Effect of Hydrated Lime on the Properties of Roller Compacted Concrete

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ABSTRACT

Roller compacted concrete (RCC) is a concrete of no slump, no reinforcement, no finishing, and compacted using vibratory roller. When compared with conventional concrete, it contains less water content when compared to traditional concrete. The RCC technique achieves significant time and cost savings during the construction of concrete. This study demonstrates the preparation of RCC slab of (38 ×38× 10) cm samples by using roller compactor which is manufactured in local markets. The Hydrated lime additive is used to study the mechanical and physical properties of that RCC slab samples. This investigation is divided into two main stages: The First stage consists of hammer compaction method with two gradation of aggregate, dense and gap graded aggregate, using five percentages of cement content (10, 12, 14, 16, and 18) as a percentage of the total aggregate content. This stage is carried out for selecting the maximum dry density, optimum moisture content, and optimum cement content which is utilized in RCC slab samples construction, a total of 49 cylinder samples sized (10 cm diameter and 11.6 cm high) are prepared.

The Second stage is classified into two sub stages; the first one consists of constructing RCC slab samples using roller compaction, 12% cement as a percentage of total aggregate weight has been used according to the data obtained from first stage, this group presents reference mixes without additives. While the second sub stage presents RCC mix with hydrated lime additive and with the same gradation of mixes compact by hammer compaction method, hydrated lime was implemented as (5, 10, 12, and 15) percentage as a partial replacement of cement content. Both of physical and mechanical properties of RCC are studied using cores, sawed cubes, and sawed beams obtained from RCC slab samples. The properties studied were porosity, absorption, and compressive strength, splitting tensile strength and flexural strength by using third point loading method. The results show that hydrated lime improved the overall properties of RCC as compared to reference mix. Mixes with 5% lime give the optimum values for most of strength properties. Dense graded mixes with hydrated lime show superior properties as compared to gap graded mixes.

Keywords: Additives, compressive strength, dense and gap gradations, hydrated lime, porosity, roller compacted concrete, RCC slabs.

الخلاصة

الخرسانه المرصوصه بالحدل هي خرسانه عديمة الهطول لاتحتاج الى حديد تسليح او عمليات انهاء وترص بأستخدام الحادلات الهزازه، عند مقارنتها بالخرسانه التقليديه فإنها تتميز بأن محتوى الماء قليل للحصول على خرسانه عديمة الهطول. هذا النوع من الخرسانه يقلل من فترة انجاز العمل وكلفة التنفيذ (معهد الخرسانة الاميركي، لجنة 211-3ر 1997). تعرض هذه الدراسه تنفيذ بلاطات من الخرسانه المرصوصه بالحدل بأبعاد (38×38×10) سم باستخدام جهاز حدل صنع محليا وباستخدام مضاف النوره المطفأه لغرض دراسة الخواص الفيزيائيه و الميكانيكيه لنماذج البلاطات هذه.يتضمن الجزء العملي مرحلتين أساسيتين هما:-

المرحله الأولى تتضمن تصميم الخلطات باستخدام طريقه الرص بالمطرقة وباستخدام تدرجين من الركام هما العالي الكثافه والتدرج المنقطع التسلسل وباستعمال خمس نسب سمنت هي (10، 12، 14، 16و 18) كنسبه مئويه من الوزن الكلي للركام .هذه المرحله نفذت لاختيار الكثافه الجافه القصوى، محتوى الماء الامثل و محتوى السمنت الامثل والتي تستخدم في تنفيذ بلاطات الخرسانه المرصوصه بالحدل، حيث تم عمل 49 نموذج بأبعاد (10سم قطرا و11,6 سم ارتفاعا) بأستخدام هذه الطريقه.

المرحله الثانيه: قسمت هذه المرحله الى مجموعتين ثانويتين هما: المجموعه الأولى تشمل إنشاء بلاطات من الخرسانة المرصوصة بالحدل وترص بأستعمال الحادله لتشابه ظروف الموقع، في هذه المرحله تم اختيار نسبة السمنت المثاليه 12 كنسبه مئويه من الوزن الكلي للركام والتي تم الحصول عليها من المرحله الاولى ولنوعي التدرج السابقين لغرض دراسة سلوك وخواص الخرسانه المرصوصه بالحدل بدون إضافات تحت تأثير نسبة السمنت هذه.

اما المجموعه الثانيه فتمثل تصميم خلطات الخرسانه المرصرصه بالحدل وبوجود مضاف النوره المطفأه كجزء مستبدل من وزن السمنت وبالاعتماد على نسبة سمنت 12٪ فقط ولنفس تدرجات الركام السابقه المستعملة في طريقة الرص بالمطرقه، تم استخدام المضاف كجزء من وزن السمنت وبنسب (5٪، 10٪، 12٪، 15٪). تم دراسة الخواص الفيزيائيه و الميكانيكية للخرسانة المرصوصة بالحدل باستعمال عينات من اللباب والمكعبات والاعتاب استخرجت من بلاطات الخرسانه المرصوصه بالحدل، و الخواص التي تم دراستها شملت المسامية، الامتصاص، مقاومة الانضغاط ، ومقاومة شد الانفلاق، ومقاومة الانثناء باستخدام ثلاث نقاط للتحميل.
بينت النتائج إن مادة النوره المطفأة تحسن من خواص الخرسانه المرصوصه بالحدل، كما تبين إن افضل نتائج يمكن الحصول عليها عند نسبة نوره 5٪ من وزن السمنت. إن الخلطات ذات تدرج عالي الكثافه والحاويه على مضاف النوره تعطي نتائج جيده مقارنة بالخلطات ذات النواقص في التدرج.

INTRODUCTION

Roller Compacted Concrete (RCC) takes its name from the construction method used in concrete placement; RCC is being used in many parts of the world such as Canada, U.S.A., and France, Vorobieff and Whitaker (2003).

ACI committee 211-3R-(1996) define RCC as "concrete compacted by roller compaction; concrete that in it's unhardened state that is transported, placed, and compacted using earth and rock fill construction equipment". The use of RCC as a material to construct pavement was stated in 1970 in Canada, it was originally used by the logging industry to provide an all-weather platform for unloading logging trucks and storing and sorting logs, Piggott (1999). Most of the investigations in Iraq have studied the behavior and properties of RCC usually used in dams, but no wide investigation has been carried out on using this new concrete in pavements design and construction. RCC has been used in Iraq in mid-eighties below the foundations of the medical drug factory near Mosul and also in the AL-Adaim Dam, Ahmed (2001). Another reported use was in the construction of extra lane for Mosul- Duhok highway during 1988, Sarsam (1988).In comparing RCC with conventional slump concrete, less water is needed to achieve a no slump concrete; therefore, less cement is required to produce an equivalent water to cement ratio. Less water in the mixture leads to less shrinkage and no bleeding water, and less cement is one means of reducing thermal induced cracking, Hansen (1996). Roller compacted concrete for pavement (RCCP) mixes compared with conventional concrete contain larger sized fine aggregate to ensure a uniform concrete mix with less surface voids.

The use of the additives such as pozzolana, lime, slags…..etc. as a partial replacement of cement had improved the properties of RCC; Rodrigues (2002) showed that the pozzolanic materials type serves some purposes as a partial replacement for cement to reduce heat generation; to increase the compressive strength at later ages; to improve the durability; to reduce the cost and; as a mineral addition to the mixture to provide fines to improve workability. The development of RCC causes a major shift in United state American, Japan and other countries; mainly for the construction of water control structures (dams) and pavements, while the same term is used to describe both types of concrete, the design and construction processes are different as shown in **Table (1),** Gupta (2004).

MATERIALS CHARACTERISTICS

1. Cement

Ordinary Portland cement (Type I) named Tasluja cement. The chemical compositions and physical properties of cement are presented in **Tables (2)** and **(3)**. The test results have shown that the cement conforms to the provisions of Iraqi specification No.5 (1984). Chemical compositions and physical properties are tested at The National Center Construction Laboratories, while the main compounds are calculated by using Bogue equations.

2. Coarse Aggregate

Crushed aggregate with 1″ (25.4mm) maximum size is used and obtained from Nibaai region, the properties of coarse aggregate is determined according ASTM C127-(2001) except SO_3 content, which was tested at The National Center Construction Laboratories. Test results are shown in **Table (4)**.

3. Fine Aggregate

Natural fine aggregate with 4.75mm maximum size is obtained from Al-Ukhaider region, the properties of fine aggregate is determined according to ASTM C128-(2001) except SO_3content, which was tested at the National Center Construction Laboratories and given in **Table(4)**.

4. Hydrated Lime

Hydrated lime is a derivative of burnt lime. It is produced by reacting burnt lime with water in a continuous hydrator, during this process, large amounts of heat are given off.

This material is available in local markets with low cost and is manufactured at Ad factory in Iran. Hydrated lime is light and fluffy and used as an additive (filler) and also as partial replacement of cement in this work. Chemical composition was tested at the laboratories of General Directorate of Geological Survey and Mining and given in **Table (5)**.

5. Preparation of Dense and Gap Gradations

The gradation of aggregate is defined as the frequency of a distribution of the particle size of a particular aggregate**,** Rached and et al (2009).

The gradation determine the paste requirement for a workable concrete since the amount of void requires needs to be filled by the same amount of cement paste in a concrete mixture. Dense graded aggregate is desirable for making concrete, as the space between larger particles is effectively filled by smaller particles to produce a well-packed structure. Gap graded aggregate is defined as a gradation at which one or more intermediate fractions are omitted.

The coarse and fine aggregates were sieved to different separate fraction sizes (seven sieves in this work) and combined to satisfy the requirements of gradation, dense gradation with 1″ (25mm) maximum size of aggregate represents the average requirement of Iraqi Standard Specification for Roads and Bridges SCRB (2004), while the gap gradation with also 1″ (25mm) maximum size aggregate represents the average requirements of British Standards B.S. (1961). The overall grain size distribution used is illustrated in **Table (6)**.

PREPARATION OF RCC SLAB SAMPLES

1. Preparation the Roller Compactor and Mould:

The roller compactor manufactured in local workshop was used throughout this investigation. It consists of a roller with (16cm) diameter and (33cm) length and its self-weight was 36 kg, while the steel mould used in this investigation was manufactured also at local workshop. It consists of four sides made from steel angle section, and base plate which has (1cm) thickness**.** The internal dimensions of the mould are (38× 38 ×10) cm. The roller compactor and mould are shown in **Figure (1)**.

2. Mix Proportioning Techniques of RCC

Mixture proportioning techniques of using modified soil compaction, optimum moisture content and maximum dry density, was implemented, such procedure correlates well with the work by Sarsam (2002). In this method, the overall combined gradation of aggregate which is suitable for base layers of the pavement is implemented. A number of concrete mixtures varying in cement and water content are prepared by using modified compaction as per ASTM D1557-(2002). The dry density-water content curve is plotted for each percentage of cement as shown in **Figure (2),** then the optimum water and cement content which give the maximum dry density is adopted as an initial design mix. Five different percentage of cement content were used in this work, (10, 12, 14, 16, 18) by weight of air dried aggregate for each gradation type (dense and gap). Different percentage of moisture content with a range of (4 –11%) of air dried aggregate weight with 1% increment were added; These percentages of moisture content are applicable for each percentage of cement content to determine the dry density-moisture content relationships. The samples were compacted using the modified hammer and steel cylinder mold of size 10cm diameter and 11.6cm high for determining maximum dry density. The mixture is placed by filling the cylinder mold in three layers and compacting each layer with 56 blows of a modified proctor hammer (4.5kg falling from 45cm high), when compaction is finished, the extension collar is removed and the surface of concrete was leveled with the mold. The wet density was calculated using eq. (1), and then the dry density was obtained using eq. (2), ASTM C-1557 (2008).

$$\gamma_{wet} = \frac{W_m}{V} \qquad (1)$$

Where:

γ_{wet}= the wet density (gm/cm³),
W_m = the wet weighting of material (gm),
V = the volume of the cylinder mold (cm³)

$$\gamma_d = \frac{\gamma_{wet}}{1+w} \qquad (2)$$

Where:

γ_d = the dry density (gm/cm³),
ω = the moisture content (%).

After determinations of the dry density for each percentage of moisture content and the five

Percentages of cement content, it can be noticed from **figures (2)** that the maximum dry density is at cement contents of 12% and 18% of total dry aggregate weight for dense and gap graded respectively. For mix proportion of RCC slab samples with and without additive, it was felt that cement content of 12% of total dry aggregate weight for two gradations is suitable and economical for design. **Table (7)** gives the proportions of mixes used.

3. Determination of the Effect of Hydrated Lime on RCC Mixes

Hydrated lime as a partial replacement of cement content was used to study the effect of this additive on the properties of RCC slab samples, four percentages of lime were used depending on trial mortar mixes. the compressive strength of these mortar mixes contains hydrated lime and compressive strength of cement paste without hydrated lime at 7 and 28 days were compared, **Table (8)** gives the percentages of hydrated lime used with RCC mixes.

4. Construction of RCC Slab Samples

The mixture was placed in the mold of size (38× 38 × 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 machine as shown in **Figure (3)** and subjected to three stages of rolling as described below, based on the work done by Sarsam (2002). 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 of the machine with weight only 1.1 kg/cm width (36 kg of roller compactor weight) for each direction.

The second stage represents the breakdown compaction by applying 10 passes using a load of 3.2kg/cm width (by using 69kg standard loads plus roller compactor weight) for each direction; this stage can represent the compaction applied by steel and pneumatic type roller in the field.

The third stage represents the final compaction which is demonstrated by application of 10 passes of the roller compactor under 5.3kg/cm width load (by using 138kg standard loads plus roller compactor weight) for each direction. This stage represents the finishing compaction in the field.

5. Curing

After finishing the rolling,, the rolled compacted samples were covered tightly with polythene sheet and kept for 24 hours at room temperature of 32±3˚c for initial setting, then, the samples are withdrawn from the moulds and immersed in a water bath for 27 days for curing at 32±3˚c.

DETERMINATION OF PHYSICAL AND ENGINEERING PROPERTIES RCC SLAB SAMPLES

Sawed beams, cores and sawed cubes were obtained from RCC slabs by using the procedure of ASTM C42/C42M-(2003). The specimens were subjected to physical properties determination as explained below.

1. Porosity Test

Porosity represents the volume of permeable pores (voids). This test was carried out using cores (6.2cm diameter and 10cm high) according to ASTM C642-(1997) and eq. (3). The average porosity of three samples was recorded.

$$V = \frac{C - A}{C - D} \times 100 \quad (3)$$

Where:
V = Volume of permeable pore space (voids) or (porosity), %
A = mass of oven-dried sample in air, gm.
C = mass of surface-dry sample in air after immersion and boiling, gm.
D = apparent mass of sample in water after immersion and boiling, gm.

2. Water Absorption Test

According to ASTM C642-(1997), the water absorption test is carried out using cores (6.2cm diameter and 10cm high), and the average water absorption of three samples was recorded by using eq. (4).

$$\text{Absorption after immersion, \%} = \frac{B - A}{A} \times 100 \quad (4)$$

Where:

A = mass of oven-dried sample in air, gm.
B = mass of surface-dry sample in air after immersion, gm.

3. Compressive Strength

sawed cube samples of size (10 × 10 × 10) cm were used for determining the compressive strength at 28 days age according to B.S.1881 part 116 (1983). The compressive strength is determined by using eq. (5).

$$f_c = \frac{P}{A} \qquad (5)$$

Where:
fc = compressive strength, psi (MPa),
P = maximum applied load indicated by the testing machine, lb.f (N), and
A = area exposed for load, in² (mm²).

4. Splitting Tensile Strength

The splitting tensile strength was carried out on core specimens according to ASTM C496-(2002). Cores has dimensions of (2.5″ (6.2cm) diameter and 4″ (10cm) high) were used in this test. Eq. (6) was used to determine the splitting tensile strength**:**

$$T = \frac{2P}{\pi d L} \qquad (6)$$

Where:
T = splitting tensile strength, psi (MPa),
P = maximum applied load indicated by the testing machine, lbf (N),
L = length, in. (mm), and
d = diameter, in. (mm).

5. Flexural Strength

Sawed beams of sizes (38 × 10 × 8) cm obtained from each slab sample are tested using third- point loading of simple beam according to ASTM C78-(2003), eq.(7) was used to determine the flexural strength property.

$$R = \frac{P L}{b d^2} \qquad (7)$$

Where:
R = modulus of rupture, psi, or MPa,
P = maximum applied load indicated by the testing machine, lbf, or N,
L = span length, in., or mm,
b = average width of specimen, at the fracture, in., or mm, and
d = average depth of specimen, at the fracture, in., or mm.

DISCUSSIONS ON TEST RESULTS

1. Porosity of RCC Samples:

The change of porosity of RCC with hydrated lime is shown in **Figure (4)**. It can be noticed that the presence of this material does not has a constant trend, this leads to decrease porosity at some ratios of lime/cement and increase it in other ratios, it can be seen in the same figure that all percentages of lime give porosity better than reference mix with 12% cement content because these materials work as fillers and partially replaces cement. Lime has high surface area that leads to decrease in voids in the mixes and reduce the porosity, but this effect is changeable and had reliance on the percentage of additive. The lowest value of porosity is achieved in mixes at 5% lime for dense and gap graded and decreases by about 13.85 % and 23.7% respectively than reference mixes with 12% cement content. The porosity of mixes with dense graded aggregate is less by 8.4% than porosity of mixes with gap graded aggregate at 5% hydrated lime

2. Absorption of RCC Samples:

Results of the effect of mixing hydrated lime on absorption of RCC with two gradations of aggregate are presented in **Figure (5)**. These results have shown that the absorption trend was the same as for porosity. For dense graded mixes, the lowest value of absorption was in the mix with 5% lime and decreases about 6.7% from reference mix (mix with 12% cement content), after that the absorption increases with increasing lime/cement ratio. The rate of increase at 10% lime mix reaches to 2.5% than reference mix, then decreases again until reaching second lower value of absorption at 12% lime, and then increases with further increase of lime. In gap graded mixes, the absorption trends are as in dense mixes but all lime/cement ratios lead to absorption less than reference mix. The rate of decrease reaches to 24.3% at 5% lime mix and 19.8% at 12% lime mix as compared to reference mix. Dense mixes show higher absorption (4.1% and 2.1%) than gap mixes at 5% and 12% hydrated lime respectively.

3. Compressive Strength of RCC Samples:

The effect of hydrated lime on compressive strength of dense and gap RCC mixes is presented in **Figure (6)**. It can be seen that the effect of lime is changeable on

compressive strength. The compressive strength increases with increasing lime/cement ratio until reaches an optimum value at 5% lime. This increase may be attributed to that the lime at this ratio of replacing worked as a filler material and fill the voids in the mixture so that it leads to increase the compressive strength, then decreases with further increasing lime content. Hydrated lime has low specific gravity (2.3) than cement (3.15) and that causes reduction in compressive strength, after that it increases again and has the second optimum value at 12% lime, that may be attributed to that the lime $Ca(OH)_2$, when mixed with cement, reacts with carbon dioxide CO_2 from atmosphere, and results calcium carbonate $CaCO_3$ which is sediments in voids in the mixture, then increases the compressive strength. Compressive strength decreases with further increasing of lime more than 12%. From the same figure, it can be seen that the gradation of aggregate does not have a constant effect on RCC mixes with hydrated lime. At 5% lime, gap mixes show high compressive strength with slightly higher value than dense mixes. This variation reaches to 1.4% at 5% lime, but after this ratio of lime, Dense mixes shows higher compressive strength (44% and 22%) than gap mixes at 10% and 12% lime respectively. After 12% lime, gap mixes give again higher compressive strength by 5% as compared to dense mixes at 15% lime.

4. Splitting Tensile Strength of RCC Samples:

Figure (7) shows that the splitting tensile strength of RCC mixes increases as lime/cement ratio increases for both gradation of aggregate until reaches an optimum value at 5% lime, then decreases. The rate of increase at 5% lime is 150% for both dense and gap mixes. The decrease in splitting tensile strength continues until reaches the lowest tensile strength at 10% lime, then increases again and reaches to second high value of splitting tensile strength at 12% lime, then decreases again with further increasing of lime content.

Dense mixes give higher splitting tensile strength than gap mixes at lime/cement ratio of approximately 7.5%, up to this ratio; gap mixes give higher splitting tensile strength than dense mixes. It can be seen that dense mixes at 5% lime show higher tensile strength (8.76%) than gap mixes, but at 12% lime, gap mixes have higher splitting tensile strength (7.78%) than dense mixes. It was noticed that the splitting tensile strength for RCC mixes with 5% lime is 20% and 18% of compressive strength, and it is 46.4% and 74.7% of flexural strength for dense mixes and gap mixes respectively, such results are in agreement with Sarsam (2002).

5. Flexural Strength of RCC Samples:

Figure (8) show the flexural strength of RCC mixes containing different percentages of hydrated lime. It can be noticed that flexural strength for dense mixes has similar trends as compressive strength and there are two optimum value of flexural strength at 5% and 12% lime. This may be attributed to the same reasons explained in compressive strength item. The rate of increase in flexure strength as compared to reference mix is 96.3% for mixes at 5% and 12% lime.

As seen from the same figure, gap mixes show that the flexural strength increases with increasing lime/cement ratios until reaches an optimum value at 5% lime then decreases with increasing lime/cement ratios, the rate of increase in the mix with 5% lime as compared to reference mix (at 12% cement content) reaches to 86.36%.

Mixes with dense graded aggregate give higher flexural strength than mixes with gap graded aggregate and for all percentages of lime. The variation is 62% at mixes with 5% lime, the flexural strength for RCC mixes contain 5% hydrated lime is 36.4% and 22.2% of compressive strength for dense mixes and gap mixes respectively, such results are in agreement with Sarsam (2002) work.

CONCLUSION

1. The lowest porosity and absorption for dense and gap RCC mixes with hydrated lime can be obtained at 5% lime. The porosity of these mixes decreases about 13.85% and 23.7% as compared to reference mix for dense and gap mixes respectively. While absorption decreases about 6.7% for dense RCC mixes and 24% for gap RCC mixes.
2. The optimum compressive strength for mixes with lime can be obtained at 5% lime. The rate of increase in compressive strength is 109% for dense mixes and 115.8% for gap mixes.
3. For RCC mixes with lime, the occurred flexural strength for dense specimens is at 5% lime and the rate of increase is 96.3% by using third-point loading method, while for gap specimens tested by this method, the optimum flexural strength is

also at 5% lime and higher about 86.36% than reference mix.

4. The use of hydrated lime causes increase in splitting tensile strength of RCC mixes. Dense and gap specimens show increase in tensile strength and the rate of increase as compared to reference mixes is 150% for dense and gap specimens at 5% lime.

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Table (1): The primary distinction between two types of RCC (dams and pavements), Gupta(2004).

Characteristics	Dams	Pavement
Binder content (Kg/m³) (cement)	60 - 250	__
Water/cement ratio	0.40 – 0.80	0.30 – 0.40
Maximum aggregate diameter (mm)	75	20
28 day compressive strength (MPa)	15	45
Vebe time (sec)	10 - 25	30 - 60

Table (2): Chemical compositions and main compounds of the cement used through this work.

Oxide	% by weight	Limit of Iraqi specification No.5/ 1984
CaO	60.78	-------------
SiO_2	20.54	-------------
Al_2O_3	5.88	-------------
Fe_2O_3	3.28	-------------
MgO	1.93	< 5.0
SO_3	1.87	< 2.80
Loss on ignition	3.47	≤ 4.0
Insoluble residue	0.15	< 1.5
Lime saturated Factor	0.85	≥ 0.66 ≤ 1.02
Main compounds (Bogue's equations)		
C_3S	41.74	--------------
C_2S	27.65	--------------
C_3A	10.04	--------------
C_4AF	9.97	---------------

Table (3): Physical properties of cement.

Physical properties	Test result	Limit of Iraqi specification No.5/1984
Specific surface area, Blain's method, m²/kg	341	≥ 230
Soundness, Autoclave's Method, %	0.03	< 0.8
Setting time, Vicat's method Initial setting hr:min Final setting hr:min	 2:35 4:45	 ≥ 45 min ≤ 10 hours
Compressive strength 3 days N/mm² 7 days N/mm²	 18.8 23.3	 ≥ 15 ≥ 23

Table (4): Properties of coarse and fine aggregate.

Type of aggregate	Bulk Specific Gravity	Density(kg/m³)	Absorption %	SO_3 %
Crushed coarse aggregate	2.56	1600	1	0.06
Fine aggregate	2.45	1780	3.13	0.45

Table (5): Chemical components of hydrated lime

Oxide	SiO_2	Fe_2O_3	Al_2O_3	CaO	MgO	L.O.I
Percent	0.74	0.19	0.5	64.23	1.17	29.94

Table (6): Grain size distributed used for RCC mixes

Sieve size (mm)	% Passing by weight	
	Dense graded (SCRB, 2004)	Gap graded(BS,1961)
25.4	100.0	100.0
19.2	98.0	95.0
12.5	85.0	80.0
9.5	76.5	75.0
4.75	62.5	70.0
0.6	26.5	17.0
0.075	7.0	7.0

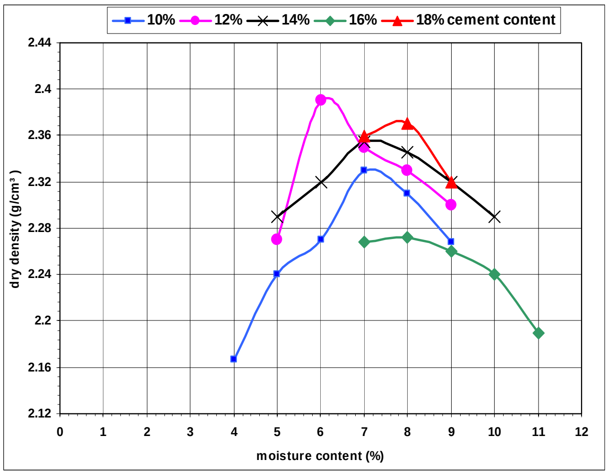
Table (7): Maximum dry density and moisture content for dense and gap RCC mixes

% cement	Maximum dry density (gm/cm³)		Moisture content %	
	Dense graded	Gap graded	Dense graded	Gap graded
12	2.395	2.347	6.0	7

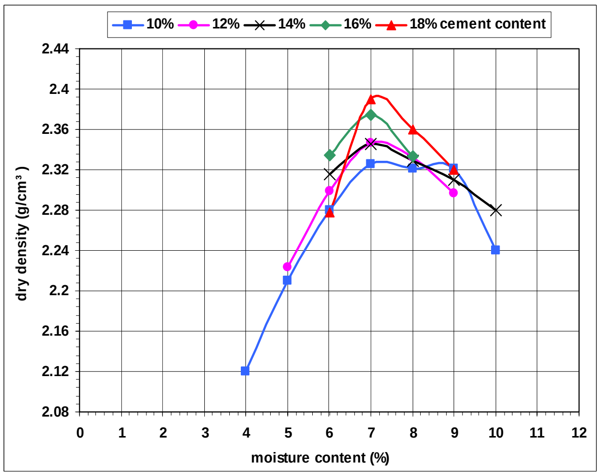
Table (8): Compressive strength of mixes containing hydrated lime

Additives	Percentages %	Compressive strength (MPa)	
		7 days	**28 days**
Cement paste	0	15.7	18.65
Hydrated lime	5	19.39	29.67
	10	23.6	32.12
	12	25.45	27.2
	15	19.39	23.03

Figure (1) Roller compactor and mould



a. dense graded



b. gap graded

Figure (2) Dry density-moisture content relationship of dense and gap graded mixes

Figure (3) Construction of RCC slab samples

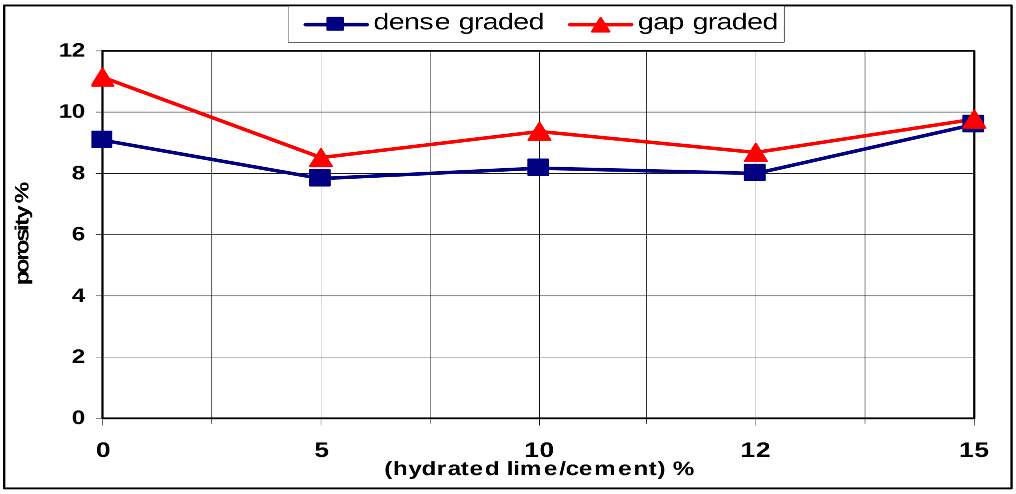


Figure (4) Variation in porosity with lime/cement ratio of dense and gap RCC mixes.

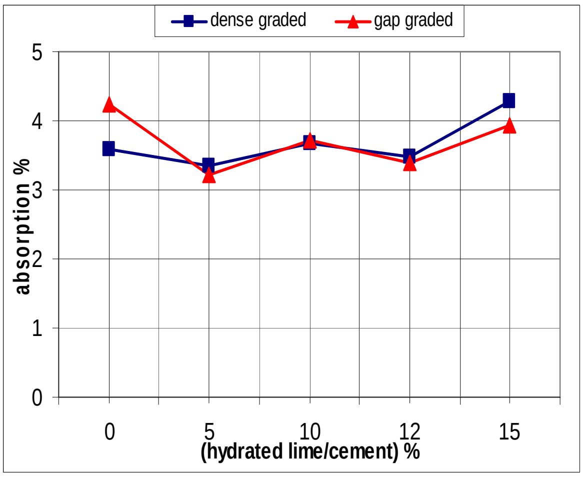


Figure (5) Variation in absorption with Lime/cement ratio of dense and gap RCC mixes.

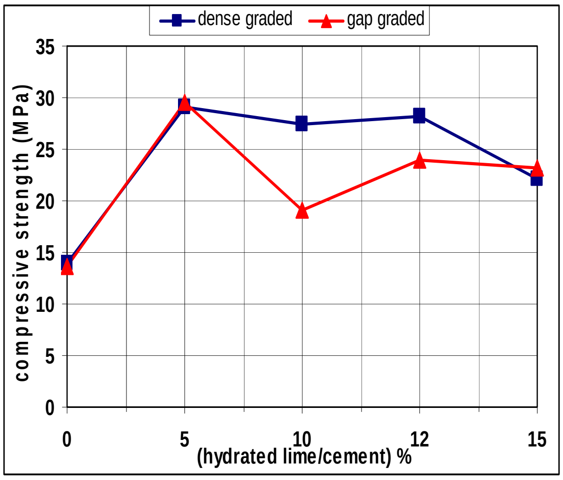


Figure (6) Variation in compressive strength with Lime/cement ratio of dense and gap RCC mixes.

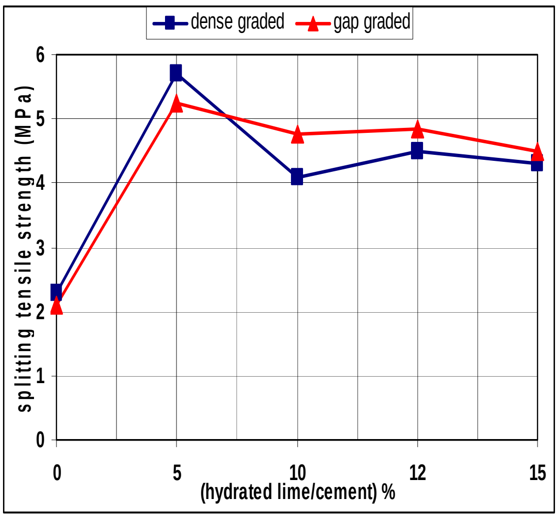


Figure (7) Variation in splitting tensile strength With lime/cement ratio of dense and gap RCC mixes.

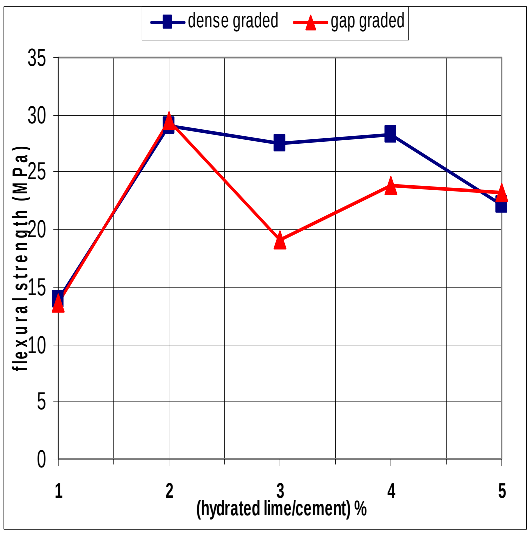


Figure (8) Variation in flexural strength with Lime/cement ratio of dense and gap RCC mixes.