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Laboratory Evaluation of Bond Strength Between Rebar and Concrete Containing Limestone Powder

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ABSTRACT: The amount of adhesion between the concrete and the reinforcing bars plays a decisive role in the behavior of the RC structures, as well as their failure mode in the final extreme cases. This adhesion, known as band resistance, can be altered by changing the concrete mix. Laboratory evaluation of bond strength between rebar and concrete containing limestone powder is carried out in the present paper. For this purpose, 5, 15 and 30% of the cement of the control specimen (without limestone powder) is replaced with limestone powder and bond and compressive strength are obtained for specimens at the age of 7, 28 and 90 days. In this study, 15 cm concrete cubic and 16 mm diameter rebar are used to evaluate the bond. The water to binder ratio (w/b) is fixed at 0.4. Also, the test of pulling out the rebar is applied to calculate the bond strength between the concrete and steel reinforcement. The overall results show that the bond strength decreases with the increasing percentage of limestone in concrete, the amount of this reduction is less than 10% for a sample with 5% limestone powder, while a reduction about 40% is obtained for a sample with 5% limestone powder. The assessment of the exciting models for prediction the bond strength indicates that these models estimate a bond strength larger than those given by the experimental results. Therefore, it is necessary to provide a suitable model for estimating the bond strength of concrete containing limestone powder.

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1. INTRODUCTION

Cement replacement materials are added to concrete to provide or improve one or more properties; These properties include: reducing cement consumption, reducing the speed and amount of hydration, increasing the strength of concrete, increasing the durability of concrete [1]. Limestone, which is one of the raw materials for the production of clinker cement, was the first material to replace some percentage of cement used in concrete [2]. Limestone powder is usually added to the cement during the production of cement to the clinker or during the preparation of concrete mixes. By increasing research, standards and specifications also provided guidelines for the use of this type of concrete mix. For example, the European Standard EN 197-1 provide two types of cement with values of 6 to 20 percent and 21 to 35 percent limestone as a limestone Portland cement (PLC) [3]. Mechanical properties such as compressive strength, tensile strength and modulus of elasticity along with effective parameters on the durability of these types of cements have been investigated by many researchers [4-6]. The effects of limestone powder on the behavior of concrete depend on the fineness of limestone and blending type with cement [7]. Ramezanianpour et al. Showed that replacement of up to 10% of cement with limestone has no detrimental effect on concrete compressive strength [8].

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The behavior of reinforced concrete structures depends on the joint performance of reinforcement and concrete, this joint performance is due to the adhesion of rebar and concrete during the development length of the reinforcement, which is called bond strength. The effect of the compressive strength of the concrete on the bond strength is expressed in terms of compressive strength, such as $f_c^{1/4}$, $f_c^{1/2}$, $f_c^{3/4}$ and f_c [9]. Therefore, any factor affecting the compressive strength must be considered in the calculation of the bond strength. Despite extensive research on the effects of cement replacement with limestone, there are few studies on its effect on bond strength. Therefore, in this paper, the effect of replacement of cement with 5, 15 and 30 percent limestone powder on the bond strength has been investigated experimentally.

2. METHODOLOGY

In this research, the compressive strength test and pull out test of reinforcement on various concrete samples have been taken. The mix design is based on the ACI standard and the water / cement ratio (w / b) is fixed to 0.4. In this research, 5, 15 and 30 percent of the cement in concrete is replaced by limestone powder. For each mix design, 18 samples were made, of which 9 were used for bond strength test and 9 samples were used to the compressive strength test, Samples were cured under standard conditions and experiments are carried out on specimens at the age of 7, 28 and 90 days

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Table 1. Concrete mix design of test specimens.

Specimen	cement (kg/m^3)	Limestone (kg/m^3)	w/c
LS05	332.5	17.5	0.42
LS15	297.5	52.5	0.47
LS30	245	105	0.57
Control	350	0	0.4

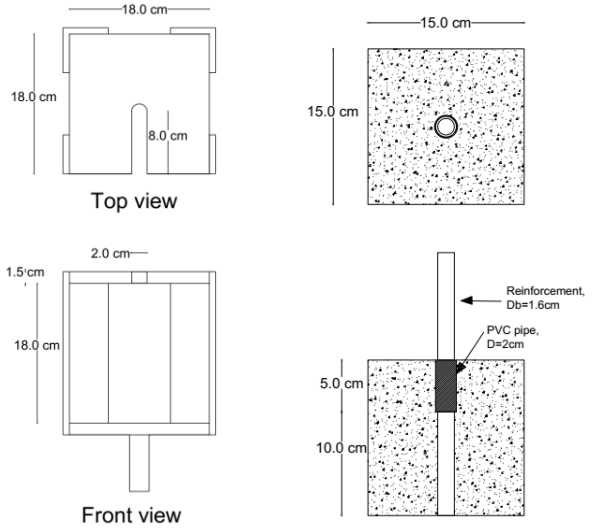

Fig. 1. (a) steel box for pull out test, (b) concrete specimen for pull out test.

Table 2. Compressive strength

Specimen	Compressive strength (MPa)		
	7 days	28 days	90 days
LS05	28.3	38.6	43.5
LS15	25.6	33.9	37.6
LS30	21.2	28.4	31.2
Control	28.1	39.2	44

after construction. The amount of different compositional components of the samples is shown in Table 1. The pull out test was performed according to RILEM 7-11-128.RC6 standard. To test the resistance of the band, a 16 mm diameter rebar is used, a 10 cm (5 inches) distance from the end of the rebar, a PVC tube with a length of 5 cm on the rebar. In Fig. 1 (a), the dimensional specification of the samples made for the bond strength is shown. To insert specimens inside the pull-out test setup, an iron box with dimensional characteristics shown in Fig. 1 (b) was used.

3. DISCUSSION AND RESULTS

The numerical results of the average compressive strength of cube samples at different ages are shown in Table 2. As it is clear from these results, the addition of limestone powder, especially in high amounts, has reduced the compressive strength of the concrete. In samples containing only 5% limestone, the compressive strength is not significantly different from that of the control, and even in 7 days, higher compressive strength is obtained, which can be attributed to increased cement hydration and dilution of the samples by limestone powder. The results of the pull-out test are shown in Table 3. To calculate the bond strength, the following equation is used:

Table 3. Bond strength

Specimen	Bond strength (MPa)		
	7 days	28 days	90 days
LS05	8.2	11.1	13.2
LS15	6.2	9.5	10.6
LS30	5	8.1	8.7
Control	8.4	13.5	14.9

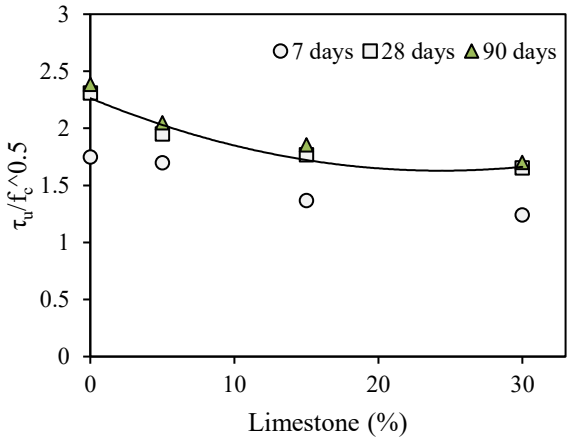

Fig. 2. Relationship between bond strength and limestone percentage

$$\tau_u = \frac{F}{\pi L_d d_b} \quad (1)$$

In this equation, F is the maximum force taken to pull out the rebar, db, the diameter of the rebar, and Ld is the length of the rebar in contact with concrete, which in this study was considered to be 10 centimeters.

Based on the results, it is observed that the bond strength, like compressive strength, is reduced by increasing the percentage of limestone powder. For example, with the replacement of 30% limestone powder, the bond strength ratio to the control sample at all ages is approximately 0.6. This percentage is obtained about 0.7 for replacing 15% limestone powder. In order to investigate the effect of limestone powder on the bond strength, bond strength values obtained from laboratory studies are divided into their corresponding $f_c^{1//2}$ and are shown in Fig. 2. As is clear from this Fig., a relationship can be found in terms of the percentage of limestone powder for $\tau_u/f_c^{1/2}$. For the results of this research, the relation is obtained as follows:

$$\tau_u / \sqrt{f_c} = 0.0011(LS)^2 - 0.052(LS) + 2.26 \ ,R^2 = 0.958 \quad (2)$$

In this Equation, LS is the amount of limestone powder.

4. CONCLUSIONS

With the increase of limestone powder in the concrete, the adhesion of concrete and reinforcing steel decreases and consequently the bond strength is reduced. This decrease is more at high levels of replacement such as a 30 percent replacement. The reason for this is to overcome the effect of dilution of cement due to the replacement of limestone powder with other beneficial physical and chemical effects due to the addition of limestone.

The replacement of 5% limestone powder in the long term reduced the bond strength by only 10%, so using this amount of limestone powder for replacement with cement does not have a damaging effect on structural performance.

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