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Polymer-Modified Portland Cement Concrete at Temperatures up to 150°C

Béton modifié par polymères à des températures jusqu'à 150°C

Polymermodifizierter portlandzementgebundener Beton bei Temperaturen bis 150°C

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SUMMARY
The flexural load-deflection curves of a styrene-acrylic copolymer modified concrete types, obtained three-point bending test carried out at temperatures between 20 and 150°C, are presented in the paper. The compressive stress-strain relationships for these modified concrete types are also given, but only at 20°C.

RÉSUMÉ
Le rapport examine la corrélation entre la charge et les déformations par flexion du béton modifié par le copolymère styrène-acrylique, dans un essai de flexion effectué à des températures entre 20°C et 150°C. Il est aussi possible de constater une relation entre l'effort de compression et les déformations du même béton, observé à 20°C.

ZUSAMMENFASSUNG
Die Biegelast-Biegungs-Linien für styrol-acrylatmodifizierte Betone, die an Balken mit einer Einzellast in der Mitte bestimmt wurden, sind bei Prüftemperaturen zwischen 20 und 150°C gegeben. Ebenso sind für dieselben Betone die Druckspannungsdehnungs-Linien dargestellt, in diesem Fall aber nur bei 20°C.

1. INTRODUCTION

New demands to improve the mechanical properties and durability of concrete in the case of chemical and/or physical influences are more and more frequent. One way to comply with these demands is represented by modifying structural concrete by the help of artificial materials. It is assumed that thermoplastic polymers used for modifications of portland cement concrete form a spatial network within inorganic binder [Konietzko A., 1988]. The polymer network plays an important role when loads are transmitted in the concrete in a complex manner. The thermal conditions, which prevail, affect significantly the loadbearing behavior of polymer-modified concrete types. At temperatures below the polymeric glass transition region, the addition of polymer results in a noticeable increase in tensile strength and strain capacity of concrete. On the other hand, at temperatures above the polymeric glass transition region the softened plastic leads to a considerable increase in ductility, and at the same time causes a reduction in strength.

The glass transition temperature (Tg) of styrene-acrylate copolymer which was used for modification equals about 19°C. The aim of our investigations was to establish a relationship between strength and deformation characteristics of modified concrete at temperatures above the polymeric Tg.

2. EXPERIMENTAL PROGRAMME

2.1 Details of mixes

Details of mixes made for the experimental study are given in Table 1. The constant quantity of portland cement in the amount of 400 kg per unit volume of concrete mix was used. For polymer-cement ratio (weight of polymer solids with respect to weight of cement, denotation P/C) ranging between 0.0 and 0.2, the water-cement ratio between 0.55 and 0.32 was adjusted in order to attain a fairly constant workability throughout. At polymer-cement ratio 0.1, 0.15 and 0.2 also the antifoaming agent in the amount of 0.5, 0.5 and 1.0 wt%, respectively, was added in order to attain the same porosity of all concrete mixes.

Mix	W/C	P/C	Vebe time (sec)	Vol. of Air (%)
FG01	0.55	0.00	2.0	2.5
FG03	0.37	0.10	4.0	2.6
FG04	0.34	0.15	3.5	2.6
FG05	0.32	0.20	3.5	2.8

Table 1 Details of mixes

Time (days)	Flexural strength (MPa)	Compressive strength (MPa)
3	5.5	31.8
7	6.8	38.1
28	7.7	47.8

Table 2 Strengths of standard cement mortar

2.2 Materials

Used were portland cement type PC 45B corresponding to the former Yugoslav Codes (JUS), river sand, and 8 mm maximum size gravel coarse aggregate. Flexural and compressive strengths determined on 4x4x16 cm standard cement mortar prisms according to JUS B.C8.022 are given in Table 2. As a modifier the water anion copolymer dispersion from ester acrylic acid and styrol without added plasticizer was used. It has a mean particle size of about 0.1μm, pH value between 7.0 in 8.0 and minimum temperature of film formation at about 30°C. The polymeric film formed from dispersion has a glass transition temperature at about 19°C, tensile strength between 7 and 10 MPa and strain at tensile strength between 500 and 800%.

2.3 Casting, curing and testing

From each mix, 100x100x360 mm prisms and 80x80x360 mm prisms were cast in steel moulds. The specimens were demoulded after 24 hours and were for the first 7 days cured in water at 20°C. Forthcoming curing took place under controlled ambient conditions at a temperature of 20°C and a humidity of 50%. Flexurally tested specimens at elevated temperatures were put into furnace with constant temperature which was equal to the forthcoming testing temperature 24 hours prior to testing. All the tests were carried out with specimens of 28 days age. For the tests a servo-hydraulic testing machine Instron type 1345 was used. The compressive stress-strain relationship was obtained by testing the 100x100x360 mm specimens under axial compression at laboratory conditions (about 20°C). The specimens were loaded by conducting the crosshead displacement of the testing machine with a velocity of 0.36 mm per minute. The measurements of the longitudinal strains were carried out using strain gauges. For each mix of concrete between 7 and 9 samples were tested. The flexural load-deflection curves were obtained at three point bending tests on 80x80x360 mm prisms. Since the aim was to get also the descending part of the flexural load-deflection curve, the testing samples were loaded by conducting the deflection of the sample with a velocity of 0.1 mm per minute, by the help of the extensometer. The flexural tests at a temperature of 20°C were carried out on all mixes, whereas at elevated temperatures (50, 75, 100 and 150°C) they were performed only on polymer-modified concrete mixes. In addition to above mentioned testing machine also the temperature chamber with a self-adaptive temperature controller and high temperature (water-cooled) extensometer of the same manufacturer as of the testing machine were used for testing at elevated temperatures. For each mix and each temperature 6 samples were tested.

3. RESULTS AND DISCUSSION

For each of both kinds of tests, for each concrete mix and temperature, the resulting curve was defined from the experimentally obtained curves by the help of the neural network-like system with the estimation of conditional average [Grabec I., 1990]. This should make possible to avoid any a-priori assumptions regarding the relationship between the empirical data, and to permit the formation of any possible nonlinear relationship that, in the statistical sense, is best adapted to the empirical data.

3.1 Compressive stress-strain relationship

Figure 1 presents the compressive stress-strain curves for concrete modified with varying amounts of polymer. Due to the plastification effect of the added polymer and the demands for the same workability the maximum compressive stress of the modified concrete at the polymer-cement ratio 0.1 is increased for about 8 MPa, i.e. 23%. With further increase of the polymer-cement ratio, the maximum compressive stress of the modified concrete decreases. At the polymer-cement ratio 0.15 it is not even 6% higher than at the nonmodified concrete. Despite the insignificant difference in maximum stresses, the strain at maximum stress is about 20% larger than at the control mix. At the polymer cement ratio 0.2 the maximum stress is even about 12% lower than at the nonmodified concrete, but the strain at maximum stress is more than 65% larger. As compared to the other three mixes the ability to absorb energy in plastic range is at the polymer-cement ratio 0.2 also significantly increased.

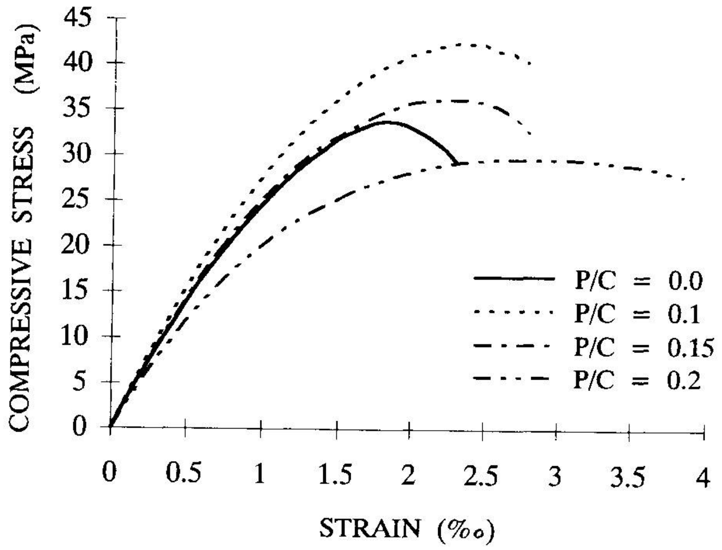

Fig. 1 Compressive stress-strains curves

3.2 Flexural load-deflection relationship at normal and elevated temperatures

For a particular polymer-cement ratio the flexural load-deflection curves, obtained at normal end elevated temperatures, are given in Figures 2 - 5. On each of those figures, comparison is given by the curve that show behavior of nonmodified concrete obtained at 20°C.

The maximum flexural load of modified concrete with the polymer-cement ratio 0.1 obtained at 20°C is about 120% higher than at control mix (Figure 2). The descending part of the flexural load-deflection curve was obtained only after instantaneous decrease of maximum load to 20% of its value. The maximum flexural load at 50°C equals 7 kN, which is about 30% lower than at 20°C, but also about 50% higher than at control mix. At temperatures 75, 100 and 150°C, there is almost no difference in diagrams, which represents flexural load-deflection relationship, i.e., until maximum flexural load equals about 5.6 kN. The difference is in descending part of the diagrams, where toughness of concrete at 150°C is about 35 and 80% higher then at 75 and 100°C, respectively.

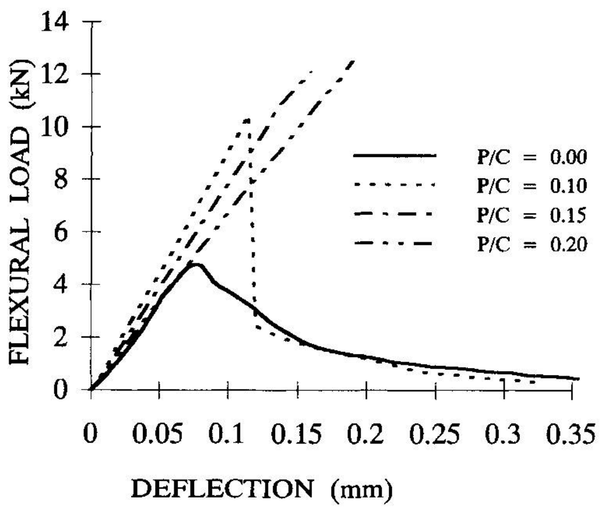

Fig. 2 Testing temperature 20°C

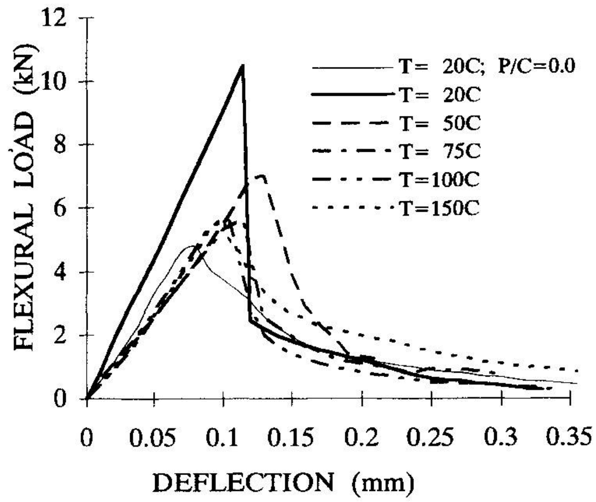

Fig. 3 Polymer-cement ratio 0.1

At the polymer-cement ratio 0.15 and normal temperature the maximum flexural load is 12 kN, which is about 150% higher than at control mix. Modulus of elasticity is lower than at the polymer-cement ratio 0.1, and the deflection at maximum load is thus increased. However, the maximum load is also the load of rupture. The reduction in strength at 50°C is about 60%

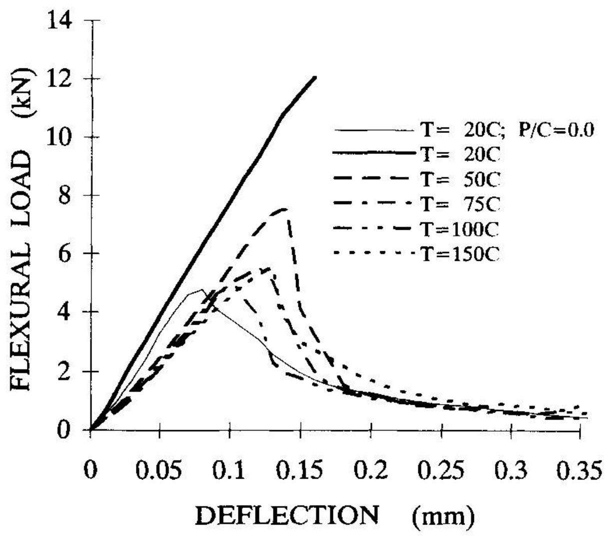

Fig. 4 Polymer-cement ratio 0.15

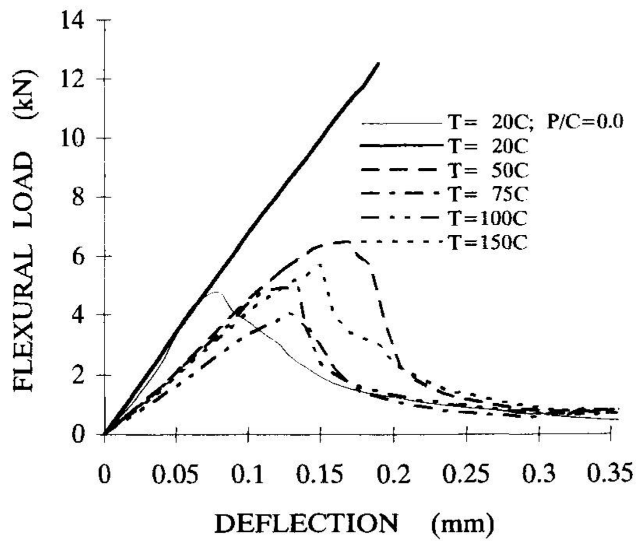

Fig. 5 Polymer-cement ratio 0.2

considering the strength at 20°C. Nevertheless, it is still about 60% higher than at nonmodified control mix. The ductility of modified concrete is also considerably increased. The maximum load of modified mix is at 75, 100 and 150°C almost the same or slightly higher than at control mix. The ability to absorb energy until the rupture is for the modified concrete at the above mentioned temperatures and for the nonmodified concrete highest at 150°C.

In the case of polymer-cement ratio 0.2 and a temperature of 20°C the maximum flexural load and its ability to absorb energy until the rupture are the highest of all. However, the rupture of material is brittle. At temperatures above the polymeric glass transition region the reduction in strength and at the same time the increase in ductility are enormous. The maximum flexural load at 50°C is only about 35% higher, at 75°C the same and at 100°C even about 20% smaller than at the control mix. At 150°C the maximum load is 20% and the ability to absorb energy about 30% higher than at the nonmodified concrete.

4. CONCLUSIONS

The results of tests carried out at temperatures above the polymeric glass transition region show considerable drop in flexural strengths of polymer modified concrete types, as compared to the strengths of modified concrete mixes at 20°C. On the other hand, adding between 10 and 20% of polymer by weight of cement, flexural strengths at 50°C are increased between 40 and 60%, as compared to the control mix which was tested only at 20°C. At the same time, the softened plastic leads to an important increase in concrete ductility. Maximal toughness pertains to the modified concrete with polymer-cement ratio 0.2 tested at 50°C. Only at 100°C and the polymer-cement ratio 0.2 the flexural strength is lower than at control mix, whereas at the polymer-cement ratio 0.15 and testing temperature 100°C is approximately equal to the flexural strength of control mix. Flexural strengths of other polymer-modified mixes tested at temperatures up to 150°C are up to 20% higher, and toughnesses pertaining to the above mentioned mixes are up to 30% higher, when compared to the control mix.

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