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RESEARCH ARTICLE

Bond of reinforcement in polymer concrete

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Abstract

Polymer concrete, a composite material in which the binding material is some type of polymer, is being used more widely in the construction industry. Polymer concretes can also contain steel reinforcing rebars; therefore, the rate of adhesion between polymer concrete and reinforcing steel must be determined.

Our study investigated the extent and behaviour of adhesion in the case of reinforcing steel with both smooth and ribbed surfaces. The results show that the bond strength of polymer concretes is much higher than those of traditional types of concrete. Therefore, structures will require a much smaller bond length than in the case of traditional concrete types.

The calculated bond strength for smooth reinforcing steels is more than ten times the characteristic strength values of traditional concrete types. In the case of ribbed reinforcing steels, the bond strength is extremely high, and the required bond length does not exceed 40 mm.

Keywords

polymer concrete · bond stress · bond length · steel reinforcement

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1 Introduction

Polymer concrete is defined as a composite material in which the binding material is some type of polymer. Material properties can vary considerably as a function of material composition; therefore, each type of polymer concrete can be characterised by its unique properties. The basic properties of polymer concrete of a given composition have been previously reported [6], [7], [8].

In general, it can be stated that all polymer concretes have excellent strength properties and solidify extremely rapidly and the material structure is compact, with good wear resistance and considerable chemical resistance properties [1], [4]. These features enable polymer concrete to be used for load bearing structures. Steel reinforcing bars may also be required in conjunction with polymer concretes. The bond strength between the reinforcement and the concrete is important, for example when designing a joint between pillar and beam, or between beam and beam.

Earlier researches on the bond between traditional concrete and steel reinforcements has shown that the most important factors influencing bond behaviour include the rib pattern of the steel rebars, the position of the rebars during casting, concrete cover, confining effects, dowel action, longitudinal splitting cracks along the bar, concrete strength and the type of load [2]. It should be stressed in this respect that bond strength and the correlation between bond strength and displacement are highly influenced by concrete quality. The bond strength of high-strength concrete (HSC), can be three times of the values which are characterising normal strength concrete (NSC) [3].

Earlier research [9] studied the bond between polyester polymer concrete and several potential reinforcements (steel bars and glass-fibre-reinforced plastic bars). The authors [9] established that the bond strength is the highest for traditional steel bars.

The aim of our study is to specify the bond strengths and the correlation between bond stress and displacement for both smooth and ribbed reinforcing steel bars.

2 Material and mechanical properties of polymer concrete

As opposed to ordinary concretes, aggregate particles in polymer concrete are bound by a polymer instead of cement. Furthermore, the composite does not contain cement or water. Tab. 1 shows the material composition of polymer concrete having an unsaturated polyester as binder ("UP polymer concrete"), as what was applied in our tests.

3 Experimental program and test specimens

In the current study a total of 10 specimens were tested. The specimens used in the study were cylinders 100 mm height and 120 mm diameters, made of UP polymer concrete according to the composition specified in Tab. 1. Cylinders were cast in a vertical position. Reinforcing bars were situated along the axis in the polymer concrete cylinders. The nominal diameter of the reinforcing bars was 12 mm. Bonding was prevented for a 60 mm length at the ends of the specimens (Fig. 1). Test variables included the rib pattern of the steel rebars (smooth or herringbone ribbed). Tests were carried out in the Material Testing Laboratory of the Department of Construction Materials and Engineering Geology at the Budapest University of Technology and Economics (BME).

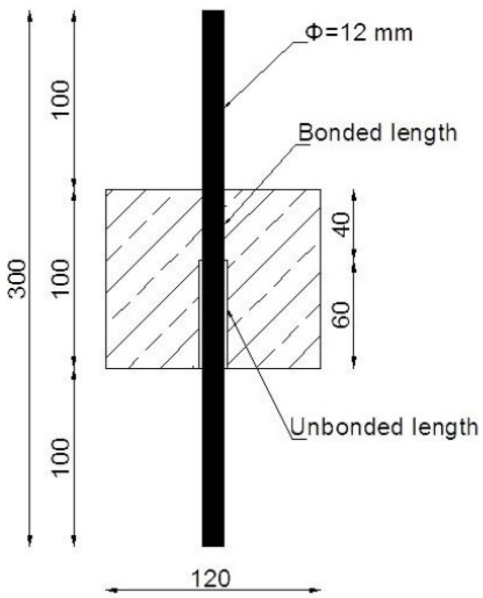

Fig. 1. Sheme of specimens

4 Pull-out test

Pull-out tests were performed based on [5]. The tests were carried out with using an Instron 5989 universal testing machine (Instron, Grove City, PA, USA) having a loading capacity of 600 kN. The applied loads were controlled by a computer, by displacement control at a rate of 2 mm/min. During testing, the relative displacement between the polymer concrete specimen and the reinforcing steel inside it was continuously recorded with a Spider8 measuring bridge (Hottinger Baldwin Messtechnik, Germany). The setup of the pull-out testing system is shown in Fig. 2.

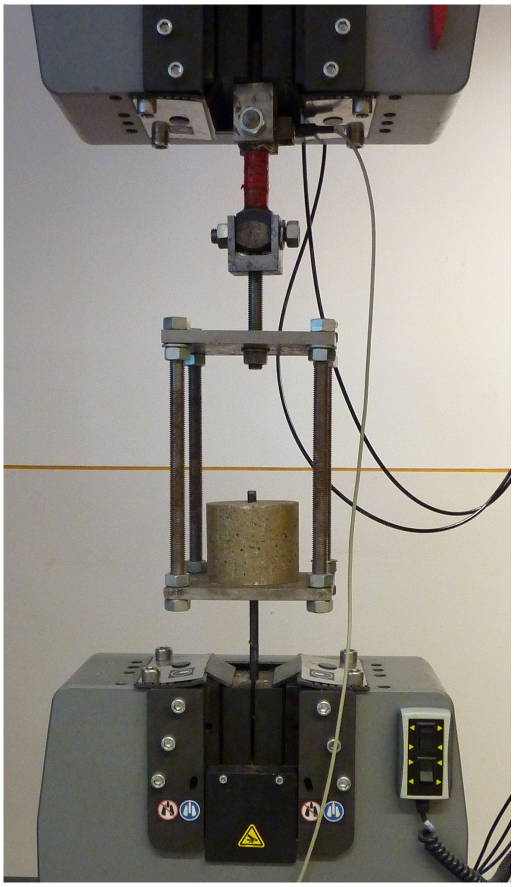

Fig. 2. Setup of the pull-out testing system

The maximum pull-out forces were recorded for the calculation of the average ultimate bond strength (τ_{bu}) according to Eq. (1):

$$\tau_{bu} = \frac{F_{max}}{\pi} \Phi_n l_b \tag{1}$$

where F_{max} is the ultimate pull-out force, and Φ_n and l_b are the nominal diameter and the bond length of the rebars, respectively.

The required bond length value ($l_{b,rqd}$) can be calculated from the ultimate bond strength based on Eq. (2):

$$l_{b,rqd} = \frac{\Phi_n}{4} \frac{f_{ym}}{\tau_{bu}} \tag{2}$$

where Φ_n is the nominal diameter of the rebars, f_{ym} is the mean value of the yield stress of the rebars, and τ_{bu} is the mean ultimate bond strength value.

5 Experimental results

5.1 Smooth reinforcing steel bars

When testing plain (smooth) reinforcing steel bars, failure was always caused by the slipping out the reinforcing bars (Fig. 3). The next figure (Fig. 4) shows the force vs. displacement diagrams recorded during the tests.

Fig. 4 shows that the initial linear sections of the force vs. displacement diagrams have the same slop, so the diagrams overlap. The final values of the initial bond strength

Tab. 1. Material composition

Binder	POLIMAL 144-01 unsaturated polyester	16 m %
Aggregate	2-4 mm particle-size dried bulk graded quartz gravel	38 m %
	0-2 mm particle-size quartz sand	38 m %
Other components	Trigonox 44 B catalyst	3 m %
	CO-1 Cobalt initiator	
	Calcium-Carbonate	5 m %

(Eq. (1)) and the basic bond length value (Eq. (2)) was calculated, which are given in Tab. 2. The main value of yild stress of the smooth reinforcing steel bars was $f_{ym} = 450.05$ N/mm^2 (SD = 14.57 N/mm^2).

Fig. 3. Specimen destroyed by the pull-out of the reinforcing rebar

The average initial slope is tg$\alpha = 5900$ kN/mm (SD = 0.039 kN/mm), which is nearly vertical ($\alpha = 89.97°$). After the transitional zone following the linear section, the diagrams become nearly horizontal. This means that after the chemical bond ceases to exist, the polymer concrete and the reinforcing rebar will work together by friction only, which gradually decreases and then diminishes upon pull-out.

5.2 Ribbed reinforcing steel bars

In the case of the ribbed reinforcing steel bars, destruction was caused by the steel bars being torn (Fig. 5).

The force vs. displacement diagrams (Fig. 6) show the maximum force associated with the section without displacement; the strength values to be calculated therefrom on the basis of Eq. (1) are shown in Tab. 3. The average initial slope of the diagram is tg$\alpha = 2507$ kN/mm, where $\alpha = 89.97°$, that's means practically no displacement before sliping of bar. Chemical adhesion discontinues at the moment of sliding. The following transitional period is characteristic of mechanical adhesion. Reinforcing steel rebars are torn by the increasing stress, which means that the required bond length can be specified below 40 mm in the case of ribbed 12 mm steel reinforcing bars. The main value of yild stress of the ribbed reinforcing steel bars was $f_{ym} = 638.79$ N/mm^2 (SD = 12.00 N/mm^2).

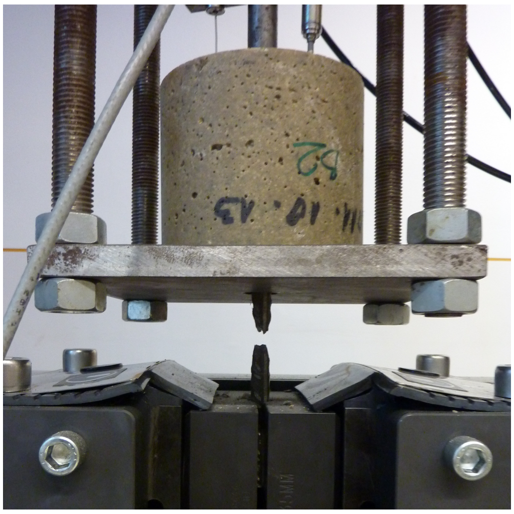

Fig. 5. Failure of specimen by the reinforcing steel bar being torn

6 Conclusions

Our study investigated the extent of adhesion in the case of reinforcing steel bars with both smooth and ribbed surfaces, embedded in UP polymer concrete.

In the case of bars with a 12 mm nominal diameter and a smooth surface, the average bond strength was 11.73 N/mm^2 , based on a standard experiment. This is more than ten times the value characterising the bond strength of traditional concrete types. The recommended value of the required bond length is 180 mm, in the case of bars with a 12 mm diameter and a smooth surface.

Ribbed steel bars were examined under circumstances identical to those used for plain ones. The material composition of polymer concrete, the quality and the nominal diameter of the reinforcing steel bars, the length of surfaces with and without adhesion, and the dimensions and age of specimens were all

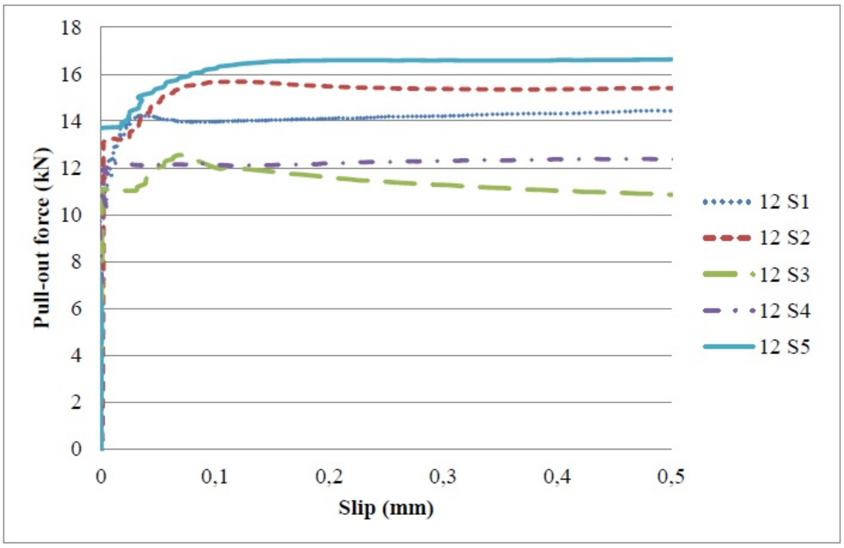

Fig. 4. Force vs. displacement diagrams in the case of steel reinforcing bars with 12 mm diameter and smooth surface

Tab. 2. Results for plain reinforcing steel bars

	Nominal rebar diameter (mm)	Bonded length (mm)	Pull-out force (kN)	Average of pull-out force (kN)	Bond strength (N/mm^2)	Average of bond strength (N/m^2)	SD (N/m^2)	Bond length (mm)	Average of bond length (mm)	SD (mm)
S1	12	40	10.582	11.733	7.02	7.78	1.05	273.10	249.83	32.62
S2	12	40	13.105	11.733	8.69	7.78	1.05	220.52	249.83	32.62
S3	12	40	11.097	11.733	7.36	7.78	1.05	260.43	249.83	32.62
S4	12	40	10.157	11.733	6.74	7.78	1.05	284.52	249.83	32.62
S5	12	40	13.723	11.733	9.10	7.78	1.05	210.59	249.83	32.62

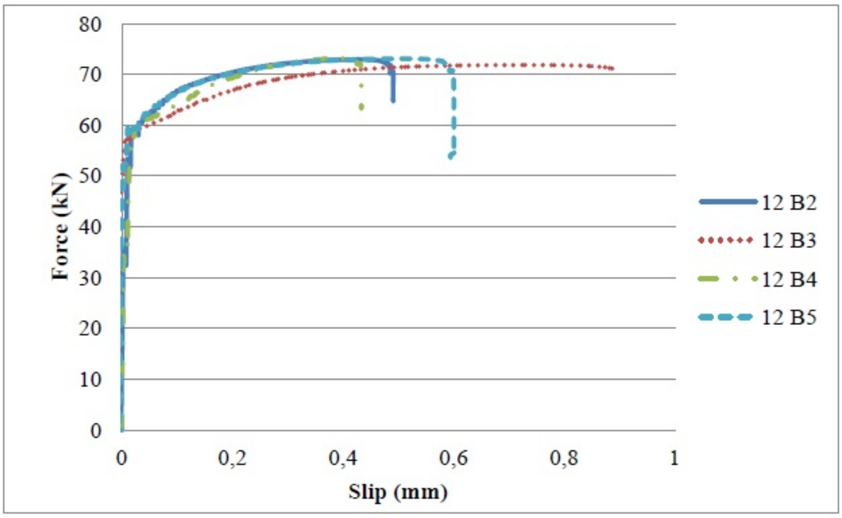

Fig. 6. Force vs. displacement diagrams in the case of steel reinforcing bars with 12 mm diameter and ribbed surface

Tab. 3. Results for ribbed reinforcing steel bars

	Nominal diameter (mm)	Bonded length (mm)	Force at the end of linear section (kN)	Average force at the end of linear section (kN)	Bond strength at the end of linear section (N/m^2)	Average of bond strength at the end of linear section (N/m^2)	SD (N/m^2)
B1	12	40	60.2523	59.7454	39.96	39.62	0.47
B2	12	40	60.3750	59.7454	40.04	39.62	0.47
B3	12	40	58.6500	59.7454	38.89	39.62	0.47
B4	12	40	60.0146	59.7454	39.80	39.62	0.47
B5	12	40	59.4353	59.7454	39.41	39.62	0.47

identical. For all specimens, failure occoured due to the tearing apart of the reinforcing steel bars and not by bond failure. Based on the strength value, which was calculated from the average measured forces at the moment of slipping, the bond strength is not lower than 39.62 N/mm^2. Based on the value calculated, it can be stated that the required bond length does not exceed 40 mm, which is clearly supported by the experiment (reinforcing steel bars tore at a bond length of 40 mm). Based on the experimental result the recommended required bond length is 60 mm, in the case of 12 mm bars with a 12 mm diameter and a ribbed surface.

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Notation

Φ_n reinforcing rebar nominal diameter

f_{ym} main value of yield point

$l_{b,rqd}$ required value of bond length

F_{max} main value of ultimate pull-out force

τ_{bu} ultimate bond strength

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