Pergamon

Cement and Concrete Research, Vol. 25, No. 3, pp. 497-502, 1995

0008-8846/95 $9.50 + .00

0008-8846(95)00038-0

INVESTIGATION OF THE ADHERENCE AND THE FRACTURE BEHAVIOUR OF POLYMER CEMENT CONCRETE

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(Communicated by F.W. Locher)
(Received December 5, 1994)

ABSTRACT

Samples with different amounts of a commercial grade powder dispersion (vinylacetate/ethylene copolymer) have been compared with an unmodified concrete. To show the effect of the polymer additive alone all mixtures were prepared with constant w/c-ratio, air void content and workability. Using a wedge splitting test method it was shown that the polymer addition is very effective in increasing the bonding strength and the fracture energy of the interface between the polymer cement concrete and a prefabricated unmodified concrete, but it lowers the fracture energy and the strength of the polymer cement concrete itself.

Introduction

Polymer Cement Concrete and Mortar (PCC) has wide spread applications, one of them being its use in repair systems for concrete (1). Two important mechanical properties of repair mortars are the adherence and a sufficient flexibility that avoids crack formation due to movements of the coated structure. The influence of the polymer additive (PA) on these properties is of great interest. Many PA increase the workability (2); that is why observed benefits are often due to a lower w/c-ratio (1). Moreover the air entrainment is usually raised by the PA. The investigations had the aim to determine the influence of the PA on the adherence and the fracture behaviour of PCC at constant workability, w/c-ratio an air void content.

Preparation of Mixtures

All mixtures have been prepared with an Ordinary Portland Cement PZ 375 (H) (3),a w/c-ratio of 0.45 and a maximum grain size of 4 mm (limestone). The ratio limestone/cement was 3.33, the cement content 450 kg/m³ and the air void content 10%. For keeping the air void content and the workability constant antifoamer (AF), air entraining agents (AEA) and superplasticizer (SP) have been added dependent on the amount of the PA. The dosage was determined by preliminary tests.

TABLE 1
Variable Components of the Investigated PCC Mixtures

Additive	Mixture Nr.			
	1	2	3	4
PA %	0	1	3	5
AF %	0.00	0.00	0.08	0.10
AEA %	0.09	0.00	0.00	0.00
SP %	0.24	0.00	0.00	0.00

The content of the PA is relatively to the amount of the total weight of cement plus limestone, all other percentages are relatively to the cement weight. After the homogenisation in a forced action mixer one part of the mortar was casted in cubic moulds (edge length 100 mm) and densified by vibration. From these specimens the properties of the homogenous PCC mixtures have been determined. For the investigation of the adherence a compound with an appr. one year old unmodified cement concrete (CC) was used (maximum grain size 16 mm, w/c=0.55, crushing strength 42 N/mm² after 28 days water storage). The surface of the CC was prepared with a needle hammer. The PCC mixes have been applied on the wetted horizontal surface of the CC by hand. All specimens were cured in a water bath at 20°C for 25 days (beginning from the second day), then cut with a diamond blade (specimen geometry see next section) and stored at appr. 55% relative humidity until the testing procedure at the age of 28 days.

Testing Method

For the determination of the specific fracture energy G_F for the whole fracture process, the specific fracture energy G_C for crack initiation, the Young´s modulus E and a nominal notch tensile strength σ_{max} a wedge splitting test method according to Tschegg (4) was applied. As details are explained elsewhere (5,6) it is described only briefly. The principle is shown schematically in Fig. 1. The wedge splitting device composed of the wedge, two roll bodies and two load transmission pieces is inserted in a rectangular groove of the specimen which has a starter notch on its bottom. The shaded area in Fig. 1 characterizes a compound specimen, which can be investigated with the same specimen geometry as homogenous concrete, and shows where the interface is situated. The displacement δ is measured with electronic displacement gauges, the horizontal force F_H can be calculated from the measured vertical force F_V and the wedge angle.

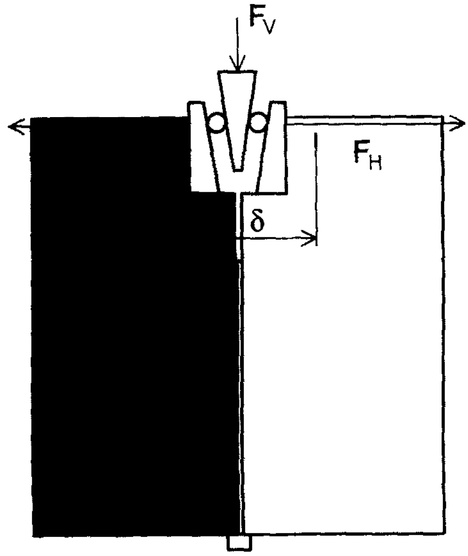

FIG. 1
Schematic drawing of the wedge splitting test method according to Tschegg (4,5,6)

The specific fracture energy G_F is obtained from a registered load-displacement curve by dividing the area under the curve by the fracture area A:

$$G_F = \frac{1}{A} \cdot \int F_H d\delta \qquad [1]$$

Young´s modulus E is proportional to the slope $\partial F_H/\partial\delta$ of the load-displacement curve in its origin:

$$E \propto \partial F_H/\partial\delta \qquad [2]$$

For G_C the proportionality

$$G_c \propto \frac{F^2_{H,max}}{E} \qquad [3]$$

ist valid; $F_{H,max}$ denotes the maximum of the horizontal force. The proportionality constants have been calculated by a finite element program for the specimen geometry of Fig. 2 and a wedge angle of 10°; the results are 252.1 m^{-1} for [2] and $6.246 \cdot 10^4$ m^{-3} for [3]. Moreover from $F_{H,max}$ a nominal notch tensile strength σ_{max} was calculated by superposition of the tensile and the bending stress caused by the horizontal force. Due to the development of a process zone sufficient large specimens are necessary to ensure that the size effect can be neglected. By preliminary tests it was shown that this is valid for the specimen geometry of Fig. 2.

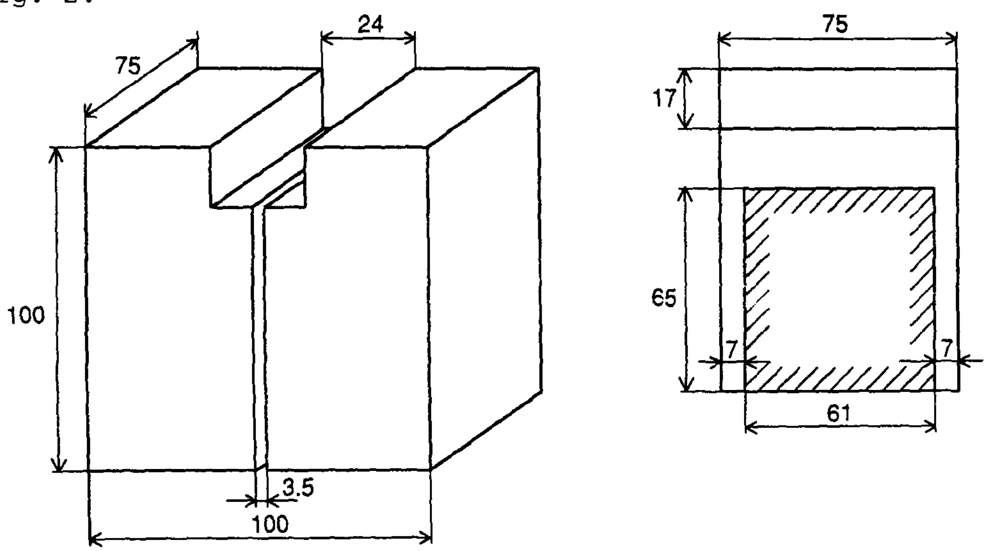

FIG. 2
Specimen geometry used for the investigations
(all dimensions in mm)

The method described here was applied for the investigation of concrete and of the adherence between old and new concrete in several cases (6,7,8); it was chosen here because of the relatively small specimens and the enhanced stability behaviour.

Results

The Table 2 shows the results for the homogenous PCC specimens. The characteristic length l_{ch} is calculated according to

$$l_{ch} = \frac{G_F \cdot E}{\sigma^2_{max}} \qquad [4]$$

It characterizes the brittleness of a material and is inversely proportional to a brittleness number (9); for the same geometry a higher value of l_{ch} indicates a more ductile material behaviour. The results of Table 2 show, that an increase of the polymer addition significantly lowers the fracture energy G_F up to a content of 3%, followed by a relatively small increase betwenn 3% and 5%.

TABLE 2
Results for the Homogenous PCC Mixtures

Property	Mixture Nr.			
	1	2	3	4
G_F [N/m]	97.6	84.4	62.4	67.2
G_C [N/m]	12.8	12.1	9.6	10.5
σ_{max} [MPa]	3.97	3.99	3.43	3.24
E [GPa]	19.0	20.4	18.7	15.3
l_{ch} [mm]	117.7	108.2	99.4	99.9

The value of σ_{max} remains nearly constant up to an addition of 1% PA, it is lowered at higher amounts, but even with 5% PA it still reaches 82% of its original value. The decreasing trends of both σ_{max} and E cause a minimum of G_C at 3% PA. The value of l_{ch} is decreasing for polymer additions up to 3% and remains nearly constant between 3% and 5%; the minimum is still 85% of the original value. That means a rather small increase of brittleness.

Table 3 shows the results for the compound specimens:

TABLE 3
Results for the Compound Specimens

Property	Mixture Nr.			
	1	2	3	4
G_F [N/m]	20.0	21.6	26.5	31.0
G_C [N/m]	2.9	3.3	3.8	5.4
σ_{max} [MPa]	1.69	1.82	2.13	2.28

The results show that G_F increases by 55%, G_C by 86% and σ_{max} by 35% of the original value at 5% PA.

Conclusions

The investigations demonstrate the importance of PA for the adherence of repair mortars; the increase of both the fracture energy and the tensile strength of the interface is advantageous. The brittleness of the PCC mixtures invstigated shows only a small increase with rising amounts of PA and all other parameters kept constant. The polymer addition results in a favourable performence of repair mortars under different conditions: If the joint has to bear an imposed load (e.g. weight) the increase of the tensile strength dominates the behaviour. Under other loading conditions (e.g. imposed strain due to thermal expansion or shrinkage) the increase of the fracture energies G_F and G_C of the joint causes a higher crack growth resistance. Even at constant w/c-ratio small amounts of PA (<1%) do not affect the strength; this means an increase of strength at constant workability and lower w/c-ratio (1,2).

For the investigations described here a maximum grain size of 4 mm was used in respect of the application of the results for repair mortars. In many other cases a by far smaller grain size is common; the fracture mechanical characterization of these materials is of interest for future research (10).

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