is represented in Figure III, taken from reference 6.

EPS-concrete has a bulk density range of between  $500$  and  $1000 \text{ kg/m}^3$  and a pore volume of about 75 to 50% if the polystyrene beads are included in the pore volume. Because of this high pore volume, the stability of the thin cell wall of the cement paste is also a determining factor of the compressive strength<sup>(5)</sup>. Since the increase in the modulus of elasticity of the matrix as a function of the time will be quicker than the increase in the compressive strength of the matrix, the earlier stiffness of the cell walls will cause a different development of the strength compared with that of normal concrete.

Furthermore, the strength development of EPS-concretes will be accelerated by the high temperatures during the hardening process. With thicker elements the EPS-concrete has, in effect, an internal heat treatment which is caused by the good thermal insulation.

For these reasons, the quick increase in strength cannot be attributed to the admixtures only, as has been stated by Mr Bagon and Professor Frondistou-Yannas.

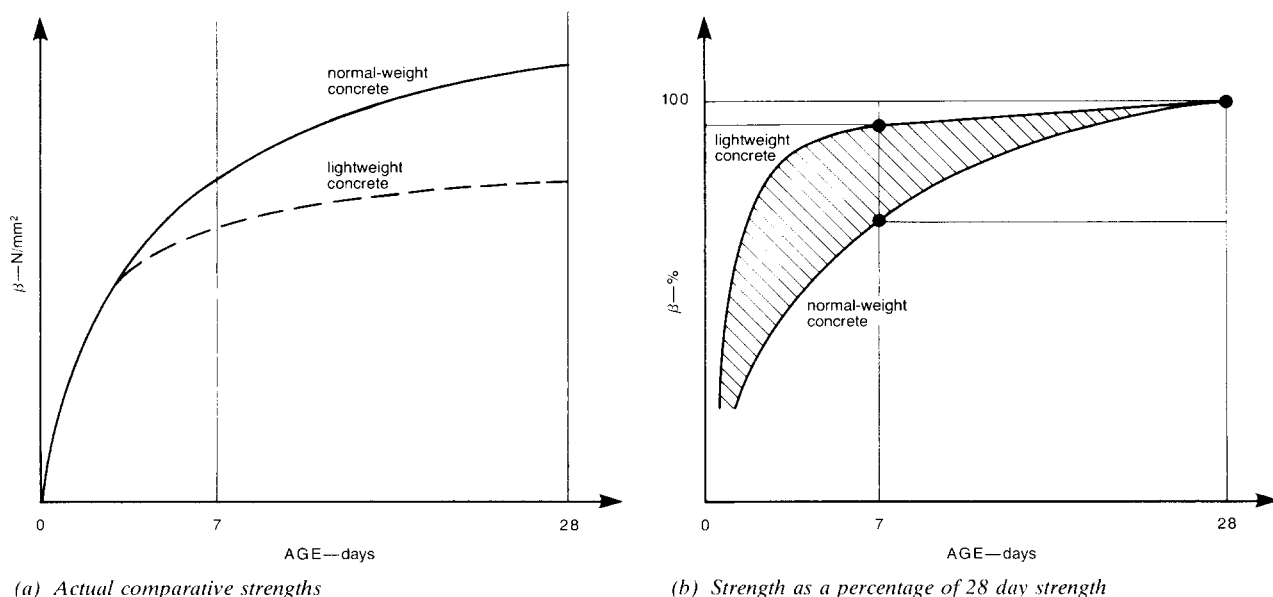


Figure III: Development of hardening of normal-weight (NC) and lightweight concretes.

## Reply by the authors

We wish to thank Dipl. Ing. V. Hermann for his observations and the valuable data presented in his discussion of our paper.

On the basis of his Figure I, one has to make the assumption that the polystyrene beads in our paper were indeed partially melted and that this caused an absorption of 22 to 26%. Even though such absorption may be small compared with that of perlite concrete, it is high for expanded-polystyrene concrete. One is then led to conclude that, however favorable our results are for floating polystyrene concrete, they could be improved by maintaining an appropriately low temperature at all times.

The primary reason why polystyrene concrete gains strength more rapidly than normal-weight concrete is the presence of a water-reducing admixture in the former. The additional mechanisms suggested in the discussion could only produce second-order effects. For instance, it is suggested that, because

polystyrene concrete is a better insulator, hydration temperatures in it are higher, leading to a more rapid strength development. The above assumes comparison on an equal basis, including the use of the same type of cement. In our work, we are comparing polystyrene concrete produced with type II cement (low heat of hydration) and normal-weight concrete produced with type I cement (normal heat of hydration). This difference in the type of cement used decreases the effect of the mechanism suggested above.

Mr Hermann suggests that the amount of cement used in our work be considerably reduced and that this decrease be compensated by the use of fine sand, silicate flour or fly ash. Such a substitution seems promising from the point of view of lowering hydration temperatures and costs. On the other hand, it might affect adversely the protection of embedded steel against corrosion and the freezing-and-thawing resistance of the member.

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