Influence of Additives on Flexural Strength of Roller Compacted Concrete

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*Flexural Strength,
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Abstract

Roller compacted concrete is considered as a sustainable solution. In the present investigation, three types of additives namely (fly ash, fumed silica, and hydrated lime) are implemented as partial replacement of Portland cement for preparation of roller compacted concrete slab samples using dense and gap aggregate gradation. The slab samples were prepared at optimum cement requirement of 12 % and at (2 and 4) % cement below and above the optimum. Beam specimens of (38 x 10 x 8) Cm were extracted from the slab samples using diamond saw. The specimens were subjected to flexural strength determination using two testing modes, the three and the four points loading. It was noticed that the flexural strength under four-points loading mode is lower by a range of (0.787 to 0.732) folds than that under three-points loading mode for dense and gap graded mixtures respectively. It was concluded that the flexural strength increases by (96.2, 84, and 17.2) % and (109, 86, and 9.3) % after replacement of (10, 12, and 15) % of cement by hydrated lime while it declines by (50, 64.6, and 77) % and (0.1, 30.8, and 63.5) % after replacement of (5, 7, and 10) % of cement by fumed silica for dense and gap graded aggregates respectively. The flexural strength of dense graded mixtures increases by 63 % at 20 % replacement by fly ash, however, it increases by (99.7, 53.8, and 1.0) % after replacement of (10, 12, and 15) % of cement by fly ash for gap graded aggregates respectively.

1. Introduction

The flexural strength of rigid pavement is a major design parameter since it is subjected to repetitive fatigue loads and flexural stresses. Adamu et al., [1] incorporate additives such as polymers and fibers into the roller compacted concrete mixture to absorb the deformation and strain energy caused by the repetitive loadings, and to improve the flexural strength of the pavement. Nano silica was added by weight of cementitious materials at (1, 2, and 3) %. The addition of nano silica increases the flexural strength of roller compacted concrete and making the concrete more rigid. Saluja et al., [2] revealed that the flexural strength of roller compacted concrete mixture containing blast furnace slag of (20 and 60) % shows a decrease in flexural strength as compared to control roller compacted concrete mixture at all curing ages. Flexural strength gains from 28 days to 365 days in mix of blast furnace slag G50, GS20, GS40, and GS60 observed was (23.84, 33.40, 43.18, and 41.20) %, respectively. It was concluded that increasing the replacement level of cement with blast furnace slag results in a percentage increase in strength. Hesami et al., [3] investigated the impacts of coal waste powder, coal waste ash, and limestone powder on the mechanical properties of roller compacted concrete mixture. The mixtures were prepared by partial replacement of cement with the above cementitious materials at different replacement levels of (5, 10 and 20) %. The compressive strength, tensile strength, and flexural strength of roller compacted concrete mixtures were determined at (7, and 90) days. The test results showed that any further increase up to 20% substitution of cement with the supplementary cementitious materials decreased the strength values of the mixtures at all ages. Adamu et al., [4] used high-volume fly ash as partial replacement for cement to prepare roller compacted concrete mixture while nano-silica was used as an additive to cementitious materials. The mixtures were tested for compressive, flexural, and splitting tensile strengths. Replacing 53 % of cement with fly ash by volume and the addition of 1.2% of nano-silica by weight of cementitious materials can provide an optimized

mixture. However, such mixture exhibits lower compressive, tensile, flexural strength as compared to the control roller compacted concrete mixture. It was revealed that nano-silica partially ignited the pozzolanic activity of fly ash at early ages and can leads to higher performance of roller compacted concrete at early age. Ashteyat et al., [5] stated that increasing white cement bypass dust replacement ratio to more than 10% can result in degrading the mechanical properties (compressive strength, splitting tensile strength and modulus of elasticity) of mixtures. Zabihi and Nejad, [6] revealed that the flexural strength test results of roller compacted concrete indicate that adding polypropylene fiber causes improvement in flexural strength samples and more enhancement can be achieved in combination with pozzolanic materials. Samples containing polypropylene fibers and limestone powder has similar results to samples containing only propylene fiber. Samples containing polypropylene fibers and micro silica has the greatest increase in flexural strength compared to the control sample and it has 45% at the age of 90 days. Rahmani et al., [7] revealed that as the W/C ratio of roller compacted concrete pavement increases from 0.3 to 0.55, the flexural strength decreases by 35%. Increasing the C/A ratio from 12% to 17% in concrete resulted in an approximately 40% increase in flexural strength. Rooholamini et al., [8] evaluated the effect of macro-synthetic fibre on the mechanical properties of roller-compacted concrete pavement using response surface methodology and concluded that the Three-point bending test results showed that Macro-synthetic fibre has a very promising potential in improving flexural strength. Khed et al., [9] stated that the flexural strength of high-volume fly ash roller compacted concrete pavement decreased with increasing crumb rubber content as replacement of fine aggregate, while the addition of nano-silica increases the flexural strength. The variation between two modes of testing flexural strength was investigated by Kumar and Murthy, [10], it was revealed that in general, the fundamental differences are the location of the maximum bending moment and maximum axial stresses: the maximum stress occurs directly below the loading nose in three-point loading but is spread out over the area between the

loading noses in the four-point system. Brancheriau et al., [11] advises that the values obtained by one method of flexural testing cannot be directly compared with those of other methods and so the bending properties must be converted before using them and correctly compared with others from different references. Caviello et al. [12] performed various types of tests for determining the indirect tensile strength, including the Brazilian, and three and four-point bending tests. It was stated that three and four-points loading tests indicated acceptable standards in determining the bending strength of materials such as rocks, building materials, and concrete. Efe et al., [13] investigated the three- and four-points loading test for rock. It has been found that the dimensions of the test specimens play an important role in determining the value of the flexural strength. It was concluded that four-point bending test is more suitable for determining of indirect tensile strength of marble. According to the results obtained from this study, it is suggested that new scientific studies, including correction coefficients, should be carried out on more rock types to be able to estimate tensile strengths from bending experiments.

The aim of this investigation is to assess the influence of implementing additives (fly ash, fumed silica, and hydrated lime) as partial replacement of Portland cement on the flexural strength of roller compacted concrete prepared with dense and gap graded aggregates. The effect of testing mode (three and four points loading) on flexural strength will also be verified. Mathematical models relating the flexural strength under four points loading with that under three points loading for dense and gap graded mixtures will be developed.

2. Materials and Methods

2.1. Portland Cement

Type 1 Ordinary Portland cement was implemented, it complies with Iraqi specification No.5, [14]. The physical properties of the Portland cement are listed in Table 1.

Table 1. Physical Properties of the Portland Cement

Physical Properties	Test Result	Limits of Iraqi specification No.5 , [14]
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 and Fine Aggregates

Crushed coarse aggregates with 25.4 mm nominal maximum size were implemented. It was obtained from Nibae quarry. the properties of coarse aggregates are tested according to ASTM C127, [15]. Fine aggregate with 4.75mm maximum size was obtained from Al-Ukhaider region, the properties of fine aggregates are evaluated according to ASTM C128, [15]. The test results and listed 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

2.3. Fumed Silica

Fumed silica is produced by a vapor-phase hydrolysis process using chlorosilanes such as silicon tetrachloride in a flame of hydrogen and oxygen. Fumed silica is supplied as a white, fluffy powder, and obtained from local markets with 10 kg in one sack. Physical properties of fumed silica are listed in Table 3.

Table 3. Physical Properties of Fumed Silica as supplied by the Manufacturer.

Physical Properties	Test result
Specific surface area m ² /kg	170000-230000
Density kg/m ³	202
SiO ₂ % (when firing at 1000°C for 2 hours)	> 99.8
Loss of weight% when drying at 1000°C for 2 hours	< 2
Loss of weight% when drying at 105°C for 2 hours	< 1.5
PH	3.9-4.3
% Retained on 40 µm sieve	< 0.04
Moisture %	0.82

2.4. Fly ash

The coal fly ash was obtained from local market; Table 4 demonstrates its physical properties.

Table 4. Physical Properties of Fly Ash

Maximum Sieve size (micron)	% Passing	Specific gravity	Specific surface area (m ² / kg)
0.075	98	2.645	650

2.5. Hydrated Lime

Hydrated lime was obtained from local market. The physical properties of hydrated lime are shown in Table 5.

Table 5. Physical Properties of Hydrated Lime

Chemical Formula	Appearance	Density gm/cm ³	Specific surface area m ² /kg	% Passing Sieve No. 4
Ca(OH) ₂	White powder	2.211	4404	100

2.6. Water

Potable water of Baghdad area was implemented in roller compacted concrete RCC mixture preparation and Curing.

2.7. Preparation of Dense and Gap Graded Concrete Mixtures

The fine and coarse aggregates are oven dried, then separated to different sizes by sieving, and stored in plastic containers. The Aggregates were recombined to satisfy the requirements of dense and gap gradations with 25 mm nominal maximum size of aggregate. The gap gradation satisfies the British Standards B.S., 882, [16]. However, the dense gradation satisfies the Iraqi Specification for Roads and Bridges, SCRB, [17]. The grain size distribution of both mixtures is illustrated in Table 6.

Table 6. Grain size distribution Implemented.

Sieve size (mm)	Percent finer by weight	
	Dense gradation	Gap gradation
25.4	100	100
19.2	98	95
12.5	85	80
9.5	76	75
4.75	62	70
0.6	26	17
0.075	7	7

The concrete mixture is prepared according to ASTM D-1557, [18] (modified proctor) standard. This proportioning method involves establishing a relationship between the moisture content and dry density of the mixture. Oven dried fine and coarse aggregates were implemented. Various percentages of water and cement content are implemented for determination of the dry density-moisture content relationships. The range of cement percentages is (10 -18) with 2 % increment by weight of oven dried aggregate while the range of water content is (4 -8%) with 1% increment. Similar procedure was implemented by Sarsam, [19]. The optimum Portland cement content was selected to be 12 %. Details of the proportioning could be found in Sarsam et al., [20]. Three types of additives (fumed silica, hydrated lime, and fly ash) have been implemented with three percentages for each as partial replacement of Portland cement. Details of optimizing the additives percentages could be referred at Sarsam, [21]. Specimens with (10, 12, and 16) % of Portland cement for each type of additive and aggregates gradation were prepared for the present investigation.

2.8. Preparation the Roller Compacted Concrete Samples

The mold used to prepare roller compacted slab samples has internal dimensions of (38 x 38 x 10) cm while the roller has (16cm) diameter and (33cm) length and its self-weight was 36 kg. The required weight of the mixture of aggregates, cement, water, and additives for compacting a slab sample to the target density was combined, mixed, and placed in the mold of size (38x 38 x 10) cm and subjected to initial compaction on a vibrating table for 3 cycles of 30 seconds time interval. Then, the mold was placed in front of the roller compactor and subjected to three stages of rolling based on the work done by Sarsam [19]. Each rolling stage was conducted by applying 10 passes of the roller for each rolling direction. This number of passes was felt to be suitable to achieve the good rolling with lowest labor power. The first stage represents the primary compaction which was performed by applying 10 passes with 1.1 kg/cm width load for each direction. The second stage represents the breakdown compaction which was conducted by applying 10 passes using a load of 3.2 kg/cm width for each direction. The third stage represents the final compaction which is demonstrated by application of 10 passes of the roller compactor under 5.3 kg/cm width load for each direction. The rolling process is shown in Figure 1.

Figure 1. Roller Compaction Process

After finishing the rolling, the prepared slab samples were covered tightly with polythene sheet and left to cure for 24 hours at room temperature of $30 \pm 2^\circ\text{C}$. The samples were withdrawn from the mold and immersed in a water bath for 27 days for curing at $30 \pm 2^\circ\text{C}$. Sawed beam specimens of size (38 x 10 x 8) cm were obtained from the roller compacted slab with the aid of diamond saw according to the procedure by ASTM C78, [15]. The specimens were subjected to flexural strength determination using two testing modes, the first mode is the three points loading, while the second mode is the four points loading. Figure 2 exhibit the flexural strength testing modes. The testing for flexural strength was conducted after 28 days curing according to ASTM C-78, C-293, [15].

Figure 2. Flexural Strength Testing Modes

3. Results and Discussions

3.1. Influence of Additives on Flexural Strength

Figure 3 exhibit the influence of gradation type and additives on flexural strength of roller compacted concrete tested with the three points loading scheme. It can be noticed that for control mixture, the flexural strength increases as the cement content increase regardless of the aggregate's gradation type.

Figure 3. Influence of Gradation Type and Additives on Flexural Strength of Roller Compacted Concrete

The flexural strength of dense graded mixtures is higher than that of gap graded mixtures by (39.5, 37.8, and 20) % for mixtures with (10, 12, and 16) % cement content respectively. However, the flexural strength increases by (16.6, and 50) % when the cement content rises from (10 to 12 and 16) % for dense graded mixture while, the flexural strength

increases by (18, and 74.4) % when the cement content rises from (10 to 12 and 16) % for gap graded mixture. Such behavior is attributed to the increase in cementation and bonding between the aggregates particle's the cement binder increases. When fumed silica was implemented as partial replacement of Portland cement, the flexural strength declines as the percentage of replacement increases regardless of the aggregate's gradation type. Similar behavior was reported by Ashteyat et al., [5]. The flexural strength decreased by (50, 64.6, and 77) % and (0.1, 30.8, and 63.5) % after replacement of (5, 7, and 10) % of cement by fumed silica for dense and gap graded aggregates respectively. this may be attributed to the high specific surface area of fumed silica which is higher than that of cement by many folds, it absorbs most of the water required for hydration of cement. However, gap graded mixtures exhibit higher flexural strength than dense graded mixtures after replacement of cement with fumed silica. Such behavior agrees well with Adamu et al., [1].

When hydrated lime was incorporated for replacement of cement, the flexural strength increases regardless of the gradation type or replacement percentages. The flexural strength increases by (96.2, 84, and 17.2) % and (109, 86, and 9.3) % after replacement of (10, 12, and 15) % of cement by hydrated lime for dense and gap graded aggregates respectively. Dense graded mixture exhibits higher flexural strength than gap graded mixture after partial replacement of cement with lime. This could be attributed to the chemical reaction of the lime which provide extra cementation and bonding in the structure of aggregates. However, as the lime content increases, the tensile strength declines. This may be attributed to the extra fine particle in the mixture since the specific surface area of lime is higher than that of cement by 13 folds. When fly ash was incorporated for replacement of cement, the flexural strength of dense graded mixtures increases by 63 % at 20 % replacement by fly ash while it declines by (0.1 and 34.5) % at (30 and 40) % replacement. Test results agrees with the behavior of fly ash as reported by Adamu et al., [4]. However, the flexural strength increases by (99.7, 53.8, and 1.0) % after replacement of (10, 12, and 15) % of cement by fly ash for gap graded aggregates respectively. This could be related to the finer particle and higher specific surface area of fly ash in the mixture than that of cement. Similar behavior of coal ash was reported by Hesami et al., [3] and Khed et al., [9].

3.2. Influence of Testing Mode on Flexural Strength

The four-points loading test scheme is recommended for concrete and other composite materials. However, in the present investigation, both three- and four-points loading test scheme have been adopted to study the flexural properties of roller compacted concrete. Three-point loading strength and four-point loading strength tests are direct methods for measuring the flexural strength as well as an indirect method which are used in determination of the tensile strength as mentioned by Brancheriau et al., [11]. Figure 4 demonstrates the influence of additives and testing mode on the flexural strength of dense graded roller compacted concrete. It can be observed that the three points loading scheme exhibits higher flexural strength than that of four points loading scheme regardless of the type of additives implemented. The flexural strength increases as the Portland cement content increase for both testing schemes. When fumed silica was implemented for partial replacement of cement, the flexural strength declines as the replacement percentage increases. For hydrated Lime incorporation for partial replacement of cement, the flexural strength exhibits significant improvement as compared with the control mixture.

Figure 4. Influence of Testing Mode on Flexural Strength of Dense Graded Mixtures

Twenty percent replacement of Portland cement with hydrated lime exhibits the highest flexural strength among other additives regardless of the testing scheme. When the fly ash was incorporated for partial replacement of Portland cement, the flexural strength exhibits no significant changes as compared with the control mixture and it declines with the increment of replacement of cement.

Figure 5 exhibits the influence of additives and testing mode on flexural strength of gap graded roller compacted concrete. Similar behavior regarding the variations in flexural strength with the additives and loading scheme could be noticed. The three points loading scheme also exhibits higher flexural strength than that at four points loading scheme. Significant improvement in the flexural strength property of roller compacted concrete could be noticed when lime or fly ash are implemented as partial substitute of Portland cement. 20 % of hydrated lime and 20 % of fly ash exhibits the best additives percentages for partial replacement of cement and shows the highest flexural strength for gap graded roller compacted concrete. This behavior could be attributed to the fact that for the points loading scheme, the shear stress is present in the concrete specimen except on the vertical plane containing the central loading nose. However, for the four points loading scheme, there is no shear stress in the region between the two loading noses, while the shear exists outside this central region. On the other hand, concentrated compressive loading is applied on the specimen in case of three points loading, while such compressive stresses are distributed and reduced in case of four points loading as revealed by Efe et al., [13].

Figure 5. Influence of Testing Mode on Flexural Strength of Gap Graded Mixtures

Figure 6 demonstrates the relationship of both testing schemes on flexural strength of roller compacted concrete.

Figure 6. Influence of Testing Mode on Flexural Strength

It can be detected that the three-point loading mode exhibit higher flexural strength when compared with the four-points loading mode regardless of the aggregate's gradation type. However, dense graded mixtures exhibit higher flexural strength as compared with the gap graded mixtures. The flexural strength under four-points loading mode is lower by a range of (0.787 to 0.732) folds than that under three-points loading mode for dense and gap graded mixtures respectively. Table 7 presents a summary of the mathematical models of flexural strength testing modes.

Table 7. Mathematical Models for Flexural Testing Mode

Aggregates Gradation Type	Mathematical Model	R ²
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Dense Graded	Flexural strength (four point) = 0.339 + 0.787 Flexural strength (three point)	0.95
Gap Graded	Flexural strength (four point) = 0.310 + 0.732 Flexural strength (three point)	0.92

4. Conclusions

Based on the testing program and the limitations of materials, the following conclusions can be addressed.

- The flexural strength of dense graded mixtures is higher than that of gap graded mixtures by (39.5, 37.8, and 20) % for mixtures with (10, 12, and 16) % cement content respectively.
- The flexural strength decreased by (50, 64.6, and 77) % and (0.1, 30.8, and 63.5) % for replacement of (5, 7, and 10) % of cement by fumed silica for dense and gap graded aggregates respectively.
- The flexural strength increases by (96.2, 84, and 17.2) % and (109, 86, and 9.3) % for replacement of (10, 12, and 15) % of cement by hydrated lime for dense and gap graded aggregates respectively.
- The flexural strength of dense graded mixtures increases by 63 % at 20 % replacement by fly ash while it declines by (0.1 and 34.5) % at (30 and 40) % replacement. However, the flexural strength increases by (99.7, 53.8, and 1.0) % for replacement of (10, 12, and 15) % of cement by fly ash for gap graded aggregates respectively.
- The flexural strength under four-points loading mode is lower by a range of (0.787 to 0.732) folds than that under three-points loading mode for dense and gap graded mixtures respectively.
- Hydrated lime and fly ash are recommended as additives for partial replacement of cement in roller compacted concrete from flexural strength point of view.

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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