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Polymer Impregnated-Steel Fiber Reinforced Concrete

Béton renforcé de fibres d'acier imprégnées et polymérisées

Imprägnierter und polymerisierter stahlfaserbewehrter Beton

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SUMMARY

The investigation reported in this paper had the goal of developing the new composite material "polymer impregnated-steel fiber reinforced concrete". The mechanical properties, ductility and relative impermeability of this material suggest the possibility for its use in bridge deck and pavements.

RÉSUMÉ

Les recherches présentées dans cette étude ont pour but d'étudier un nouveau matériau de construction « Béton renforcé de fibres d'acier imprégnées et polymérisées ». Les propriétés mécaniques, la ductilité, ainsi que la relative imperméabilité de ce matériau le rend apte à la construction des tabliers de ponts et pour les surfaces de roulement.

ZUSAMMENFASSUNG

Der Zweck dieser Arbeit ist die Untersuchung eines neuen imprägnierten und polymerisierten stahlbewehrten Betons. Die mechanischen Eigenschaften, die Duktilität und relative Wasserdichte dieses Materials, unterstreichen die Möglichkeit der Verwendung für die Fahrbahn von Brücken und als Strassenbelag im Allgemeinen.

1. INTRODUCTION

Fiber reinforced concrete is essentially a composite system in which, unlike conventional reinforced concrete, the material as a whole carries the tensile and compressive stresses due to load. In the composite material discussed in this paper, short discrete steel fibers are randomly distributed throughout the concrete mass.

Polymer impregnated concrete (PIC) is a precast and cured hydrated cement concrete which has been impregnated with a low viscosity monomer and polymerized in-situ. The significant improvement in structural and durability properties have been obtained with PIC comparated to ordinary concrete.

The investigation reported in this paper had the goal of developing the new composite material "polymer impregnated - steel fiber reinforced concrete". The mechanical properties, ductility and relative impermeability of this material suggest the possibility of using for bridge deck and pavement.

2. LABORATORY INVESTIGATIONS

2.1. Steel fiber reinforced concrete (SFRC)

This investigation was made to determine the influence of the randomly oriented fiber on the mechanical properties and ductility of SFRC. Both plain and fiber reinforced concrete were tested. The concrete mixture consisted of : Portland cement (P40; Pa35); regular tap water; sand (0...10 mm); Romanian additive DISAN (0,3% of cement). The fiber used for the investigations were of 0.28 mm diameter, 30 mm length (aspect ratio is 107) and manufactured from low-carbon steel wire by a chopping process. The concrete specimens were reinforced with 1-1.5 % by volume. All mixings were done in a rotary mixer : sand and cement were first dry mixed (30 sec.), then the fiber were added slowly to insure random distribution; the water was then addet and all components were mixed (30 sec.).

Main characteristics of SFRC are presented in Table 1. For a wide spectrum of mechanical properties, the improvement imported by fibers is mainly dependent on fiber concentration μ (μ represent the volume reinforcement coefficient) and aspect ratio L/D (L and D are the length and the diameter of the fiber).

On the basis of the large amount of data for flexural strength analysed in [1], it was found :

$$r_1 = 1 + 0.57\mu\frac{L}{D} - 0.018\left(\mu\frac{L}{D}\right)^3 \quad (1)$$

where r_1 is the ratio of the flexural strength of SFRC members to that of plain concrete members.

2.2. Polymer impregnated concrete (PIC)

The main steps of process techniques for producing PIC has been : fabrication of precast concrete specimens in similar way with conventional concrete; oven-drying for 24 h at 105°; saturation with monomer by immersion in methyl-methacrylate (MMA) at normal pressure and temperature; in-situ polymerization by thermal-catalytic techniques at 75°C for 2 h.

Characteristics		Plain concrete	Steel fibre reinforced concrete	
			Value of characteristics	μ (%)
Flexural strength	MPa	1.98	3.38	2
Impact resistance	MPa	6.9	17.25	1
			19.12	1.5
			16.90	2
Freeze-thaw (200 cycles)	Loss of flexural strength %	18.3	4	1.5
Flexure toughness	Area under load-deflexion curve	1	14.8-23.5	2

Table 1 Main characteristics of steel fibre reinforced concretes

Main mechanical and physical properties are given Table 2 for unimpregnated and MMA-impregnated concrete polymerized by thermal -catalytic means.

Characteristics			Unimpregnated Concrete	Polymer Impregnated Concrete
Compressive strength	(R_c)	MPa	25.00	68.00
Tensile strength	(R_t)	MPa	2.60	11.50
Flexural strength	(R_{ti})	MPa	4.42	19.55
Modulus of elasticity	$(E)^1$	MPa	$3.5 \cdot 10^4$	$4.28 \cdot 10^4$
Abrasion loss	(U)	(mm)	1.00	0.48
Water absorption	(W_m)	(%)	3.0	0.40
Density	(ρ_b)	kg/m^3	2400	2416

Table 2 Main characteristics of polymer impregnated concrete

The efficiency of impregnation on compressive strength of PIC is defined as the difference between compressive strength of PIC and unimpregnated concrete $-\Delta R_c$ [3]. It was found [2] [3] that the efficiency of impregnation ΔR_c is an exponential relation with the polymer loading p_g (in %), as (Fig. 1) :

$$\Delta R_c = \alpha \, p_g^{3/2} \qquad (2)$$

where α is a numerical parameter (α_{min} = 4; α_{midd} = 6; α_{max} = 8). The dependence between the efficiency of impregnation ΔR_c and the polymer loading p_v (in % by volume) is an exponential relation too :

$$\Delta R_c = 2.5 \, p_v^{3/2} \qquad (3)$$

2.3. Polymer impregnated - steel fiber reinforced concrete

The data in Table 3 give some characteristics of the new composite

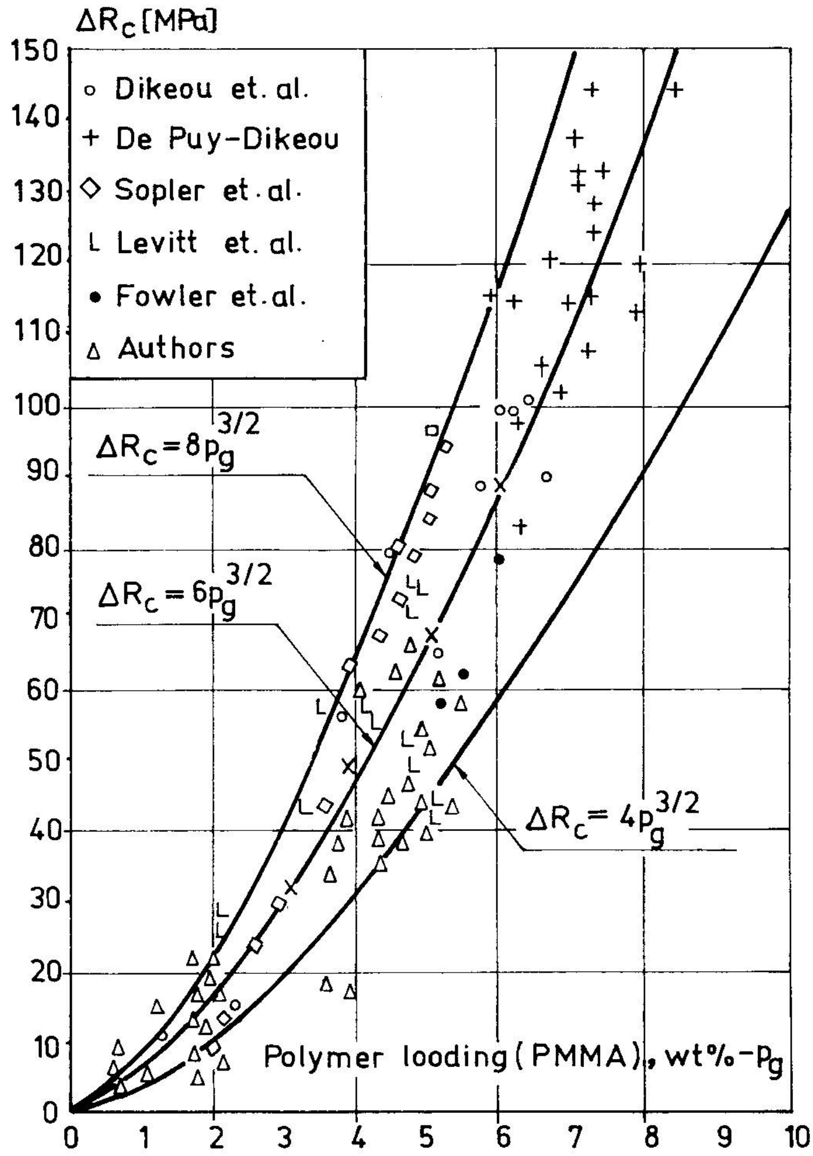

Fig.1 The dependence between the efficiency of impregnation and the polymer loading

material : monomer MMA and steel fiber loadings as well as flexural strength. It was found the efficiency of polymer impregnation on flexural strength and the influence of the reinforcement with steel fiber on the nature of failure : it become more ductile.

	Plain concrete composition		
Specimen size, mm	Cement, Pa35, kg/m^3	Water/cement	Sand 0-3 mm, kg/m^3
40 x 40 x 160	445	0.47	1570

Characteristics of :		Flexural strength , MPa	
Monomer MMA P_g, %	Steel fiber (L=20 mm;D=0.29 mm) μ, %	Plain concrete	Polymer impregnated steel fiber concrete
4-5	1.25	4.02	15.36

Table 3 Polymer impregnated - steel fiber reinforced concrete characteristics

3. APPLICATIONS

The applications of SFRC have been in the areas of pavements, over lays, refractories, patching, mine tunnel lining etc.; in Romanian it was used as an experimental section of a road from prefabricated slabs and for repairing of a rigid overlays. Numerous applications of PIC are under development which indicates a large potential for this material : bridge deck, vessels used in varied applications, tunnel linings, sewer pressure pipes, panels etc. The authors tested a PIC anchorage for prestressed concrete elements.

Polymer impregnated - steel fiber reinforced concrete was used by the authors for two bridge decks. In order to provide an efficient solution, a steel fiber reinforced concrete layer of 5 cm in depth was performed. The compositions of steel fiber reinforced concrete used is given in Table 4.

Experimental section	Cement, Pa35, kg/m^3	Water / Cement	Sand kg/m^3		Steel fiber				Additive DISAN (20 %)
			0-3 mm	3-7 mm	L mm	D mm	μ %	Batch kg/m^3	
DN 59 B km 35+050	520	0.55	900	653	30	0.28	1.5	120	1.5 l for 100 kg cement
DN 59 B km 43+320	520	0.55	900	653	22	0.24	1.5	120	1.5 l for 100 kg cement

Table 4 Compositions of steel fiber reinforced concrete

The application of the monomer system for field applications to bridge decks consisted of :

(1) cleaning the concrete surface by simply swept and scrubbed

with hard brushes;
(2) drying the surface with ceramic bulbs at 105°C for 1-4 hours or by solar heating for 5-7 days;
(3) applying of the monomer with a watering can in many layers;
(4) covering the surface with polyethylene to retard evaporation;
(5) applying heat by ceramic bulbs for 2 hours (70-75°C) to polymerize the monomer.
The total monomer required was of p_g = 4 % for 2.5 cm depth.

4. CONCLUSIONS

4.1. Application of SFRC for rigid overlays and bridge decks leads to the following : significant increases in mechanical properties and ductility; the mixing of the concrete is carried out with similar equipment as for plain concrete; the depth of the fiber reinforced concrete layer shold be no less than 5 cm and the minimum volume percent of reinforcement should be 1.5.

4.2. Polymer - impregnated concrete surface treatment indicated very good freeze - thaw durability and resistance to water penetration before and after freeze - thaw as well as increases in flexural and compressive strengths, modulus of elasticity and resistance to acid attack.

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