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PERFORMANCE OF SUSTAINABLE CONCRETE CONSTRUCTED WITH LOCALLY AVAILABLE AGGREGATES

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ABSTRACT:

As is desired, more sustainable concrete has become the target of many infrastructural engineers. To produce more sustainable concrete, it should take into account the materials' cost and CO2 footprint. Coarse aggregate occupies more than 60% of concrete's weight, making it the most consumed component. The majority of quarries that produce coarse aggregate are far away from cities, so the necessary transportation operations increase carbon dioxide emissions and the cost of the materials. Therefore, it has become necessary to find alternatives for these coarse aggregate types presently in use. In this study, five coarse aggregate types: three new types (limestone aggregate, white crushed stone, and white rounded gravel) were selected as coarse aggregate in concrete mixtures besides the two common coarse aggregate types (black round and crushed black aggregates) to investigate the bond behavior of the aggregates with steel rebar. A ranking analysis approach was adopted to examine the performance of the new aggregate types. Test results reveal that the new aggregate types perform well in bond strength and can be adopted in civil structural applications.

KEYWORDS: Coarse Aggregate, Cost, Carbon Dioxide Emissions, Ranking Analysis, Sustainable Concrete.

1. INTRODUCTION

In the last decades, there has been an increase in concrete construction projects [1]. This has led to an increase in concrete consumption. The rate of concrete consumption in Iraq is expected to reach more than 100 million tons annually by 2050. In the past few years, Najaf province has witnessed a significant increase in concrete consumption rates due to the construction of various concrete projects. This leads to a continuous decrease in the coarse aggregate resources currently used since coarse aggregate is the most consumed component in concrete. Furthermore, transportation costs rise due to the long distance between these sources and Najaf city because, most coarse aggregate quarries currently used are more than 230 km away from Najaf province, as shown in Fig. 1a. Moreover, the required transport operations by trucks lead to air pollution due to carbon emissions where the average carbon emission is 160 grams per kilometer [2]. This will inevitably lead to an increase in global warming. Therefore, the need for sustainable concrete with less CO2 emissions and less cost rose. One of the solutions to achieve sustainable concrete is finding alternatives to these currently used coarse aggregate types to achieve short distance, low cost, and good quality. The Najaf Sea region is home to many coarse aggregates such as limestone aggregate, white crushed stone, and white rounded gravel. These types are readily available naturally in large quantities and at a reasonable cost; also, the short distances (less than 45 km) between the city of Najaf and the quarries of these new types of coarse aggregates as shown in Fig. 1b.

2. MATERIALS AND THE PERFORMED TESTS

This study used ordinary Portland cement (Type I), normal fine aggregate, and five coarse aggregate types. The coarse aggregate varied between rounded and crushed types, as shown in Fig. 2. These types are Limestone (LISA), White crushed stone (WCSA), White rounded (WRGA), Black rounded (BRGA), and Black crushed (BCSA). The coarse aggregate properties such as specific gravity, gradation, and absorption, were calculated according to the ASTM standards.

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Table 1 summarizes the properties of coarse and fine aggregate. The properties of fresh concrete discovered were slump and temperature. Fig. 3 shows the fresh concrete properties results. The mechanical properties of hardening concrete were represented by compressive strength, flexural strength, and splitting strength, and the results are represented in Table 2.

3. BOND SPECIMEN DESIGN AND TESTING

Pull-out specimens were used to calculate the bond strength and RILEM 7-11-128 [3] was adopted to design these specimens. The embedment length of the reinforcement was ten times the rebar diameter (db). Half of the embedment length was deboned using a polyvinyl chloride pipe (PVC) section to ensure the slip failure is the controlling mode of failure. To maintain a proper cover, RILEM recommends a distance of no less than 4.5 db measured from the center of the reinforcing rebar to the outer edge of the specimen. A 980 kN universal machine was used to test the pull-out specimens as shown in Fig. 4.

4. BOND STRENGTH RESULTS

The results of bond strength are shown in Table 3. The results indicate that the WCSA had the highest bond strength. Also, according to the results, increasing the diameter of the reinforcing bar for all types of coarse aggregates lowered the bond strength value.

5. STATISTICAL ANALYSES

A statistical approach was used in this study to optimize the concrete mixtures. Based on the analysis of the data through a statistically planned experimental program, several responses were selected to evaluate the performance of the five concrete mixtures. The selected responses were bond strength, compressive strength, flexural strength, splitting strength, cost, and CO2 emissions. The performance rank analysis approach [4] was utilized to optimize the performance of the five mixtures. The objective of this analysis is to know the best aggregate type to have sustainable concrete depending on the responses that have been selected. The overall performances of the investigated mixtures were compared in terms of high performance to secure high bond strength, high compressive strength, high splitting strength, high flexural strength, low transportation cost, and low CO2 emissions. Weighting factors of 4 were assigned to the bond strength, 3 were assigned to the cost and CO2 emissions, and 2 were assigned to the compressive strength. while the splitting strength and flexural strength were assigned a factor of 1. These factors reflect the most important property of materials' performance throughout the long-term service life for achieving more sustainable concrete. Table 4 presents the ranking of the investigated mixtures. As shown in Table 4, the sum of the final ranking is normalized using Eq. 1:

$$\text{Normalize sum of ranking (\%)} = \frac{R_x - R_{min}}{R_{max} - R_{min}} \quad (1)$$

Rx refers to the sum of the ranking of the investigated mixtures, and Rmin and Rmax refer to the maximum and minimum sum of ranking among investigated mixtures.

The normalized total ranking ranges from 0 and 100%, corresponding to the best and worst performance. The highest-ranking value shows the best performance of the investigated concrete mixtures. The performance of the mixes is classified into three categories in this section. High-performance mixtures with a normalized sum of ranking ≥ 85%. Medium performance mixtures correspond to the normalized sum of ranking between (85 % > the normalized sum of ranking > 50%). Low-performance mixtures with a normalized sum of ranking ≤ 50%. The analysis results showed that the WCSA mixture appears to have the highest performance followed by WRGA.

6. CONCLUSIONS

1- The WCSA had the highest bond strength value, and that relates to the influence of the waviness and roughness of the coarse aggregate on the interdependence between the concrete components.

2- Increasing the diameter of the reinforcing bar for all types of coarse aggregate lowered the bond strength value

3- The statistical analysis results coincide with the experimental results which showed that the WCSA mixture appears to have the highest performance and is more sustainable.

Acknowledgments

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Table(1):-Properties of Coarse Aggregates and Fine Aggregates

Coarse Aggregate Type	DRUW (kg/m^3)	Max Size (mm)	BSG	Density (kg/m^3)	Absorption
LISA	1550	19	2.5	2500	3.1
WCSA	1600	19	2.65	2650	2.8
WRGA	1550	19	2.6	2600	2.5
BRGA	1600	19	2.64	2640	0.5
BCSA	1650	19	2.6	2600	0.7
Specifications	ASTM C29 [6]	ASTM C136 [7]	ASTM C127 [8]	---	ASTM C127 [8]
Limits [5]	(1200-1750) kg/m^3	---	2.4-2.9	(2400-2900) kg/m^3	(0.2-4) %
Fine Aggregates	---	---	2.5	---	2%
Specifications	---	---	ASTM C 128-15 [9]	---	ASTM C 128-15 [9]

Table (2):- Properties of Hardened Concrete

Mix ID	Compressive strength (MPa)				Flexural Strength (MPa)	Splitting Strength (MPa)
	Day 3rd	Day 14th	Day 28th	Test day*	Test day*	Test day*
LISA	17.2	21.5	23.4	25.1	3.9	1.62
WCSA	20.6	25.8	28.6	30.7	4.4	1.75
WRGA	18.1	23.5	26.4	29.0	4.2	1.75
BCSA	21.9	26.4	28.7	30.8	4.4	1.70
BRGA	18.5	24.4	28.2	29.8	4.3	1.65

*Test day represents the day on which the bond specimens were tested.

Table (3):-Bond Strength Results

	Mix ID	LISA	WCSA	WRGA	BCSA	BRGA
Ranking	Compressive Strength	1	4	2	5	3
	Splitting Strength	1	5	5	3	2
	Flexural Strength	1	5	2	5	3
	Bond Strength	1	5	2	4	3
	Transportation Cost[3]	3	5	5	1	2
	CO_2 Emissions[4]	4	4	4	2	2
Total Performance[2a]		29	63	44	41	34
Normalized Total Performance[2b], %		0	100	45	36	13
Performance Level[1]						

Notes:

1-

High Performance — Low Performance

2- Example of Calculation (WRGA):

a) Total Performance = 2* Compressive strength + 4* Bond strength + 3* Transportation cost + 3* CO2 emissions + 1* flexural strength + 1* splitting strength D: 43

Total Performance = (2*2) +(4*2) +(3*5) + (3*4) + (1*5) + (1*2) =44

b) Normalized sum of ranking (%) = [(44-29) / (63-29)] * 100 = 45%

3- Based on local material cost, the transportation cost of coarse aggregate type was calculated.

4- Depending on the average emissions of CO2 of 1.6 kg/km, the total emissions from the transportation operations of each coarse aggregate type were calculated.

Table (4):- Ranking Analysis

Mix ID	Bar Diameter (mm)	Bond strength* (MPa)
WCSA	12	25.1
WRGA		22.7
BRGA		23.0
BCSA		24.7
LISA		19.7
WCSA	16	23.8
WRGA		21.7
BRGA		22.4
BCSA		23.7
LISA		19.1

*Bond strength = $\frac{P_u}{\pi * d_b * l_s}$ where P_u is the ultimate load, d_b is the diameter of the bar, l_s is the bonded length.

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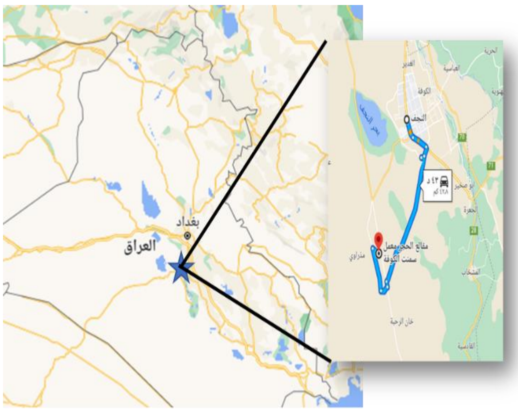
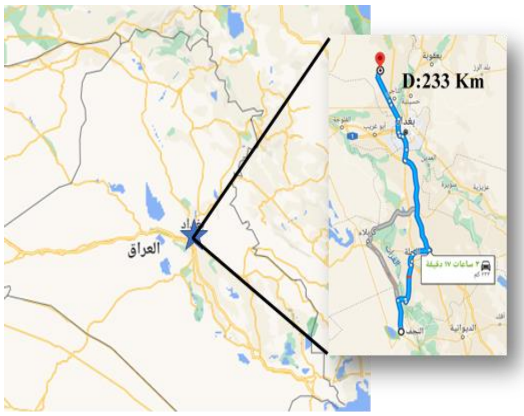


(a) Distance Between Najaf City and Old Sources Quarries



(b) Distance Between Najaf City and New Gravel Sources Quarries

Fig.(1):-Coarse Aggregate Quarries Locations

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White Crushed

Limestone

White Rounded

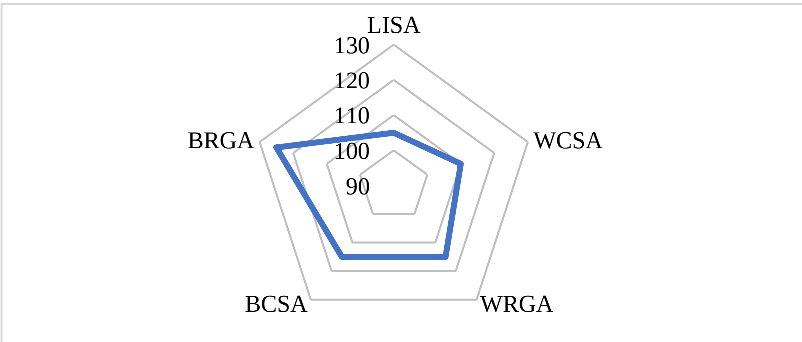
(a) New coarse aggregate types

Black Crushed

Black Rounded

(b) common coarse aggregate types

Fig.(2):-Sample of Coarse Aggregate Types



(a) Slump results

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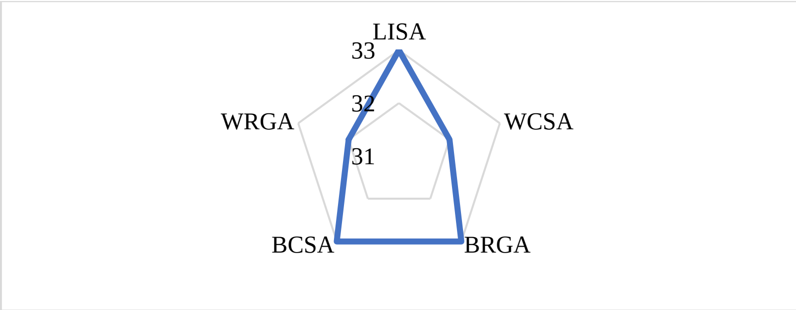

(b) Temperature Results
Fig.(3):- Sample of Coarse Aggregate Types

Fig.(4):-Pull-Out Test Setup