Correlating the Durability Properties (Porosity, Density, And Absorption) of Roller Compacted Concrete Pavement

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Abstract

Roller compacted concrete is the zero-slump concrete mixture, usually prepared at low cement content and low workability, and subjected to compaction by rollers to increase the density and improve the aggregate particles interlock. It is recommended for heavy duty pavement and can withstand harsh environment. Modeling the physical behavior of roller compacted concrete exhibits a quick and easy start to predict the future behavior of the material. In the present assessment, roller compacted concrete mixtures have been prepared in the laboratory using three percentages of Portland cement (10, 12, and 16) % to simulate low, medium, and high cement content from roller compacted concrete point of view. The mixtures were poured into the cylinder mold of 101.6 mm diameter and 116.4 mm height in five successive layers. Each layer had practiced 25 blows of the modified Proctor hammer with 4.5 kg weight, falling from 450 mm height. Specimens were withdrawn from the mold after 24 hours and cured for 28 days in a water bath at 20°C. Specimens were subjected to bulk density, absorption, and porosity determination. Test results were analyzed and modeled. It can be observed that the gradation of aggregates (dense or gap) does not exhibit a significant issue in the absorption-density relationship. However, Dense gradation exhibits lower porosity than gap gradation. It can be concluded that the obtained mathematical models may be implemented to predict the relationship between the durability parameters of roller compacted concrete in terms of porosity, absorption, and density with high coefficients of determination.

1. Introduction

Roller compacted concrete is the zero-slump concrete mixture, usually prepared at low cement content and low workability, and subjected to compaction by rollers to increase the density, improve the aggregate particles interlock. It is recommended for heavy duty pavement and can withstand harsh environment as reported by Sarsam, [1]. Nikkhah et al., [2] used the response surface methodology for designing roller compacted concrete. The dry density, permeable voids, and capillary absorption coefficients were determined at ages up to 180 days. Test results were subjected to the statistical analyses, the prediction models and contours of the durability characteristic and 28 days compressive strength were derived. Data were also subjected to the analysis of variance to estimate the significance of the factors. It was concluded that the cement and water content, and their interaction significantly influenced the responses of the dry density, water absorption and permeable voids. It was also noticed that by obtaining an optimum level of dry density, the lowest level of permeable voids and water absorption can be reached into the concrete. This could be achieved by adjusting the interaction of cement content and water content. However, no meaningful correlation was found between the dry density and capillary absorption coefficient. Fardin and Santos, [3] implemented the maximum dry density method to prepare roller compacted concrete mixtures with 200 kg/m³ of cement content. Four mixtures were produced with recycled coarse aggregates ratios (0, 5, 15, and 30) %. The compaction test, porosity, density, and water absorption tests were performed to analyze the physical properties of the mixtures. One-way Analysis of Variance (ANOVA) was implemented to identify the influences of recycled coarse aggregates on RCC properties. The porosity tends to affect the RCC negatively while the dry density tends to provide better values of compressive strength when it increases

when comparing the correlations between compressive strength and porosity. Poor correlation was observed between the porosity and dry density. Hashemi et al., [4] revealed that increasing the coarse to fine aggregates ratio from 0.6 to 1.2 significantly decreased the porosity of roller compacted concrete to about 60% when 9% cement was used and 38% when 12% cement was implemented. It was concluded that the most suitable coarse to fine aggregates ratio appeared to be from 1.2 to 1.4. It was recommended that a workable, high-strength and durable roller compacted concrete could be achieved when 12% cement and 1.2 aggregates ratio is employed. Shafigh et al., [5] investigated the variation between roller compacted concrete and normal vibrated concrete. It was revealed that the water absorption and porosity values of roller compacted concrete specimens is lower by about 8 % and 10.6 % in comparison with normal vibrated concrete. This points to better durability performance of roller compacted concrete. Yildizel et al., [6] investigated the durability properties of roller-compacted concrete. The water contents of the mixture were optimized with the maximum density method. Durability characteristics, such as water absorption rates were evaluated in the study. It was concluded that inclusion of calcium carbonate exhibited an improvement in the durability properties of the specimens. Vahidi et al., [7] applied the adaptive neuro-fuzzy inference system (ANFIS) model in predicting the permeability and compressive strength of roller compacted concrete. The obtained results shows that the predicted value by this model is in good agreement with the experimental, which shows the proposed model is a useful, reliable, and fast tool to predict the permeability and compressive strength with a mean relative error percentage of less than 1.1%.

The aim of the present investigation is to correlate the durability parameters of roller compacted concrete in terms of bulk density, porosity, and water absorption. It was felt that such correlation can be

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implemented for quick prediction of the expected durability of roller compacted concrete.

2. Materials and Methods

2.1. Portland Cement

Ordinary Portland cement (Type I) as per Iraqi specification No.5,[8] was implemented. The physical properties of the cement are listed in Table 1.

Table 1. Physical Properties of Portland Cement

Physical Properties	Test Result	Limits of Iraqi specification No.5 , [8]
Specific surface area, Blain's method, m ² /kg	341	≥ 230
Soundness, Autoclave's Method, %	0.03	< 0.8
Setting time, Vicat's method		
Initial setting hour : min	2:35	≥ 45 min
Final setting hour : min	4:45	≤ 10 hours
Compressive strength		
3 days N/mm ²	18.8	≥ 15
7 days N/mm ²	23.3	≥ 23

2.2. Coarse Aggregates

Crushed aggregates with 25.4 mm nominal maximum size were obtained from Nibae quarry. the properties of coarse aggregates are determined according to ASTM C127, [9]. Test results and listed in Table 2.

2.3. Fine Aggregates

Natural fine aggregate with 4.75mm maximum size was obtained from Al-Ukhaider region, the properties of fine aggregates is determined according to ASTM C128,[9] and demonstrated in Table 2.

Table 2. Properties of Coarse and Fine aggregates

Type of aggregate	Bulk Specific Gravity	Density (kg/m ³)	Absorption %	SO ₃ %
Crushed coarse aggregate	2.56	1600	1	0.06
Fine aggregate	2.45	1780	3.13	0.45

2.4. Water

Potable water of Baghdad area is used in RCC mixture preparation and Curing.

2.5. Preparation of Dense and Gap Graded Mixtures

The coarse and fine aggregates are washed, oven dried, then sieved to different sizes and stored in plastic containers. Aggregates were recombined to satisfy the requirements of gradation Gap and dense gradations with 25 mm nominal maximum size of aggregate. The dense gradation satisfies the Iraqi Standard Specification for Roads and Bridges SCRB, [10], while the gap gradation satisfies the British Standards B.S., 882,[11]. The grain size distribution of both mixtures is illustrated in Figure 1.

Figure 1. The Implemented Grain size distribution

The concrete mix is designed according to ASTM D-1557, [12] standard. This proportioning method involves establishing a relationship between the density and moisture content of the mix by compacting the mix in steel molds of 101.6 diameter × 116.4 high mm. Oven dried coarse and fine aggregates were implemented. Five different percentages of cement content are implemented (10, 12, 14, 16, 18) by weight of oven dried aggregate and six different percentages of moisture content of a range of (4 -8%) with 1% increment are implemented for determination of the dry density-moisture content relationships. After mixing thoroughly by hand, the mixture was poured into cylinder mold in five successive layers. Each layer had practiced 25 blows of the modified Proctor hammer with 4.5 kg weight, falling from 450 mm height according to ASTM D-1557,[12] (modified proctor) test method. Similar procedure was reported by Sarsam, [1]. A total of 48-cylinder samples were prepared and the dry density of each specimen was determined. The moisture-density relationship was obtained for each type of mixture. Details of proportioning can be referred to Sarsam et al., [13]. A moisture-density test is used to determine the optimum moisture content and maximum density of RCC mixtures for each mixture and the optimum cement content was selected to be 12 %. Details of mixture design can be referred at Sarsam, [14]. Specimens with (10, 12, and 16) % of Portland cement for each type of aggregates gradation were reserved for further investigation. The selected cement percentages represent low, medium, and high cement content from the roller compacted concrete point of view. Cylindrical specimens were withdrawn from the molds after 24 hours and subjected to curing for 28 days in a water bath at 20°C. Specimens were subjected to bulk density determination, and practiced porosity and absorption evaluation according to ASTM C642,[9]. Figure 2 exhibit part of the prepared cylindrical specimens. Table 3 exhibits the quantities of Materials Implemented for Roller Compacted Concrete.

Figure 2. Part of the prepared specimens

Table 3. Quantities of Materials Implemented for Roller Compacted Concrete

Gradation Type	Materials	Mix at 10% cement	Mix at 12% cement	Mix at 16% cement
Dense	Cement	233	287	364
	Water	163	144	182
	Fine aggregate	618	635	602
	Coarse aggregate	1712	1760	1670
Gap	Cement	233	282	380
	Water	163	164	166
	Fine aggregate	395	400	404
	Coarse aggregate	1930	1947	1970

3. Results and Discussions

3.1. Water absorption

Water absorption is an important property of roller compacted concrete which has an impact on the durability. The absorption characteristics of roller compacted concrete indirectly represent its porosity. It can be noted that all water absorption values of all RCC mixtures were between (3 and 9.5)%, while the range specified for average concrete is (3–5) % in accordance with ACI, [15]. Figure 3 exhibit the bulk density-absorption relationship of roller compacted concrete; linear mathematical models are applied; it can be observed that the absorption declines as the bulk density increases regardless of the gradation type of aggregates. This can be attributed to the fact that increasing the density is a result of lowering the permeable voids and the ability of the roller compacted concrete to absorb water. This may also be due to the limited pore connectivity and reduced porosity of the RCC mixes. It can be noted that the variation in the intercept which represent the absorption at low density between gap and dense gradation is not significant. However, the variation in the slope of the relationship which represent the rate of decline of absorption as the density increases, is also not significant.

Figure 3. Density – Absorption Relationship

It can be concluded that the gradation of aggregates is not significant in the absorption-density relationship. Test results does not agree with Nikkhah et al., [2]. However, the findings agree with the findings reported by Adamu et al., [16].

3.2. Porosity

Figure 4 demonstrates the porosity-bulk density relationship of roller compacted concrete. linear mathematical models are applied. It can be noticed that the porosity, which is the volume of permeable voids in concrete, also declines as the bulk density increases. Such behavior may be attributed to the closer of permeable voids as the density increases. Gap gradation exhibits higher intercept of 12 % as compared to that of dense gradation. However, the slope of the relationship of gap gradation is higher by 12.3 % than that of dense graded mixture. It can be revealed that dense gradation exhibits lower porosity than gap gradation. Such finding does not match with the results reported by Fardin and Santos, [3].

Figure 4. Density – Porosity Relationship

As demonstrated in Figure 5, the absorption is directly proportional to the absorption of roller compacted concrete.

Figure 5. Porosity – Absorption Relationship

It can be observed that dense gradation exhibits higher intercept value of 57.3 % than that of gap gradation. However, the slope of the relationship of dense gradation is lower by 13.5 % than that of gap gradation. Table 4 summarizes the mathematical models obtained for roller compacted concrete. Similar behavior was reported by Ashteyat et al., [17].

Table 4. Linear Mathematical Models for Roller Compacted Concrete

Mixture Type	Mathematical Models	Intercept	Slope	R ²
Gap Graded	% (Absorption) = 36.43 – 0.0141 (Density kg/m ³)	36.43	0.0141	0.937
Dense Graded	% (Absorption) = 36.55 – 0.0142 (Density kg/m ³)	36.55	0.0142	0.958
Gap Graded	% (Porosity) = 83.261 – 0.0318 (Density kg/m ³)	83.261	0.0318	0.924
Dense Graded	% (Porosity) = 74.305 – 0.0283 (Density kg/m ³)	74.305	0.0283	0.980
Gap Graded	% (Porosity) = 1.222 + 2.2527 (Absorption %)	1.222	2.2527	0.987
Dense Graded	% (Porosity) = 1.922 + 1.9477 (Absorption %)	1.922	1.9477	0.984

4. Conclusions

The following conclusions may be addressed based on the limitations of testing program and materials.

1- The water absorption values of all RCC mixtures studied ranges between (3 and 9.5)%. The gradation type of aggregates (gap or dense) is not significant in the absorption-density relationship.

2- The water porosity values of all RCC mixtures studied were ranging between (7.5 and 21) %. The dense gradation exhibits lower porosity than gap gradation.

3- For porosity-absorption relationship, dense gradation exhibits higher intercept value of 57.3 % than that of gap gradation. However, the slope of the relationship of dense gradation is lower by 13.5 % than that of gap gradation.

4- The obtained mathematical models may be implemented to predict the relationship between the durability parameters of roller compacted concrete with high coefficients of determination.

Declaration of Conflict of Interests

The author declares that there is no conflict of interest. He has no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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