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DENSE PACKING OF CEMENT PASTES AND RESULTING CONSEQUENCES ON MORTAR PROPERTIES

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ABSTRACT

Dense packing of cement particles in the starting mix results in high-strength mortars of low porosity. Mathematical models of J.E. Funk and D.R. Dinger and their computer implementations are good tools for making efficient use of the filler effect. Mortars made of blended cements show very positive overall properties. Hydration is quickened, compressive strength becomes higher, porosity decreases, and microstructure becomes homogeneous and dense. Those factors result in good mechanical properties and great durability of the material. © *1997 Elsevier Science Ltd*

Introduction

Mortar properties are directly dependent on particle packing of the whole raw material mix. Aggregates in concrete are used according to the Fuller curve that gives hints concerning the resulting technological consequences. The present work shows that cement particle packing is an important factor for the properties of products made from such dense-packed cement materials.

Earlier work showed that mathematical models of J.E. Funk and D.R. Dinger and their computer implementations are good tools for making efficient use of the filler effect (1). The programs helps to optimize the amount of filler to achieve a dense cement paste packing. It will be shown that overall mortar properties are influenced very positively. Mechanical properties directly depend on the quality of powder packing.

Characterization of Raw Materials and Experimentals

Mikrodur® is a very fine blast furnace slag-based cement. Typically this material is used for mineral injections. It is characterized by its maximum particle size. There are several grades available (Table 1).

All types named in Table 1 are similar in chemical composition, but different in particle size distribution. They were mixed up with an ordinary Portland cement (OPC; CEM I 32,5, here named PZ 35) in order to achieve dense packing of the cement particles.

Figure 1 compares the particle size distributions of all used components. They were determined by laser granulometry (Cilas) dispersed in propanol.

Blending of PZ 35 was done theoretically according to methods described by Dinger and

TABLE 1
Maximum Particle Size Diameter of Mikrodur® Grades

Grade	D[μm]
S	24
U	9,5
X	6

Funk (3) and verified by experiments afterwards. By using their programs, it was possible to calculate the porosity of different mixes of PZ 35 and fine cements. Theory and experiment fit together quite well as it was reported in earlier publications.

Concentrations of 5, 10, 15, 30, and 70 mass%, respectively, are considered in this work comparing properties of cement slurries with resulting mortar properties.

Due to the high surface area of the fine cements, it seems that the water demand of blends incorporating fine cements will increase. Therefore, measurements of the water requirement were performed to characterize the cement pastes experimentally.

EN 196 defines a certain consistency of a cement slurry that is described by its water demand. Properties of the resulting mortars were characterized concerning their strength, porosity, and microstructure. Strength was tested according to EN 196 after 7, 28, and 90 days. During the curing time, the mortar was stored in water.

Mortar cubes were freeze-dried to stop further hydration. Afterwards, porosity and microstructure were characterized by Hg-porosimetry and investigations under the scanning electron microscope (SEM).

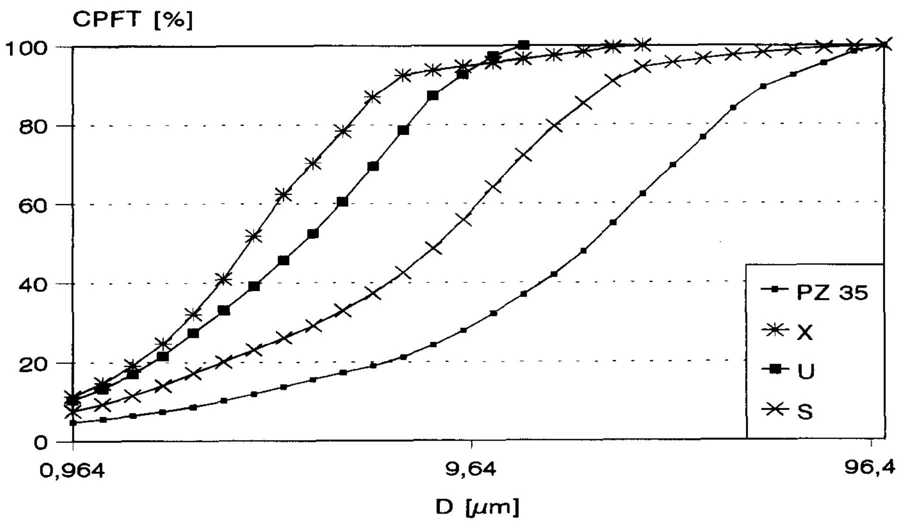

FIG. 1.
Particle size distribution of fine cements (Mikrodur®) in comparison to ordinary cement PZ 35.

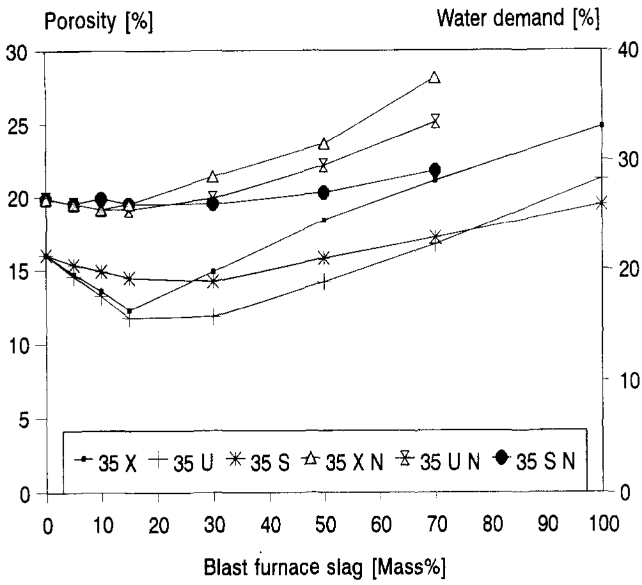

FIG. 2.

Comparison of calculated porosity for powder mixes (1) and experimentally determined water requirement (*N*).

Dense Packing of Pastes

The addition of fine cements to PZ 35 affects the particle size distributions of these mixes significantly. Also, for very low concentrations of fine cements (5 to 30 mass%), the influence is remarkable. Grades X and U affect particle packing much stronger than grade S because their distributions differ greatly from PZ 35, to which grade S is more similar (1).

Figure 2 proves that water requirement (experimental) and porosity (theoretical) of cement slurries are decreasing if fine cements are added to the mix. It is clearly demonstrated that the densest packing can be achieved by blending PZ 35 with 15 and 30 mass% of grade U. A grade X with 15 mass% will also result in a very dense powder packing, but adding a little bit more results in a rapid increase of porosity of the cement mixes. Grade S decreases porosity a little bit, but nevertheless it does not increase it as drastically as it could be expected by its great fineness in comparison to PZ 35. Experimental measurements concerning the water demand of all blends prepared in this work show that calculated decreasing porosity is in good agreement with experimentally decreasing water demand of the cement slurries. Experimental and calculated data fit well together.

Mortar Properties

Strength

For characterization of the mechanical properties, compressive strength was taken to indicate the differences between the different mixes.

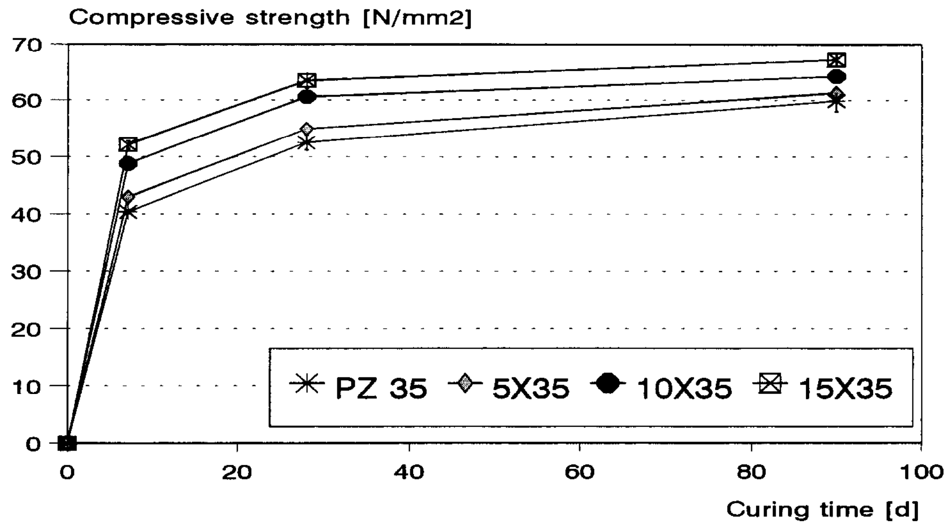

FIG. 3.
Strength development of PZ 35 mortars blended with 5, 10, and 15 mass% of fine cement grade X.

By having a close look at mortar strengths of all tested samples containing Mikrodur® at all studied ages, one is able to see that hydration takes place much faster. Blended mortars at 28-days-old are almost as strong as those of OPC at 90-days-old. The more fine cement is added to the mix the faster hydration occurs. Every blend incorporating fine cements developed better strength properties than the regular OPC.

Strength growth for PZ 35 in combination with 15 mass% fine cement grade X (15X35) in comparison to the standard mortar of the same age (PZ 35 mortar) shows an increase of 29% after 7 days, 21% after 28 days, and 12% after 90 days (Fig. 3).

Taking into consideration that there were different grades of fine cements to be investigated, Figure 4 shows the influence. Grades X and U have got a very dominant influence on mortar properties in early ages. Hydration occurs very fast. The influence of fine cements becomes almost independent from the finess of Mikrodur® with increasing mortar age.

Bending strength showed no influence concerning fine cements at all. It remained at a constant level of about 9 MPa (28 and 90 days). Mortars made with very high concentrations of fine cements (e.g., 70 mass%) showed decreasing bending strengths, but a high compressive strength. SEM observation of polished samples proved that microcracking occurred in these cases at a very high level. Bending strength reacts very sensitive on microcracking. The influence of microstructure will be discussed in detail in the following paragraphs.

Porosity

It is widely believed and very often proved that the strength of ceramic materials in general increases with decreasing porosity. So it is no surprise to investigate that porosity of mortars decreases with increasing amount of fine cements. Porosity investigations were performed by Hg-porosimetry in this case.

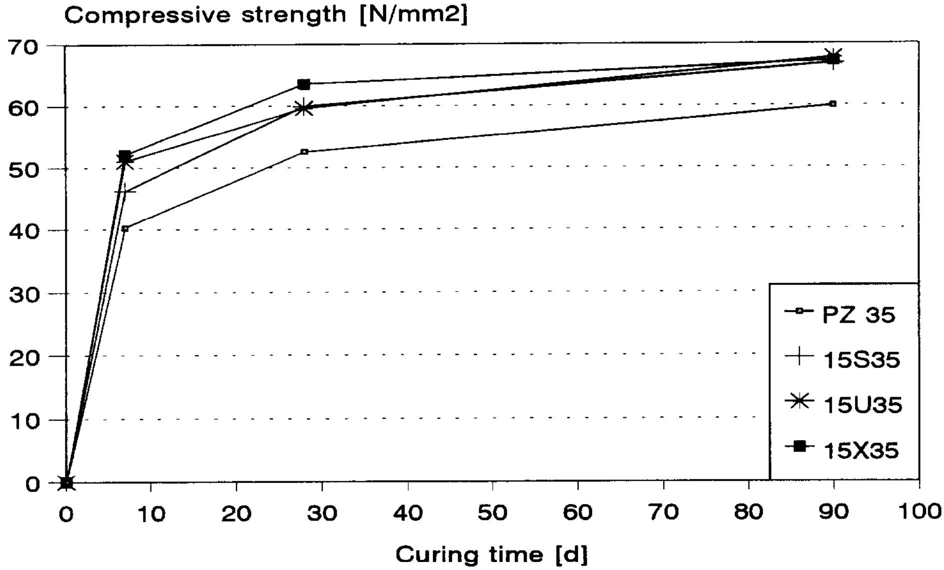

FIG. 4.
Strength development of mortars made of PZ 35 and 15 mass% fine cements grade X, U, and S.

Conversely, it is not possible to correlate the finess of Mikrodur® in combination with the concentration in the mixture to the absolute porosity data of the resulting mortar. It remains true that porosity decreases while strength is growing when PZ 35 is blended in optimum concentrations (e.g., 10 or 15 mass%) with fine cements.

Microstructure

Microstructure is changing very much when OPC is blended with fine cements such as Mikrodur® (1). In this case, SEM investigations of polished mortar-samples (backscattered electrons) shall be discussed.

The observations prove clearly that the microstructure of those blended mortars in general show a very high CSH-gel content, they were much denser, diameters of remaining pores were very small, and, most important, microstructure became very homogeneous. All those factors in combination are leading to very positive properties of those materials as described before: fast hydration, high strength, and great durability.

The following two micrographs of polished mortar sections show the great difference of microstructure. Pores can be identified as black areas, unhydrated cement grains appear white, and CSH-phases are gray. These microstructures represent typical mortars made of OPC cements on the one hand (Fig. 6) and made of blended cements on the other hand (Fig. 7).

Mortars containing very high concentrations of fines tend to build a system of microcracks caused by shrinking of the CSH-gel (Fig. 8). Those microcracks lead to a decreasing bending strength and minimize the durability of the mortar. Figure 7 and 8 in comparison clearly show at which extent microcracking occurs if too much fine cement was mixed with PZ 35. There

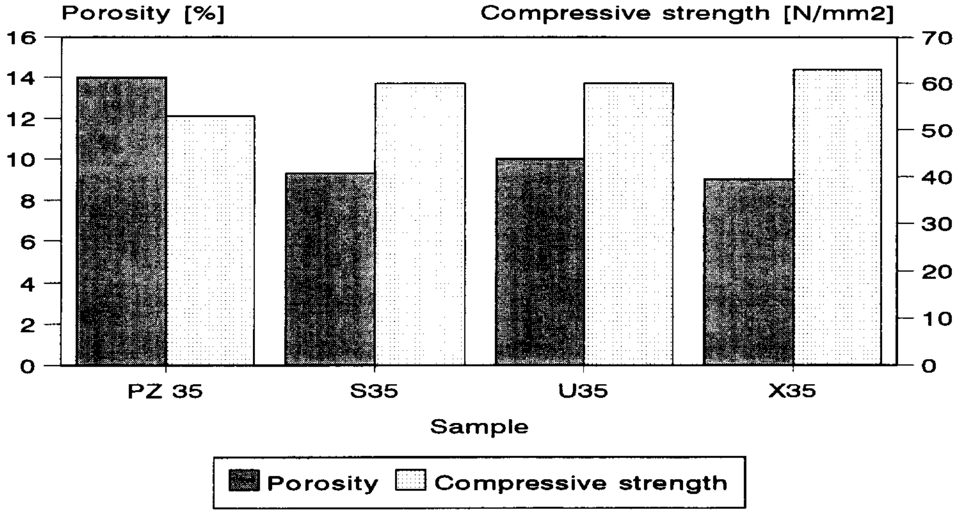

FIG. 5.
Porosity of mortars (28 days) with 15 mass% of fine cements grade X, U, and S.

is no doubt that the microstructure is very much dependent on the particle size distribution of the starting raw material mix. Microstructure itself is the main factor leading to the resulting mechanical and chemical properties of mortars.

Summary

The present work clearly shows that the dense packing of cement particles in the starting mix results in high strength mortars of low porosity.

FIG. 6.
Microstructure of a mortar (28 days) made of OPC PZ 35.

FIG. 7.
Microstructure of a mortar (PZ 35, 28 days) blended with 10 mass% Mikrodur® grade X.

Earlier work showed that mathematical models of J.E. Funk and D.R. Dinger and their computer implementations are good tools for making efficient use of the filler effect. The programs are suitable to optimize the amount of fine ground cement in combination with OPC to achieve a dense cement paste packing.

In the discussed case, PZ 35 was blended with Mikrodur®, which is a very fine ground blast furnace slag-based cement.

Calculations based on Dinger and Funk lead to an optimum amount of 10–30 mass% fine cement in combination with PZ 35. Model and experiment fit together quite well. Mortars

FIG. 8.
Microcracking in CSH gel of a mortar containing 70 mass% fine cement.

made of blended cements show very positive overall properties in this concentration range. Hydration is quickened very much by adding fine cements into the raw material mix. The compressive strength in general becomes higher than the strength of OPC. The porosity of mortars decreases drastically when fine cements are added. The microstructure appears to be very homogeneous and dense. Almost no microcracking occurs. Those main factors are the reasons for the mechanical properties and durability of those new materials.

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