Pergamon

Cement and Concrete Research, Vol. 28, No. 11, pp. 1621–1628, 1998

0008-8846/98 $19.00 + .00

PII S0008-8846(98)00135-5

RESISTANCE OF CONCRETE CONTAINING STYROL ACRYLIC ACID ESTER LATEX TO ACIDS OCCURRING ON FLOORS FOR LIVESTOCK HOUSING

Nele De Belie and Joke Monteny[1]
Department for Rural Constructional and Environmental Engineering, Gent University, Coupure links 653, 9000 Gent, Belgium

(Received January 20, 1998; in final form August 4, 1998)

ABSTRACT

Lactic and acetic acid cause a quick degradation of concrete floors in pig houses in the vicinity of the feeders. A testing apparatus for accelerated degradation tests was developed to simulate in a standardized and automatized way chemical attack by aggressive liquids and abrasion caused by animals and cleaning. Polymer cement concrete, containing different amounts of styrol acrylic acid ester, was subjected to an accelerated deterioration test in a liquid containing both feed acids. The average attacked depth and the Ra-value, which is a measure of surface roughness, were measured with laser sensors, connected to a computer. It appeared that increasing the concentration of polymer by weight of cement from 0% to 2.5%, 5%, and 7.5% each time caused an additional significant decrease in average attacked depth. No significant improvement was observed by increasing the polymer content from 7.5% to 10% or 15%; therefore, a polymer concentration of 7.5% would provide an economic optimum. No significant difference could be found between two concrete types with 10% polymer addition, cured during 1 or 3 days at 90–95% relative humidity. *© 1998 Elsevier Science Ltd*

Introduction

Polymer cement concrete (PCC) contains fairly large amounts of organic polymers, typically about 5–20% by weight of cement. Polymers mostly are incorporated in the concrete mix as emulsions of polymer in water (latexes), but redispersible dry polymer powders or liquid monomers or resins may be used. When part of the water in the polymer latex has been used by the cement hydration or has evaporated, the polymer particles start to coagulate, which finally results in the formation of a three-dimensional polymer network through the hardened cement paste network (1). The nature of microstructural modification and void filling and bridging of cracks that occurs when polymer formulations are incorporated in cement systems is such that polymers substantially change the pore structure (2). The porosity is decreased in the pore radius range of 240 nm or more, whereas it increases greatly in the smaller pore radius range of 140 nm or less (2,3). Furthermore, when added to concrete,

[1]To whom correspondence should be addressed.

polymers normally exhibit water-reducing qualities, because of the dispersing agents in the polymer latexes and the spherical shape of the polymer drops. The characteristics of hardened PCC are the combined result of the lower water-to-cement ratio and the three-dimensional polymer structure (3). The quality of the transition zone between cement and paste and other materials may be improved, because of the relatively high concentration of polymer particles in this zone, due to their fineness (4). Different authors report an increase in resistance to aggressive liquids, impact and abrasion, frost, and de-icing salts (3,5–9).

From the characteristics of PCC, it could be expected that its use for concrete floors in animal houses possibly would increase the resistance to feed acids. Lactic and acetic acids are formed in acidifying meal–water mixtures in the vicinity of feeders and water supplies and are the source of quick local degradation of concrete floors (10,11). In previous experiments (12), it was shown that addition of 10% by weight of cement of different types of polymers to the concrete mix greatly increased the resistance of concrete with gravel aggregates to simulation liquids. These liquids contained lactic and acetic acid in the same concentrations as measured on floors in pig houses (30 g/L for both acids) (10). The pH of the liquids is 2, which is lower than pH values encountered in practice, due to the absence of buffering feed ingredients. This lower pH resulted in an accelerated concrete degradation. The most resistant PCC, containing a styrol acrylic acid ester, showed an average attacked depth 12 times smaller than the reference concrete after six standardized attack cycles. Other polymers, including styrene butadiene rubbers and an acrylate, improved the resistance to a lesser extent. The current experiment focuses on the optimum concentration of this polymer in concrete with limestone aggregates. Because of the significant impact of polymer addition on the concrete cost, a compromise has to be found between increasing resistance and the price.

Materials and Methods

Test Specimens

For the reference concrete (Ref) a composition used by a manufacturer of precast concrete slats was adopted. Limestone aggregates of calibre 4/14 (1,104 kg/m^3 concrete), silica sand of calibre 0/5 (840 kg/m^3 concrete), and ordinary Portland cement CEM I 42.5 R were used. [Note: The calibre gives the nominal dimensions (d and D in mm) of the granulates, where d is the the smallest dimension and D is the greatest.] The cement content amounted to 324 kg/m^3 of concrete, and the water-to-cement ratio was reduced to 0.40 by using a superplasticizer (2.4 L/m^3 concrete). The other tested concrete types (P) contained styrol acrylic acid ester in an amount of 2.5%, 5%, 7.5%, 10%, or 15% by weight of cement. The polymer was added to the mixing water as latex, containing 51% dry matter. The different mix compositions are presented in Table 1. Because of the water-reducing properties of the polymer, use of a superplasticizer was not necessary for PCC. The total water content could be reduced even more when increasing amounts of polymer was added. Slump and flow of the concrete mixes were measured in accordance with the Belgian standards NBN B15-215 and NBN B15-220, respectively.

From each concrete mix three cylinders for degradation tests (see following) and six cubes (sides 158 mm) for compressive and water absorption tests were made. The test specimens were first stored at 20° ± 2°C and 90–95% relative humidity (RH) for 1 day, to allow cement hydration to proceed properly. Then they were stored at 20° ± 2°C and 60 ± 5% RH for 27

TABLE 1
Mix compositions of reference and polymer cement concrete.

Concrete	100.P/C (kg/kg)	Superplasticizer (L/m^3 concrete)	Mixing water (L/m^3 concrete)	W/C	Slump (mm)	Flow (mm/mm)
Reference	0	2.4	129.6	0.40	2.5	1.22
P2.5	2.5	0	130.6	0.43	2.5	1.61
P5	5	0	115.2	0.40	0	1.41
P7.5	7.5	0	99.6	0.38	5	1.48
P10–P10*	10	0	84.2	0.35	5	1.55
P15	15	0	53.5	0.34	20	1.26

P10*: curing at 90–95% relative humidity for 3 days instead of 1 day; P/C: polymer (dry matter)/cement; water-to-cement ratio, including the water contained in the polymer latex.

days, which favours release of water from the polymer latex and formation of the polymer film. An extra series of test specimens (P10*)containing 10% of polymer was stored at 90–95% RH for 3 days instead of 1 day, to investigate the influence of the curing process.

Testing Apparatus for Accelerated Degradation Tests

To simulate in a standardized and automatized way chemical attack by lactic and acetic acid and abrasion caused by animals and cleaning, a testing apparatus for accelerated degradation tests was developed (12). Three concrete cylinders (diameter 230 mm, height 70 mm) of each composition were mounted on rotating axles, which are fixed on a frame (Fig. 1). During six attack cycles of 6 days, the cylinders were turning through containers with simulation liquids at a speed of 1.04 revolutions per hour, so that only their outer 50 mm was submersed during 30% of the time. The simulation liquids contained lactic and acetic acid in the same concentrations as measured on floors in pig houses (10), i.e. 30 g/L for both acids (pH = 2). The turning movement of the cylinders caused alternate wetting and drying of the concrete, which is more detrimental than continuous immersion and accelerates the attack.

After each period of 6 days (= one attack cycle) the concrete was brushed with rotary brushes. This allowed removal of the concrete layer weakened by chemical attack and simulation of the abrasion of concrete floors caused by animals and cleaning.

Concrete degradation was measured with laser sensors connected to a computer. The sensor head projects a laser beam on the concrete surface. A part of the reflected beam is caught as a “spot” in the sensor. The distance between the concrete surface and the sensor is determined by means of optical triangulation. These sensors provided a $\pm$10 V signal, which was linearly related to the distance between the concrete surface and the sensor. During the measurement, the cylinders were rotating at 24.41 revolutions per hour. The data acquisition rate was taken such that five measurements per millimeter were recorded along the concrete surface. A software trigger was programmed to start the measurement of a cylinder profile when the raised edge of a stainless steel plate, fixed on the concrete cylinders, passed by the laser beam. For each concrete cylinder five profiles equally distributed along the cylinder width were scanned after each attack cycle. The average attacked depth of each cylinder

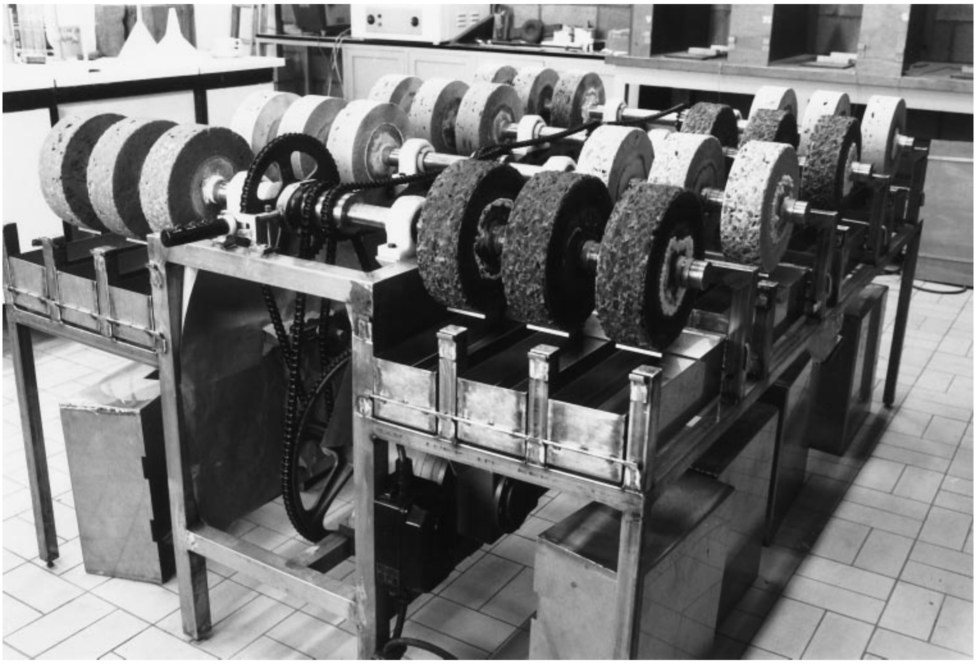

FIG. 1.
Testing apparatus for accelerated degradation tests.

profile was calculated by comparison of the profiles after each attack cycle with the initial profile at the same place. Because the surface roughness is extremely important regarding animal welfare, a Ra-value, which is a measure of the surface roughness, was calculated according to the British Standard BS 1134 with a sampling length of 50 mm.

Results and Discussion

Compressive Strength and Water Absorption

The compressive strength of three cubes of each type was measured as prescribed by the Belgian standard NBN B15-220 at 28 days and the other three were submitted to a water absorption test, which gives an indication of the porosity, as prescribed by the Belgian standard NBN B15-215. In the water absorption test the cubes are first immersed in water until a constant mass is reached. Then the cubes are dried in the oven at a temperature of 105°C until a constant mass is reached. The quantity of water absorbed by the cubes is expressed in percent of the dry weight of the cubes. The results (Table 2) clearly show that the increase in amount of polymer results in decreasing water absorption. Furthermore, the compressive strength appears to increase with the polymer content. The use of polymers in concrete can slow down concrete setting, which may have a negative effect on the compressive strength of concrete at early ages. At polymer contents of 5–10%, however, this effect

TABLE 2
Average density, compressive strength, and water absorption at 28 days.

Concrete	Density (kg/m^3)	Compressive strength (N/mm^2)	Water absorption (%)
Reference	2390	58	3.2
P2.5	2300	55	3.0
P5	2345	61	2.6
P7.5	2375	63	2.2
P10	2360	60	2.5
P10*	2385	66	1.8
P15	2380	67	1.2

can be exceeded by the positive effect of the polymer film itself on the concrete strength and by the lower water-to-cement ratio (13).

Average Attacked Depth

The accumulated average attacked depth of the different concrete types versus the number of attack cycles is shown in Figure 2. In Table 3, the concrete types for the successive attack cycles are classified in order of increasing average attack depth. Concrete types of which the average attack depths are not significantly different (determined by a Student-Newman-Keuls test with level of significance 0.05) are connected by a line.

It appeared after one attack cycle that already polymer addition reduced concrete attack by lactic and acetic acid. The results after two attack cycles confirmed that the reference concrete was most vulnerable to the attack and that increasing quantities of polymer in the concrete mix led to a significant reduction of concrete degradation. The differences between concrete compositions,

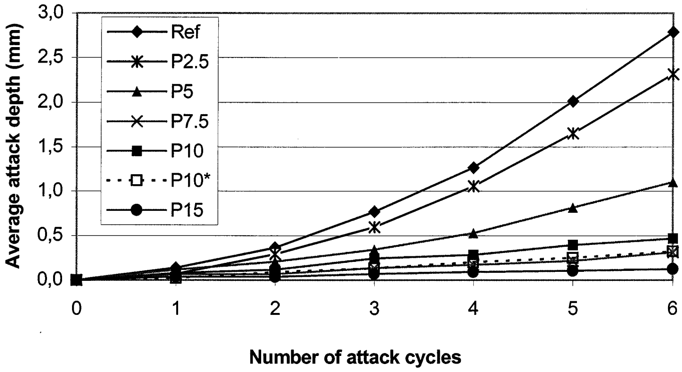

FIG. 2.
Average attacked depth of the different concrete types versus number of attack cycles in simulation liquid with lactic and acetic acid.

TABLE 3
Significant differences in average attacked depth between concrete types for the successive attack cycles C1 to C6.

C1	P10*	P15	P7.5	P2.5	P10	P5	Ref
C2	P15	P7.5	P10*	P10	P5	P2.5	Ref
C3	P15	P10*	P7.5	P10	P5	P2.5	Ref
C4	P15	P7.5	P10*	P10	P5	P2.5	Ref
C5	P15	P7.5	P10*	P10	P5	P2.5	Ref
C6	P15	P7.5	P10*	P10	P5	P2.5	Ref

Concrete types are classified in order of increasing attacked depth and connected by a line if not significantly different (level of significance 0.05).

which already could be noticed after two attack cycles, became larger during the subsequent cycles. An increase of the polymer contents from 0% to 2.5%, from 2.5% to 5%, or from 5% to 7.5% resulted every time in a significant decrease in average attack depth. No significant improvement could be reached by increasing the polymer content from 7.5% to 10% or 15%; therefore, a polymer concentration of 7.5% would provide an economic optimum.

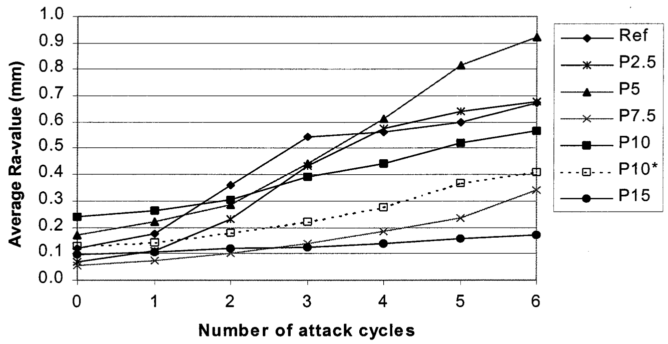

FIG. 3.
Ra-value of the different concrete types versus number of attack cycles in simulation liquid with lactic and acetic acid.

Average Surface Roughness

The average Ra-value of the different concrete types versus the number of attack cycles is shown in Figure 3. There appeared to exist a difference in initial Ra-value between the concrete types. For example, the surface of the P10 cylinders was significantly rougher than most other concrete cylinders. Most of the other differences, however, could be classified as insignificant. The subsequent increase in Ra-value was largely the same for P7.5, P10, and P10* (0.28, 0.33, and 0.28 mm, respectively). It was significantly larger for the reference concrete, P2.5, and P5, and significantly smaller (only 0.07 mm) for P15.

Conclusions

With the testing apparatus designed for accelerated degradation tests, the resistance of different concrete types to feed acids can be simulated and compared objectively.

The use of styrol acrylic acid ester polymer in the concrete mix resulted in a significant improvement of the resistance to simulation liquids, containing lactic and acetic acid in the same concentrations as measured on floors in pig houses. Increasing the polymer contents from 0% to 2.5%, 5%, and 7.5% by weight of cement each time caused an additional significant decrease in average attack depth. No significant improvement could be reached by increasing the polymer content from 7.5% to 10% or 15%. Also, the increase in Ra-value, which is a measure of surface roughness, was largely the same for the concrete types with 7.5% or 10% polymer addition; therefore, a polymer concentration of 7.5% would provide an economic optimum.

No significant difference could be found between two concrete types with 10% polymer addition, cured during 1 or 3 days at 90–95% RH.

Acknowledgments

The first author is a Postdoctoral Fellow of the Fund for Scientific Research–Flanders (FWO) and would like to thank the FWO for the financial support.

References

1. D.G. Walters, Concr. Int., 9, 44 (1987).
2. Y. Ohama, ACI Mater. J. 6, 511 (1987).
3. R.N. Swamy, Durability of Concrete Composites with Polymers, Proceedings of the VIIIth International Congress on Polymers in Concrete, Oostende, 21 (1995).
4. J.M. Bijen, Cement 43, 60 (1991).
5. D.G. Walters, The Effect of Polymer Variables and Other Parameters on the Properties of Polymer-modified Cement Mixtures, Polymer-modified Hydraulic-cement Mixtures, ASTM STP 1176 (1993).
6. H.F. Zoumut, Flexible Cementitious Products, Polymer-modified Hydraulic-cement Mixtures, ASTM STP 1176 (1993).
7. V. Pollet, W. Van Laecke and J. Vyncke, The Use of Polymers for Industrial Floors: A State of the Art Report, Proceedings of the VIIIth International Congress on Polymers in Concrete. Oostende, 387 (1995).
8. Y. Ohama, K. Demura and W.K. Kim, Freeze-thaw Durability of Polymer-modified Mortars Using Redispersible Polymer Powders, Proceedings of the VIIIth International Congress on Polymers in Concrete, Oostende, 251 (1995).

9. S. Chandra and Y. Ohama, Polymers in Concrete, CRC Press, Boca Raton, FL, 1994.
10. N. De Belie, B. De Blaere and R. Verschoore, Landwards, 51, 22 (1996).
11. N. De Belie, H.J. Verselder, B. De Blaere, D. Van Nieuwenburg and R. Verschoore, Cem. Concr. Res. 26, 1717 (1996).
12. N. De Belie, R. Verschoore and D. Van Nieuwenburg, Transactions of the ASAE. In press.
13. R.N. Swamy and H. Nagao, Some Durability Properties of Polymer-modified Mortars, Proceedings of the VIIIth International Congress on Polymers in Concrete, Oostende, 257 (1995).