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Evaluation of lightweight Concrete Core Test Including Steel Bars

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ABSTRACT

In many steel reinforced concrete members, steel bars are not avoidable during concrete core drilling and the presence of these steel bars have a direct impact on the results of this test. This study aims to examine the effect of steel bars presence on the test results of recycled aggregate lightweight concrete (LWC) cores. For the purpose, one lightweight concrete mix was made with a total number of 48 concrete cores were taken from a slab having the dimensions of 1 m width, 1.5 m length and 0.15m thickness. Each core has the dimensions of 90 mm in diameter and 150 mm in height. Three different sizes of steel bars (12, 16 and 20 mm) were used in six different locations (25, 45 and 65 mm) from the base of the core and (15 and 30 mm) from the center line of the core. A recycled crashed clay brick (CCB) was used as an alternative to the coarse aggregate. Compare to the density of the normal concrete (2400 kg/m^3), the LWC was able to achieve nearly 20% reduction of the total weight by fully replacing of normal aggregate with CCB. It has been found that the presence of the steel increases the compressive strength of the LWC cores. This effect is more noticeable when the location of the steel bar is near to the mid-height or the centerline of the concrete core. Also, the influence of the steel bar diameter has increased by increasing the size of the steel bar.

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1. INTRODUCTION

Reducing the total self-weight of any structure is an important key in many structural designs. There are several advantages of this self-weight reduction including but not limited to improving the structural behaviour to seismic loads and reducing the total cost of the structure [1-3]. Decreasing the total weight of the structural elements can be achieved by different methods such as using thin concrete sections with high concrete strength or reducing the specific gravity of the concrete. Normally, concrete is produced with relatively high specific gravity of nearly 2400 kg/m^3 and the main reason for that is the high content of the normal aggregate within the concrete mix (nearly 70% of the total weight of the mixture) [4]. The ACI C213 committee [5] mentioned that the specific gravity of the light weight concrete should not be acceded the limit of 1850 kg/m^3. Accordingly, several studies were conducted to partially or fully replacing the normal aggregate of the concrete with other types of aggregates that having a lower specific gravity than the normal aggregate [6-9]. In general, by replacing normal aggregate with lightweight aggregate, the concrete strength is dramatically affected. The ACI requirements for compressive strength of light weight concrete should be kept more than 17 MPa for structural design [5]. Therefore, many researches were conducted on light weight concrete that aimed to achieve a reliable quality and strength in which could be suitable for structural applications [10-15].

It is well-known that the concrete quality is determined based on the test results of concrete samples at the age of 28 days. However, in some cases the test results do not fulfill the specified 28-day strength due to many reasons, such as; incorrect practice methods or improper testing procedures. In such cases, concrete coring could be one of the desired solutions to evaluate the in-situ quality of the placed concrete. Extracting concrete cores from existing concrete is preferable for some other reasons, especially when the placed concrete

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is subjected to any type of deterioration, for instance; effect of fire, chemical attack, fatigue or other kinds of degradation effects. Concrete coring is considered as a semi-destructive test and can be performed on different types of structural members in horizontal or vertical directions. Normally, steel reinforcement is used along with concrete in the structural elements to resist the tensile stresses or to confine the concrete in which increases the loading carrying capacity of the structural members. The presence of the steel reinforcement is not desirable in the concrete coring and many international codes recommended testing concrete cores without steel bars, such as ASTM committee [16]. However, in some situations where heavy steel reinforcement is used, it would be very difficult to avoid steel bars during concrete core drilling. For this reason, some international codes [17, 18] suggested empirical equations to correct the compressive strength test results of the drilled concrete cores depending on many factors, such as the size, location and number of the steel bars within the core. These factors are also related to the geometry of the drilled core, for example the effect of the steel bar size is taken as a ratio of steel bar diameter to the core diameter.

Tuncan et al. [19] studied the reliability of testing small diameter drilled concrete cores and it has been found that the compressive strength of the smaller diameter drilled cores were more likely to be affected by the length of the core and the characteristics of the aggregate with in the concrete mixture. Also, by increasing the length to diameter ratio (l/d) of the concrete cores, the compressive strength tends to show lower values.

Momeni et al. [20] performed a study to investigate the reliability of steel bars correction factors for drilled cores. It has been stated that these factors are highly related to the size and the location of the steel bars. According to the experimental results, the inclusion of steel reinforcement led to an increment for the compressive strength and it was more noticeable for concrete cores with l/d ratio equal to one. Momeni et al. [20] also suggested a linear and nonlinear regression models to predict the cube compressive strength of an existing concrete from the test results of drilled concrete cores.

Lessly et al. [21] conducted an experimental study on the effect of steel reinforcement on the compressive strength of drilled concrete cores. This study was included different orientations and different sizes of the steel bars within the extracted cores. It had been found that the presence of steel bars led to a reduction up to 36% in the compressive strength of the concrete cores. The compressive strength reduction was explained as a result to the loss of bond strength between the steel bars and the concrete during the core cutting process. Accordingly, there are limited numbers of studies in the research field to obtain a fully understanding the effect of steel bars presence on the test results of drilled concrete cores.

The outcomes of this research could be helpful when steel reinforced lightweight concrete is used in real structural applications and drilled cores are needed for quality control reasons. All the available researches were performed on normal concrete cores [22-24] and there is no single study dealt with drilled cores of light weight concrete. For this reason, the current study aimed to experimentally examine the effect of steel bars presence on the test results of light weight concrete cores made of locally crashed clay bricks.

2. EXPERIMENTAL PROGRAM

In order to attain the aim of this study, to examine the effect of steel reinforcement bars on the test results of compressive strength of light weight concrete (LWC) cores. The experimental work is executed at the Concrete laboratory of the civil engineering department in college of engineering/Wasit University. The testing program is organized to obtain information about the effect of steel bars on test results of concrete cores for light weight concrete. One concrete mix have been made with a total number of 48 concrete cores were taken from concrete slab having a dimensions of 1 m width, 1.5 m length and 0.15m thickness. Three different sizes of steel bars (12, 16 and 20 mm) have been used in three different locations (25, 45 and 65 mm) from the base of the core and (0, 15 and 30 mm) from the center line of the core. Table 1 shows the test matrix of this study. All concrete cores are tested for compressive strength at 28 days. Figure 1 shows the core samples before testing.

TABLE 1. Test matrix of core specimen

	Core ID	Steel bars location [mm]		Steel bar diameter [mm]
		From the base of the core in Y direction	From the centerline of the core in X direction	
	R	----	-----	-----
Steel bars in Y direction	S12-Y25	25	-----	12
	S12-Y45	45	-----	12
	S12-Y65	65	-----	12
	S16-Y25	25	-----	16
	S16-Y45	45	-----	16
	S16-Y65	65	-----	16
	S20-Y25	25	-----	20
	S20-Y45	45	-----	20
	S20-Y65	65	-----	20
Steel bars in X direction	S12-X15	-----	15	12
	S12-X30	-----	30	12
	S16-X15	-----	15	16
	S16-X30	-----	30	16
	S20-X15	-----	15	20
	S20-X30	-----	30	20

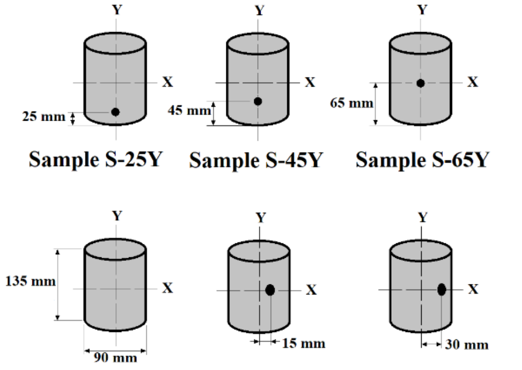

Figure 1. Steel bar location within the core samples

2. 1. Materials Effective production of LWC is achieved by several methods. One of these methods is to use light weight aggregate within the concrete mix. In this study, crashed clay brick (CCB) was used as an alternative to the coarse aggregate, see Figure 2. The CCB can be prepared locally as a recycled material from demolished brick buildings. The mix design of this study was planned to use the CCB as fully replacement to the normal course aggregate. As mentioned earlier, the CCB was prepared using local materials to comply with the Iraqi Standard 45: 1985 [25]. Tables 2 and 3 show the properties of the CCB that has been used to produce the LWC in this study. Along with the CCB aggregate, normal fine aggregate (sand) of Zone 2 grading (according to Iraqi Standard 45: 1985) [25] was used to form the filler ingredient within the LWC mixture.

Figure 2. Preparing the CCB for lightweight aggregate

TABLE 2. Grading of CCB aggregate of MAS (20 mm)

Sieve size (mm)	Passing by weight%	Limits of the Iraqi specification No. 45/1984[23]
25	100	100
14	55	40-80
10	41	30-60
5	5	0-10

TABLE 3. Other properties of CCB aggregate

Physical properties	Test results	Limits of the Iraqi specification No. 45/1984[23]
Specific gravity	1.67	--
Sulfate content	0.04%	≤ 0.1%
absorption	16 %	--

Also, ordinary Portland cement was mixed with the water to form the binder component that brings all the ingredients together. In addition to these materials, superplasticiser was also used to provide an acceptable compressive strength for the LWC due to the reduction of the water amount within the mix.

Three sizes of steel reinforcing bars are used in the present experimental work. These deformed steel bars of diameters 12, 16 and 20 mm were tested in a universal testing machine to determine the tensile properties before use. Properties of the steel bars are shown in Table 4.

2. 2. Molding The concrete cores were taken out from a concrete slab having the dimensions of 1500 mm length, 1000 mm width and 150 mm thickness. This concrete slab was designed to be reinforced in one direction parallel to the width of the slab as shown in Figure 3. Nine steel bars (3 Ø 12, 3 Ø 16 and 3 Ø 20 mm) were used and placed at a distance of 150 mm from each other in a wooden formwork as shown in Figure 3. Each group of steel bar diameter was placed in three different locations from the bottom of the mold (25, 45 and 65 mm). These steel bars were extended out of the formwork by 100 mm in length, so it can be easily located after concrete pouring.

2. 3. Lightweight Concrete Mix In order to achieve the target compressive strength of the LWC

TABLE 4. Tensile properties of steel bars

Nominal Diameter [mm]	Modulus of Elasticity [GPa]	Yield Stress [MPa]	Ultimate Stress [MPa]
12 deformed	200	400	676
16 deformed	200	485	719
20 deformed	200	517	635

Figure 3. Preparing the CCB for light weight aggregate

which is not less than 20 MPa, the following mix proportions shown in Table 5 were adopted. As mentioned above, the key to prepare a LWC mix in this study is to use crashed clay brick as a fully replacement to the normal coarse aggregate. Several trail mixes were made prior to the mixing day in order to obtain the target compressive strength. Mixing method is important to obtain the required workability and homogeneity of the concrete mix, especially when a superplasticiser is used. Concrete is mixed in drum laboratory mixer, with a capacity of (0.1 m^3). Initially, CCB aggregate and fine aggregate are poured into the mixer, followed by (50%) of the mixing water to wet them. The cement is added at this stage, followed by (25%) of the mixing water, then the remaining (25%) of water is added gradually to the mix. The superplasticizer is added gradually after this stage. The total mixing time is in the range of 4-6 minutes. The slump test is the most well-known and widely used test method to characterize the workability of fresh concrete. According to ASTM C143/C143M [26], the slump test consists of a tamping rod and a truncated cone, (300 mm) height and (100 mm) diameter at the top, and (200 mm) diameter at the bottom. The cone is filled with concrete and then slowly lifted. The unsupported concrete cone slumps down by its own weight; and the decrease in the height of the slumped cone is called the slump of concrete. After casting, the steel reinforced LWC slab was covered with a nylon cover to prevent evaporation of water. After one day, the upper surface of the slab was covered with 15 mm layer of potable water for 28 days in a laboratory conditions.

2. 4. Concrete Core Drilling The American Standard ASTM C42/C42M-20 [5] recommended avoiding the presence of any steel bars within the concrete cores during the extraction process. This can be possibly achieved by means of cover meter or pachometer. However, in some cases when steel reinforcement cannot be avoided during the drilling, the concrete cores should be trimmed to eliminate any steel bars within the cores. On the other hand, other testing standard such as the British Standard 1881: Part 120 [17] suggested a correction factor to overcome the effect of the steel bar presence within the concrete cores. This correction factor takes into account the effects of the ratio of the diameter of the bar to the diameter of the core. Also the effect of the ratio between bar location from a nearest end to the length of the core was taken into account.

In this study, the surface of the concrete slab was dried out for one day before cores drilling were conducted. Also, the surface was lined up with a permanent marker to identify the locations of the steel bars accurately. The LWC cores were obtained according to the standard test method of British Standard 1881: Part 120 [17]. A core drilling machine was used to take concrete cores out of the slab. The diameter of the cutting drill was 90 mm. The drilling machine was placed on the surface of the concrete slab. This machine was connected to a water source to cool down the drilling cylinder during cutting the concrete cores, see Figure 4.

TABLE 5. Mix proportion of the light weight concrete

Mix	Cement [kg/m³]	Fine aggregate [kg/m³]	CCB [kg/m³]	Water [kg/m³]	SP [l/m³]
LWC	360	760	1056	200	1.93

2. 5. Test Setup and Procedure

2. 5. 1. Compression Test To determine the compressive strength of the LWC cores, a Matest compression testing machine with a loading capacity of 1500 kN was used. For each group, two cores were tested under a constant loading of 20 MPa/min according to BS EN 12390-3:2019 [27] at the age of 28 days, as shown in Figure 5.

3. RESULTS AND DISCUSSION

3. 1. Concrete Compressive Strength In this experimental work, compressive strength test is made on concrete cores of 90 mm × 135 mm (diameter × height).

Figure 4. Concrete core drilling of LWC slab

Figure 5. LWC cores under compression test

The steel bars of different sizes were placed in Y and X directions as can be seen in Figure 1 to investigate the effect of the steel bars on the compressive strength of the LWC drilled cores. Figure 6 and Table 6 show the experimental compressive test results of this study at the age of 28 days.

Initially, the test results of the LWC cores are represent concrete cores with length/diameter (l/d) ratio less than two, so they need two types of correction factors to invert their strength into the design cube strength (F_{cu}). The first one is due to the effect of l/d ratio (0.97) and the second correction factor is due to the shape effect (1.2) (from cylinder to cube), see Table 6. However, LWC is defined according to the ACI C213R-14 [5] is the concrete that has compressive strength more than 17 MPa and density equal or less than 1850 kg/m^3. It can be seen that compressive strength of the LWC cores was increased by increasing the diameter of the steel bar that provide more lateral confinement for the concrete sample and delay the ultimate failure of the concrete as well as increasing the ultimate load capacity of the concrete cores.

For LWC cores with steel bars in Y direction, the compressive strength was increased by nearly 30% to 68% for Specimens S12-Y25 and S20-Y45, respectively. This gain in the compressive strength is depending on the size and the location of the steel bar, as can be seen in Figure 6a. Also, it can be noticed the compressive strength of LWC cores was dramatically affected by the location of steel bar. The closer steel bar to the mid-height of the sample, the higher compressive strength is recorded. For LWC cores with steel bars in X direction, the compressive strength was increased by nearly 20% to 53% for Specimens S12-X30 and S20-X15, respectively. This increment was depending on the size and the location of the steel bar which has the same behavior of the steel bars in the Y direction, as shown in Figure 6b.

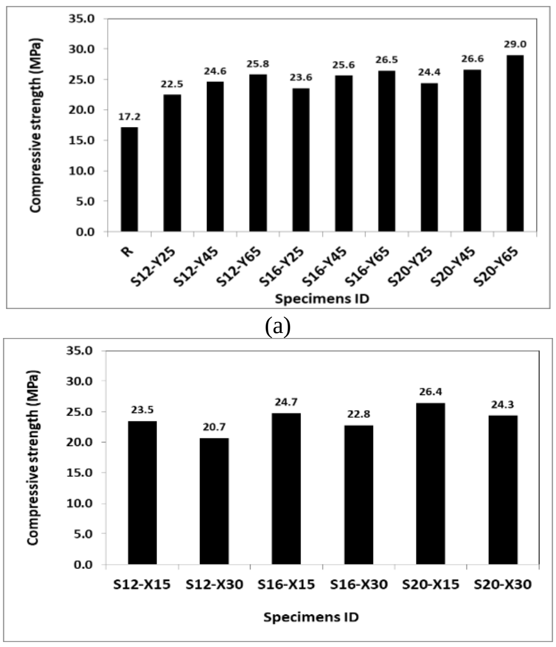

Figure 6. Compressive strength results of LWC cores; (a) for steel bars in Y-direction and (b) for steel bars in X-direction

TABLE 6. The average compressive strength of LWC cores

	Specimen ID	Applied load (kN)	Core compressive strength (MPa)	Cube compressive strength (MPa)
	R	109.2	17.2	20.0
Steel bars in Y direction	S12-Y25	143.1	22.5	26.2
	S12-Y45	156.5	24.6	28.6
	S12-Y65	164.1	25.8	30.0
	S16-Y25	149.9	23.6	27.4
	S16-Y45	163.1	25.6	29.9
	S16-Y65	168.3	26.5	30.8
	S20-Y25	155.2	24.4	28.4
	S20-Y45	169.3	26.6	31.0
	S20-Y65	184.4	29.0	33.8
Steel bars in X direction	S12-X15	149.2	23.5	27.3
	S12-X30	131.4	20.7	24.1
	S16-X15	157.3	24.7	28.8
	S16-X30	144.9	22.8	26.5
	S20-X15	168.1	26.4	30.8
	S20-X30	154.8	24.3	28.3

For concrete cores made with normal aggregate, it has been reported in previous studies that the presence of steel within the cores would dramatically reduce the strength of the cores [19]. However, in this study for concrete with LWC aggregate, the strength was increased slightly depending on the size and the location of the steel bars. This change in behaviour can be explained by the fact that more disturbance effect of core drilling is expected in normal concrete than LWC. This disturbance effect may causes weak bonding strength between aggregate and cement mortar and between concrete and steel bars during the drilling process. In contrast to normal aggregate concrete, LWC showed an excellent bonding microstructure between the light weight aggregate and the cement paste due to the high porosity of the light weight aggregate (crashed clay brick) as presented in Figure 7. This figure shows the microstructure of the LWC by the Scanning Electron Microscope (SEM) technique that shows the bonding between cement paste and the crashed clay brick aggregate after cores drilling.

3. 2. Analytical Relationship between Steel Bars and Compressive Strength of LWC Cores

From the test results of concrete core samples, it can be found that the presence of steel bars has a noticeable effect on

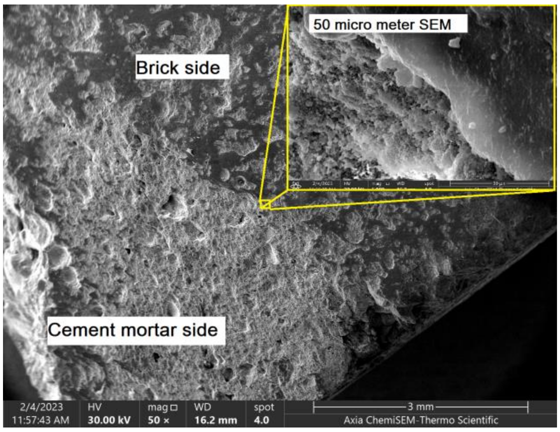

Figure 7. Scanning Electron Microscope (SEM) photo of the interfacial zone between the cement mortar and the CCB

the compressive strength test results of the LWC cores. In general, the experimental results showed that increasing steel bar diameter will increase the compressive strength of the LWC cores. Moreover; as the distance of steel bars from nearest core base increases, the compressive strength increases too. This can be explained by the effect of restrain degree, which is increase at the mid-distance of concrete core samples. The concrete cores samples that made of LWC are more affected by the presence of steel bars than those made of normal concrete.

As the steel reinforcement is unavoidable in many cases when concrete cores are taken out of the structural members, it was necessary to propose an equation that could take into account the effect of steel reinforcement. Although the current study has a limited number of concrete specimens (a total number of 48 samples) of LWC cores, but it can be the first step to suggest a new expression for LWC drilled cores to make the required correction for the compressive strength after the test. Also, there is a limited number of data in the literature that obtained from lightweight concrete which can be used to verify the proposed equation below.

The equation below takes into account the effect of steel bar diameter, the location of the steel bar from the nearest core base as well as the location of the steel bar from the centerline of the core. The general form of the equation shown in Equation 1, that showed a reliable correlation between the actual strength and the corrected strength with correlation coefficient of 0.97 as shown below:

$$f_{cc} = f_c \times [(1+1.51) \times (\frac{\emptyset}{D})^{0.136} \times (\frac{h}{L})^{0.185} \times (\frac{b}{D})^{0.04}] \quad (1)$$

where

f_{cc} : Corrected compressive strength

f_c : Actual compressive strength

Ø: diameter of steel bar

D: diameter of concrete core

h: distance between steel bar and nearest core base

L: length of concrete core

b: distance between steel bar and centerline of the core

These expressions are obtained by using nonlinear estimation regression of Statistica program V7.1.

3. 3. Concrete Density The bulk density of the LWC in this study was to the LWC cores without steel bars. The density of these specimens can be compared to the density of normal concrete in order to indicate the reduction in the total weight of this type of concrete. By using recycled lightweight aggregate of CCB the average bulk density of the LWC was recorded to have 1899 kg/m^3. Compare to the density of the normal concrete (nearly 2400 kg/m^3), the LWC in this study was able to achieve about 20% reduction of the total weight by fully replacing of natural river aggregate with the CCB lightweight aggregate. Other specimens were recorded higher bulk density due to the presence of steel bars, as can be seen in Table 7.

3. 4. Failure Mode The failure mode was dramatically affected by the presence of the steel bars and their locations. It has been observed that the steel bar was confined the lateral strain of the specimens that is developed due to the effect of Poisons ratio while applying the axial load during the test. This type of confinement is due to the friction between the steel bar and the surrounding concrete. Accordingly, by the end of the compression test, the cracks were distributed and spread away from the steel bar location. Figure 8 shows the typical failure mode for both cases of LWC cores with and without steel bars.

TABLE 7. The average apparent density of LWC cores

Core ID		Height (m)	Weight (kg)	Volume (m^3)	Density (kg/m^3)
Steel bars in Y direction	R	0.135	1.63	0.0008584	1899
	S12-Y25	0.135	1.65	0.0008584	1922
	S12-Y45	0.135	1.68	0.0008584	1957
	S12-Y65	0.132	1.7	0.0008393	2025
	S16-Y25	0.133	1.73	0.0008457	2046
	S16-Y45	0.133	1.73	0.0008457	2046
	S16-Y65	0.132	1.72	0.0008393	2049
	S20-Y25	0.135	1.8	0.0008584	2097
	S20-Y45	0.135	1.9	0.0008584	2213
	S20-Y65	0.135	1.9	0.0008584	2213
Cores in X direction	S12-X15	0.133	1.68	0.0008457	1990
	S12-X30	0.135	1.70	0.0008457	2010
	S16-X15	0.135	1.75	0.0008584	2039
	S16-X30	0.134	1.75	0.0008584	2039
	S20-X15	0.135	1.84	0.0008393	2187
	S20-X30	0.133	1.92	0.0008457	2270

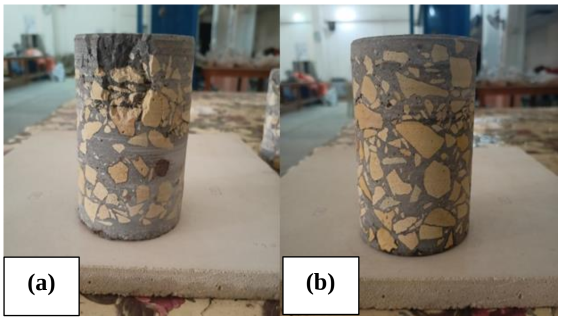

Figure 8. Typical failure mode of LWC cores (a) with steel bar and (b) without steel bar

4. CONCLUSIONS

On the basis of the experimental program presented above of the LWC mix described in the text, using two variables (steel bar diameter and steel bar location) the main conclusions can be summarized, as follows:

1. The experimental results showed that the presence of the steel bars within the LWC cores increases the compressive strength of the LWC cores. This behaviour is more noticeable when the location of the steel bar is near to the mid-height of the concrete core. Also, the influence of the steel bar diameter is increased by increasing the size of the steel bar which showed higher compressive strength.
2. An equation was suggested that can be used to determine the effect of the steel bar on the compressive strength of LWC drilled cores. However, this equation is limited to one steel bar within the core and compressive strength of with range of 17 to 27 MPa.
3. The apparent density of the LWC mix in this study was determine to have 1899 kg/m^3 which is very close to the requirement of the ACI C213 committee (1850 kg/m^3). This was achieved by full replacement of normal coarse aggregate with crashed clay brick aggregate.
4. The failure mode of the LWC cores was dramatically affected by the diameter and the location of the steel bar within the concrete cores.
5. The LWC was able to maintain excellent bond strength between the cement mortar and the crashed clay brick aggregate due to the high surface porosity of the aggregate that contained some of the hydrated cement products.

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Persian Abstract

چکیده

در بسیاری از بخش بتنی مسلح، میلگردهای فولادی در حین حفاری هسته بتن قابل اجتناب نیستند و وجود این میلگردهای فولادی تأثیر مستقیمی بر نتایج این آزمایش دارد. هدف این مطالعه بررسی اثر حضور میله‌های فولادی بر نتایج آزمایش هسته‌های بتن سبک وزن دانه‌های بازیافتی (LWC)است. برای این منظور، یک مخلوط بتن سبک با تعداد کل ٤٨ هسته بتنی از دالی به ابعاد ۱ متر عرض، ۱.۵ متر طول و ۰.۱۵ متر ضخامت تهیه شد. هر هسته دارای ابعاد ۹۰ میلی متر قطر و ۱۵۰ میلی متر ارتفاع است. سه اندازه مختلف میله فولادی (۱۲، ١٦ و ۲۰ میلی متر) در شش مکان مختلف (۲۵، ٤٥ و ٦٥ میلی متر) از پایه هسته و (۱۵ و ۳۰ میلی متر) از خط مرکزی هسته استفاده شد. یک آجر رسی شکسته بازیافت شده (CCB)به عنوان جایگزینی برای سنگدانه درشت استفاده شد. در مقایسه با چگالی بتن معمولی (٢٤٠٠ کیلوگرم بر متر مکعب)، LWC توانست با جایگزینی کامل سنگدانه معمولی با CCB، نزدیک به ۲۰ درصد کاهش وزن کل را به دست آورد. مشخص شده است که وجود فولاد استحکام فشاری هسته های LWC را افزایش می دهد. این اثر زمانی که محل میلگرد فولادی نزدیک به ارتفاع وسط یا خط مرکزی هسته بتنی باشد بیشتر قابل توجه است. همچنین تاثیر قطر میلگرد فولادی با افزایش اندازه میله فولادی افزایش یافته است.