Evaluation of Mechanical Properties of Roller Compacted Concrete

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ABSTRACT

The main aim of this research is to study the effect of using the additive materials (hydrated lime and metakaolin) on the behavior of roller compacted concrete. The experimental work includes several trial mixes to choose the most suitable roller compacted concrete mix in terms of physical concrete properties. The first step is to specify the optimum cement and water content which is designed in laboratory using 300 kg/m^3 of cement and 0.5 W/C ratio while the second step the only variation is using the optimum sand content of 700 kg/m^3 and the third step the variation is using the optimum percentage of the additive materials (metakaolin and hydrated lime) at percentages (5%, 10%, 15%, 20% and 25%) as a partial replacement by weight of cement, the optimum percentage of 15% of (HL and MK) as a partial replacement of cement at different ages. The research also includes studying the physical properties (compressive strength, splitting tensile strength and flexural strength) of specimens with additive materials and without additive materials. Also the results of RCC specimens with additive materials (MK and HL) show improvement in compressive strength, splittingtensile andflexural strength (modulus of rupture) compared with the specimen without additive materials.

Keyword: Roller Compacted Concrete, Met kaolin, Hydrated Lime, Compressive Strength, Splitting Tensile Strength and Modulus of Rupture.

تقييم الخواص الميكانيكية للخرسانة المرصوصة بالحدل والحاوية على مضافات

الخلاصة

ان الغرض الرئيسي من هذا البحث هو دراسة تأثير أستعمال المواد المضافة (الميتاكاؤلين والجير المتميأ) على سلوك البلاطات الخرسانية المرصوصة بالحدل.تضمن الجزء العملي عمل عدد من الخلطات التجريبية لاختيار الخلطة للخرسانة المرصوصة بالحدل من حيث الخواص الفيزيائية للكونكريت التي أنجزت على عدة مراحل المرحلة الاولى هي تحديد المحتوى الامثل من السمنت والماء حيث صممت مختبريا على اساس أستعمال وزن 300 كغم/م^3 من الاسمنت، 0.5 نسبة الماء الى الاسمنت بينما المرحلة الثانية تضمنت الحصول على المحتوى الامثل من الرمل وهو 700 كغم/م^3 والمرحلة الثالثة تضمنت الحصول على النسبة المثلى من المواد المضافة (الميتاكاؤلين والجير

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المتميأ)والمستخدمة بنسب مختلفة (5%، 10%، 15%، 20%، 25%) كبديل لجزء من محتوى الاسمنت، من خلال النتائج كانت النسبة المثلى 15% من (الميتاكؤلين والجير المتميأ) كبديل لجزء من محتوى الاسمنت وبأعمار مختلفةكما شمل البحث دراسة الخواص الفيزيائية (مقاومة الانضغاط ، مقاومة شد الانشطار و مقاومة الانثناء) للنماذج الخرسانية الحاوية على المواد المضافة وكذلك الغير حاوية على المواد المضافةوكذلك بينت النتائج بأن النماذج الخرسانية المرصوصة بالحدل والحاوية على المواد المضافة (الميتاكاؤلين والجير المتميأ) أظهرت تحسنا في خاصية مقاومة الانضغاطومقاومةشد الانشطار ومقاومةالانثناء (معامل التصدع) مقارنة مع النماذج الخالية من المواد المضافة.

INTRODUCTION

ACI committee 207-5R [1] defines RCC as "a concrete of no slump consistency in its unhardened state that is transported, placed, and compacted using earth and rock fill construction equipment". The principal advantages of RCC are derived from the construction process and construction cost which is lower than that of conventional concrete at range 25 to 50%, U.S.A Army Corps[2] because there is less labor involved in placing the concrete (no formwork or finishing is required), and no reinforcing steel or dowels are used.

It is addition to the existing types of concrete, whose applications are usually considered when it is economically competitive with other construction methods. Over the past several years, it has been used increasingly in the construction of dams and pavements in many countries such as Canada,USA, and France. The use of roller compacted concrete (RCC) is implemented to meet the structural requirements and balance design economy. RCC is a concrete with no slump, no dowels or reinforcements, no finishing, and cast using both vibratory and roller compactions. 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 [3].

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 bleed water, and less cement is one means of reducing thermal induced cracking [4]. 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 pozzolanic materials as a partial replacement ofcement has improved the properties of RCC, thepozzolanic materials type serves somepurposes [5]:

- 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 fine aggregates to improve workability.

The main aim of this research is to study the effect of using the additive materials (hydrated lime and metakaolin) on the behavior of roller compacted concrete.

Experimental Work

Materials:

Cement

Ordinary Portland cement (Type I) manufactured by Tasluja cement factory was used. The chemical composition and physical properties of cement are presented in Tables (1). The test results have shown that the cement conforms to the provisions of Iraqi Specification No. 5 (1984).

Aggregate

The aggregate which is used is combined aggregate, this type of aggregate was brought from (Al- Nebaiquarry), it was sieved in to different sizes which were combined in appropriate portions in order to satisfy the combined aggregate grading requirements and conform with the ACI-325-10R-95 [6], the final grading of combined aggregate is shown in Table (2).

ADDITIVE MATERIALS

Metakaolin

The Iraqi kaolin clay brought from (Dwekhla region) was used as an additive materials admixture in this investigation. This material was used after being converted to Metakaolin. In the first stage big fragments of kaolin clay were crushed with handy hammer into smaller sizes, and ground into fine particles of (600μm) in size, after that they were finely ground to the required fineness of (8900 cm^2/gm) with a laboratory ball mill Calcination process was the second stage in preparation of (**MK**) the calcination temperature and the time of calcinations at that temperature used in this work were (700C^o, 1hr.) respectively. The results of chemical and physical properties of MK conform to the requirements of pozzolan as stated in ASTM C618-06and shown in Tables (3)**.** The preparation and testing of plain mortar and cement – MK mortar specimens for pozzolanic activity test were carried out according to ASTM C311-02[7].

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 which is made in Iraq is available in local markets at low cost. Chemical composition and physical properties are given in Tables (4).

Water

Potable water of Baghdad was used in RCC mixes and curing.

Mixes:

In order to select the mixture proportion for RCC (without additive materials replacement), the design method recommended by ACI committee 207-5R-99[1] was used.

Three groups of trial mixes were carried out:

1- The optimum W/C ratio is that which produces a maximum compressive strength.
2- The optimum cement content is that which produces a maximum compressive strength with an economical mix.

3- The ideal amount of sand is that which produces a maximum compressive strength at the optimum W/C.

Based on results of these trial mixes, the final mix had the following constituents:

1. Cement content = 300 kg/m^3
2. W/C ratio = 0.5 (water content= 150 kg/m^3)
3. Fine aggregate =700 kg/m^3
4. Coarse aggregate = 1350 kg/m^3
5. Zero slump, (Vebe time = 35 sec)

That is considered a reference mix in this work.

- ❖ The percentage of MK and HL that used as a partial replacement of cement was (5%, 10%, 15%, 20%, 25%).

Mixing

The dry materials of reference mix of roller compacted concrete were placed in the mixer and initially mixed for about one minute before the required water was added to mixture, to attain a uniform mix. The required quantity of tap water was then added and the whole constituents were mixed wet for about four minutes, until homogeneous concrete was obtained. The above procedure was used for MK-RCC and HL-RCC except that the required quantity of MK or HL was mixed with cement using porcelain mix so that the lumps of MK or HL particles were completely broken. This operation was continued for one hour to ensure that MK or HL particles were thoroughly dispersed between cement particles.

Casting

The specimens of RCC were prepared by using cylinder steel moulds of size (150 × 300mm) and prisms of size (100 × 100 × 400mm). Soil compaction equipment was used automatically to compact the specimens for proctor and C.B.R tests. The concrete was placed in three equal layers if cylinder moulds and two layers if prisms moulds were used, each layer received 56 blows according to ASTM D-1557[8], (modified proctor test) method.

Curing

After that the specimens were demoulded, then placed in tap water for to the specified period before testing.

EXPERIMENTAL TESTS

Compressive Strength

The compressive strength was determined from cylinder specimens tests of 150mm diameter × 300mm height according to ASTM C-39-04. The average compressive strength of three cylinder specimens was recorded. This test was conducted at 7, 28 and 90 days of age.

Splitting Tensile Strength

The splitting tensile strength was carried out according to ASTM C-496-04, standard cylinders of 150mm diameter × 300mm height were used the average splitting tensile strength of three specimens was recorded. This test was conducted at ages 28 days.

Flexural Strength (modulus of rupture)

The flexural strength tests were carried out on (100×100×400)mm prism specimens in accordance with ASTM C78-03, using flexural strength test machine of 300kN capacity. Since fracture occurs within the central one third of the beam for all specimens. The flexural strength was determined by two – loading point's method. This test was conducted at ages 28 days.

RESULTS AND DISCUSSION

Effect of Mix Proportion on the Properties of Roller Compacted Concrete

Effect of Water Content on the Properties of Roller Compacted Concrete

From Figures (1) to (3) and Table (5) indicate that the compressive strength, splitting tensile strength and density at 28 days tends to increase with the increase in water content from 100 kg/m^3 to 150 kg/m^3 for all mixes. Further increase in water content from 150 kg/m^3 to 160 kg/m^3 causes a reduction in compressive strength, splitting tensile strength and density for all mixes. This may be due to the fact that lower water content below the optimum will reduce the paste volume to a point where entrapped air voids are not filled and the sample does not get proper compaction as at high water content. Beyond the optimum water content this phenomenon can be explained as the natural consequence of a progressive weakening of the matrix caused by increasing porosity with increase in the water content [9]. On the other hand, the excess of water will cause paste to adhere to the hammer of compacting apparatus. Then insufficient compacted concrete will be achieved. As a result the optimum water content is sufficient for hydration of cement and full compaction leads to reduction in the entrapped air voids. When water content is over the optimum, there will be excess of water for cement hydration that will lead to weakening the bond between aggregate and the paste due to the empty voids at evaporating of excess water [10]. These results are in agreement with those obtained by [11, 12, 13]. Generally the optimum water content invariably lies around (150)kg/m^3 for cement content of (275,300,350)kg/m^3.

Effect of Cement Content on the Properties of Roller Compacted Concrete

Figure (4) and Table (5) show the relationship between cement content and compressive strength at 28 days of RCC specimens at different water contents (100, 130, 150, 160)kg/m^3. Also Figures (5 and 6) show the relationship between cement content and (splitting tensile strength and density) respectively at 28 days of RCC specimens at different water contents (100, 130, 150, 160) kg/m^3. From results the following observation are made:

1- Generally it can be seen that the compressive strength at 7 and 28 days increases as the cement content increases.

2- The results also indicate that the splitting tensile strength and density at 28 days increase as the cement content increases.

However, the optimum cement content invariably lies around (300kg/m3).

Effect of Sand Content on Properties of Roller Compacted Concrete

Figures (7) to (9) and Table (6) indicate that the compressive strength, splitting tensile strength and modulus of rupture of specimens tends to increase gradually when the sand content decreases up to an optimum sand content from 885 kg/m^3 to 700 kg/m^3. Further decrease in the sand content beyond the optimum causes reduction in the compressive strength, splitting tensile strength and modulus of rupture of specimens from 700 kg/m^3 to 670 kg/m^3**.** It can be seen that the compressive strength, splitting tensile strength and modulus of rupture at 28 days increases when sand content decreases in comparison with reference mix (sand content of 885 kg/m^3). The percentage increase in compressive strength is (2.5%, 6.1%, 26.2%, 35.4%, 11.6%), (0.5%, 11.2%, 24%, 40.8%, 10%) and (2.3%, 9.1%, 18.3%, 37.1%, 11.7%) for sand content (790, 760, , 700,720 670)kg/m^3 respectively.

Effect of Addition of Additive Materials (MK or HL) on the Properties of Roller Compacted Concrete

Compressive strength

Figures from (10) to (12) and Table (7) show the relationship between different percentages of (0%, 5%, 10%, 15%, 20%, and 25%) of additive materials (metakaolin and hydrated lime) as a partial replacement by weight of cement and compressive strength of specimens at 7, 28 and 90 days age for RCC specimens.

It can be seen that the compressive strength of RCC specimens tends to increase gradually when the (HL,MK) content increases up to an optimum percentage (15%) of (HL and MK) as a replacement of cement. Further increase in (HL,MK) content beyond the optimum causes reduction in the compressive strength of specimens.

From Figures (14) and (16) it can be noticed that the compressive strength of MK-RCC specimens at 7 days is less than that of their reference RCC specimens (without pozzolana) for 20 and 25 percent cement replacement by MK, the compressive strength slightly increases at 5%, 10% and 15% of MK and the rate of increase is (1%, 3.1%, 8.8%) respectively when compared with reference RCC specimens. The reduction in compressive strength of MK-RCC compared with reference RCC specimens is 8.2%, and 17.6% for 20% and 25% of MK respectively. On the other hand, the same Figures show that at 28 days a slight increase of about 5.4%, 9.5%, 13.5% and 1.8% is observed in the compressive strength of RCC containing 5%, 10%,15% and 20% of MK respectively compared with their reference. The reduction in the compressive strength of RCC specimens containing 25% of MK is lower compared with the reference in their compressive strength at 28 days of age, the rate of reduction is 10.4%.

The Figures shows also that at 90 day age, the increase in the compressive strength of RCC specimens containing 5%, 10%, 15% and 20% of MK is 6.9%, 15.9%, 22% and 2% respectively compared with their reference RCC specimens, while the reduction in the compressive strength of RCC containing 25% of MK is 5.7% when compared to their reference RCC specimens.

The increase in compressive strength of RCC specimens containing 5%, 10% and 15% of MK compared with their reference RCC specimens at later age only may be attributed to fact that there are two elementary factors influencing the contribution that the MK improves the compressive strength when it partially replaces cement in concrete. These are the filler effect, , and the pozzolanic reaction of MK with $Ca(OH)_2$[14].

The results shown in Figure (13 and 15) and Table (7) indicate that the compressive strength of RCC specimens containing 5%, 10%, 15%, 20% and 25% of hydrated lime increases with progress of age at a rate higher than that of their reference RCC specimens. The increase in the compressive strength at 7 days of age is 6.9%, 26.4%, 34.6% and 4.4% for percentage of replacement of 5%, 10%, 15% and 20% of HL respectively, while the reduction in the compressive strength is 6.3% for percentage of replacement of 25%.

The Figures also shows that the compressive strength at 28 days of RCC specimens containing 5%, 10%, 15%, 20% and 25% of HL increases gradually with increasing percentage of replacement of HL from 5% to 25% for all ages, the rate of increase in compressive strength is18.9%, 29.3%, 37.4%, 18% and 4% of HL respectively when compared to the reference RCC specimens.

Also the same figures show that at 90 day of age, the increase in the compressive strength of RCC specimens containing 5%, 10%, 15%, 20% and 25% of HL is 21.2%, 30.6%, 39.6%, 19.6% and 9.8% respectively compared to their reference RCC specimens. This increase may be attributed to the fact that the lime at this ratio of replacing works as a filler material and fills the voids in the mixture leading to increase in density of mixture and increase in the compressive strength. Figure (17) shows the behavior of HL is better than the behavior of MK in roller compacted concrete, such results of compressive strength in the presence HL are higher than that of MK. So the optimum type of additive materials is hydrated lime with percentage of 15% as a replacement of cement.

Splitting Tensile Strength

Figure (18) and Table (7) show the relationship between percentage of additive materials and splitting tensile strength of RCC specimens at 28 days of age.

The Figure also shows that the splitting tensile strength of RCC specimens containing (5%, 10% and 15%) of MK increases gradually with the increase in the percentage of MK and the rate of increase is (2.3%, 3.7% and 10.8%) respectively, the results also indicate that the RCC specimens containing (20%) of MK exhibit splitting tensile strength equal to that of their reference RCC specimens (without pozzolana) while the splitting tensile strength of RCC specimens is reduced by 14.7% at 25% of MK compared to their reference RCC specimens. The same figure shows that the splitting tensile strength of RCC specimens containing (5%, 10%, 15% and 20%) of HL increases gradually with the increase in the percentage of HL and the rate of increase is (7.9%, 13.6%, 30.7% and 5.1%) respectively. On the other hand, the splitting tensile strength of RCC specimens is reduced and the rate of reduction is 9.1% at 25% of HL compared to their reference RCC specimens.

Modulus of Rupture

Figure (19) and Table (7) indicate the relationship between modulus of rupture of RCC specimens containing (5%, 10%, 15%, 20% and 25%) of MK and HL and age. It can be noticed that the modulus of rupture of RCC specimens containing (5%, 10%, 15%, 20% and 25%) of HL increases gradually with increase in the percentage of HL at 28 days of age, the RCC specimens containing 15% of HL attain 73% increase in the modulus of rupture compared to their reference RCC specimens, while, nearly 18.8%, 31.3%, 14.6 and 12.5% of the modulus of rupture of reference RCC specimens are attained at 28 days at percentage of replacement of 5%, 10%, 20% and 25% of HL respectively.

The results also show that the modulus of rupture of RCC specimens containing MK at percentages of replacement of 5%, 10% and 15% increases with increasing the percentage of MK, the rate of increase is 6.25%, 10.4% and 16.7% respectively. On the other hand the modulus of rupture of RCC specimens containing MK decreases with increasing percentage of replacement of MK such that the percentage increases to 25%, the percentage of decrease in modulus of rupture was 12.5%.

CONCLUSIONS

Based on the experimental work results in this investigation, the following conclusions can be drawn:

1- The results of trial mixes (without additives) indicate that the optimum mixture of RCC at which maximum compressive strength is obtained at age of 28 days is (0.5) w/c ratio, (300 kg/m^3) cement content, (700 kg/m^3) sand content and coarse aggregate (1350 kg/m^3).
2- The compressive strength of HL-RCC specimen at 90 days, shows considerable increase at percentages of replacement of 10% and 15% of HL. While MK-RCC specimen shows increase atpercentages of replacement of10% and 15% of MK and at percentage 25% shows reduction in compressive strength by about 6% compared with reference mix.
3- The addition of HL as partial replacement showed considerable increase in splitting tensile strength at percentage of 15%. On the other hand MK-RCC shows a little increase in splitting at percentage of 15% compared with reference RCC mix.
4- The results show that there is a substantial increase in modulus of rupture of HL-RCC specimens compared with reference RCC mix. While that of MK-RCC shows modulus of rupture lower than that at all percentages of replacement.
5- It was shown that the optimum percentage of additive materials (hydrated lime and metakaolin) is 15%.

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Table (1) Cement characteristics.

Chemical Analysis		Compound		Physical Properties	
Oxide	**% by weight**	**Composition**			
CaO	62.80	C_3S	58.1	Specific surface area, Blain's method, m^2/kg	322.8
SiO_2	20.30	C_2S	14.89		
Al_2O_3	4.60	C_3A	7.57	Soundness, Le-Chatelier Method (mm)	1
Fe_2O_3	2.81	C_4AF	8.69		
MgO	2.40			Setting time, Vicat's method Initial setting hr:min Final setting hr:min	 2.25 4.35
SO_3	2.45				
Na_2O	0.60				
K_2O	0.25			Compressive strength 3 days N/mm^2 7 days N/mm^2	 23.6 30.3
Loss on ignition, (L.O.I)	3.0				
Insoluble residue	0.6				
Lime saturated factor	0.87				

Table (2)Grading of combined aggregate for RCC.

Sieve size mm	Percent passing %	Limits according to ACI-325-10R-95 % passing
19	100	85-100
12.5	79	77-95
9.5	68	67-85
4.75	50	50-70
2.36	41	38-56
1.18	36	28-48
0.6	32	18-38
0.3	14	12-28
0.15	8	8-18
0.075	5	2-8

*** SO_3 content in Coarse aggregate = 0.08%**
*** SO_3 content in Fine aggregate= 0.3%**

Table (3) Chemical analysis and physical properties of MK.

Chemical Analysis	
Oxide Composition	**Oxide content %**
SiO_2	55.22
Al_2O_3	32.38
Fe_2O_3	1.54
CaO	2.24
MgO	0.41
SO_3	2.55
Na_2O	0.96
K_2O	0.3
L.O.I	2.39
Other materials	2.01
Physical properties	
Strength activity index with Portland cement at 28 days ,min. % of control	114
Specific gravity	2.6 1
Surface area (Blaine Method). cm^2/gm	8900

Table (4) Chemical analysis and physical properties of hydrated lime.

Chemical Analysis	
Oxide Composition	**Oxide content %**
CaO	55.86
SiO_2	0.45
Al_2O_3	0.035
Fe_2O_3	0.03
MgO	0.15
L.O.I	42.57
Physical properties	
Strength activity index with Portland cement at 28 days ,min. % of control	126
Specific gravity	2.3
Surface area (Blaine Method). cm^2/gm	4500

*chemical analysis was carried out in the laboratories of general directorate of geological survey and mining.

** physical properties was carried out in the laboratories of building and construction department – university of technology.

Table (5) Effect of water and cement content on properties of RCC.

Symbol	Water content kg/m³	Cement content kg/m³	Combined aggregate		Compressive strength (MPa)		Splitting tensile strength (MPa) at 28 days	Density kg/m³ at 28 days
			Fine aggregate kg/m³	Coarse aggregate kg/m³	7 days	28 days		
A1 (Ref.)	100	275	885	1180	7.1	10.7	1.6	2380
A2	100	300	885	1180	8	12.1	1.81	2400
A3	100	350	885	1180	8.7	13.9	2.15	2450
B1	130	275	885	1180	11.2	15.5	2.37	2410
B2	130	300	885	1180	11.9	15.8	2.49	2430
B3	130	350	885	1180	12.7	16.2	2.75	2470
C1	150	275	885	1180	11.3	15.7	2.45	2430
C2	150	300	885	1180	12.4	16.4	2.5	2450
C3	150	350	885	1180	13.5	17.1	2.73	2490
D1	160	275	885	1180	9.5	13.6	1.77	2410
D2	160	300	885	1180	10.1	14.5	2.1	2420
D3	160	350	885	1180	11	15.95	2.3	2460

Table (6) Effect of sand content on mechanical properties of RCC.

Symbol	W/C ratio	Cement content kg/m³	Combined aggregate		Compressive strength (MPa)		Splitting tensile strength (MPa) at 28 days	Modulus of Rupture (MPa) at 28 days
			Fine aggregate kg/m3	Coarse aggregate kg/m3	7 days	28 days		
Reference Mix	0.5	300	885	1180	12.4	16.4	2.5	3.5
E1	0.5	300	790	1260	12.9	16.8	2.52	3.58
E2	0.5	300	760	1290	13.5	17.4	2.78	3.82
E3	0.5	300	720	1330	14.8	20.7	3.1	4.14
E4	0.5	300	700	1350	15.9	22.2	3.52	4.8
E5	0.5	300	670	1380	14.0	18.3	2.75	3.91

Table (7) Effect of (HL,MK) on mechanical properties of RCC.

Symbol	(HL,MK) (%)	Compressive strength (MPa)			Splitting tensile strength (MPa) at 28 days	Modulus of Rupture (MPa) at 28 days
		7 days	28 days	90 days		
Reference Mix	0%	15.9	22.2	24.5	3.52	4.8
HL1	5% (HL)	17	26.4	29.7	3.8	5.7
HL2	10% (HL)	20.1	28.7	32	4.0	6.3
HL3	15% (HL)	21.4	30.5	34.2	4.6	7.1
HL4	20% (HL)	16.6	26.2	29.3	3.7	5.5
HL5	25% (HL)	14.9	23.1	26.9	3.2	4.9
MK1	5% (MK)	16	23.4	26.2	3.59	5.1
MK2	10% (MK)	16.4	24.3	28.4	3.65	5.3
MK3	15% (MK)	17.3	25.2	29.9	3.9	5.6
MK4	20% (MK)	14.6	22.6	25	3.54	4.8
MK5	25% (MK)	13.1	19.9	23.1	3.0	4.2

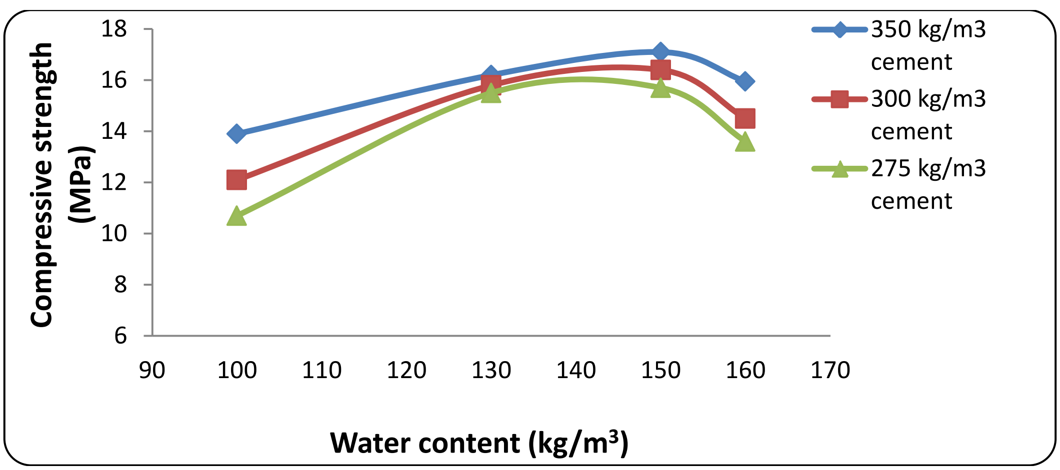

Figure (1) Relationship between compressive strength at 28 days and Water content for different cement content of RCC.

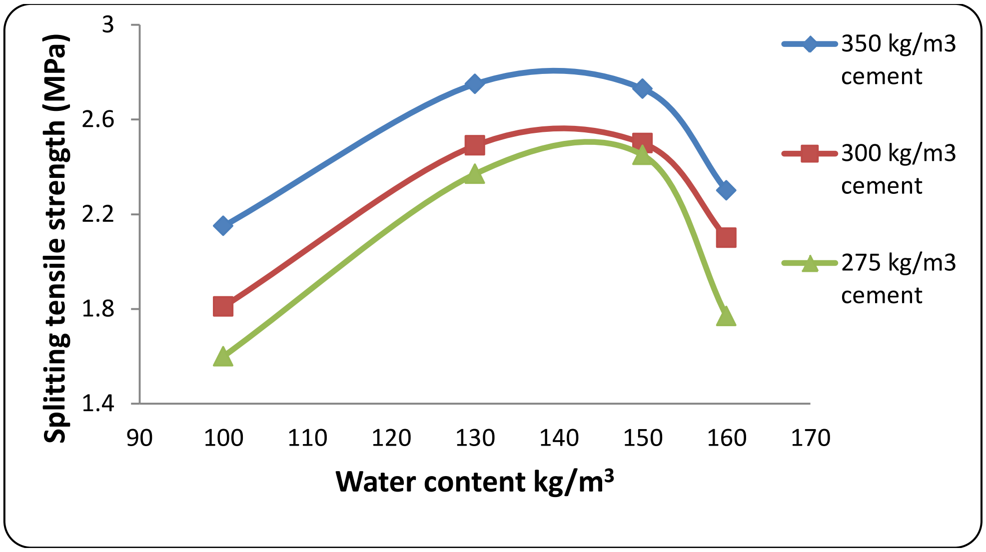

Figure (2) Relationship between splitting tensile strength at 28 days and water content for different cement content of RCC.

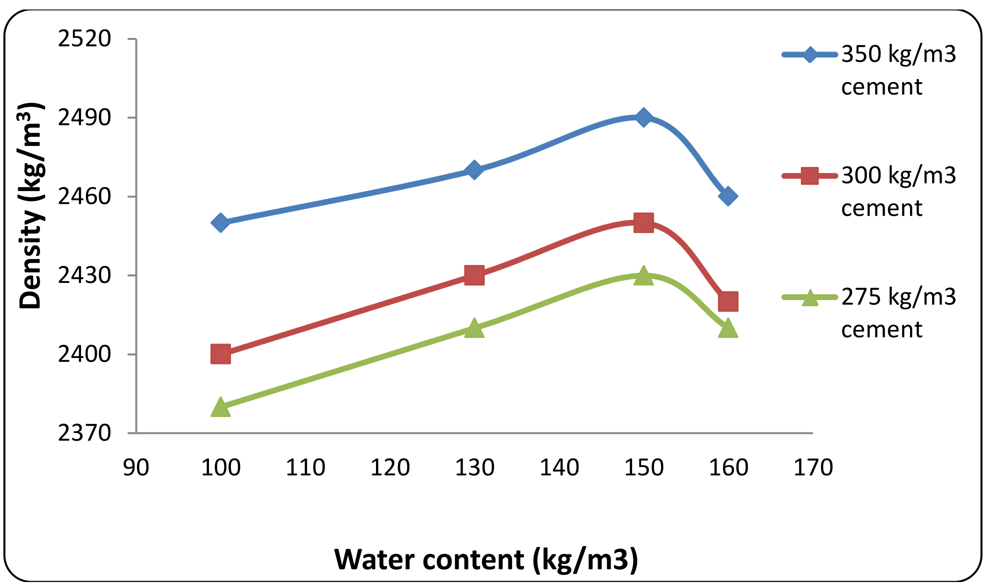

Figure (3) Relationship between density at 28 days and water content for different cement content of RCC.

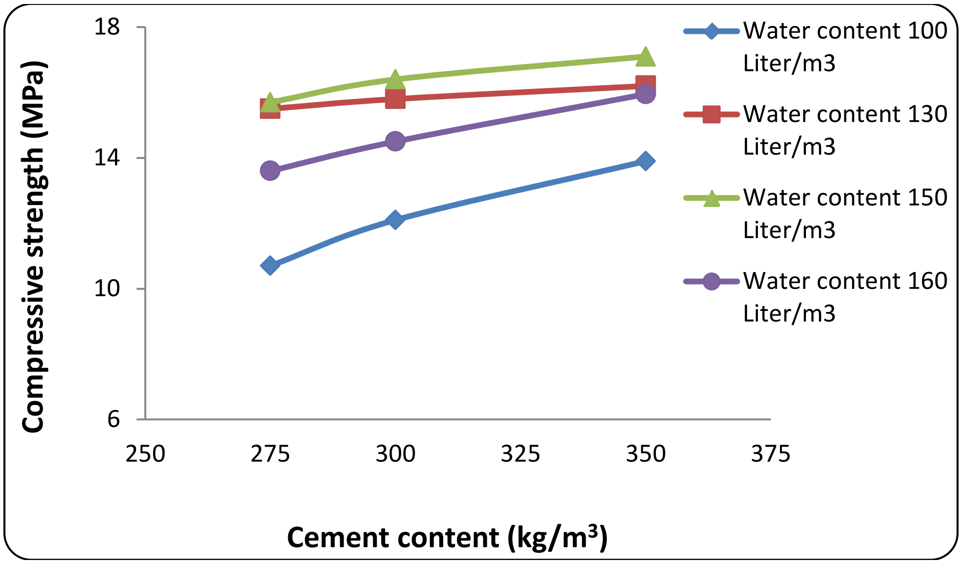

Figure (4) Relationship between Compressive strength at 28 days and cement content for different Water content of RCC.

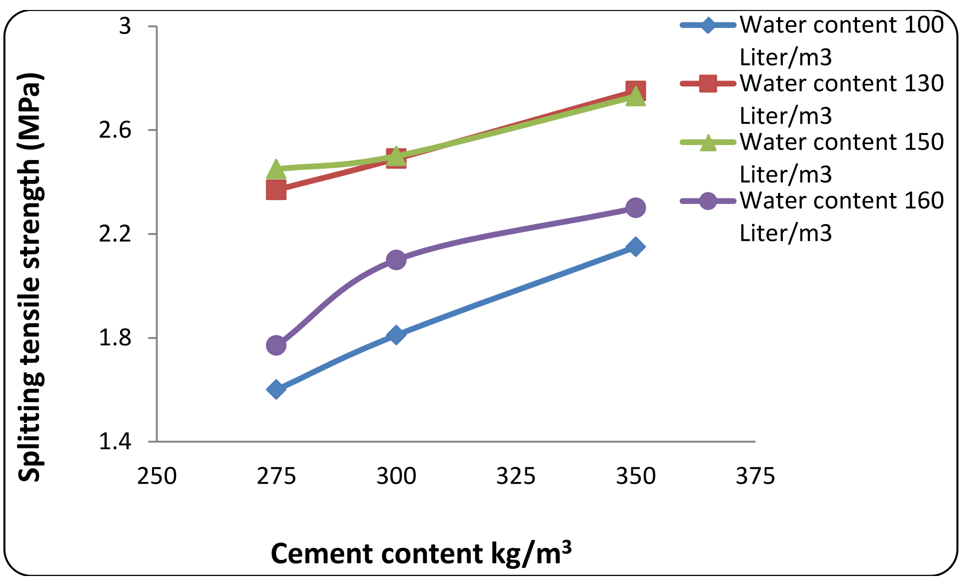

Figure (5) Relationship between splitting tensile strength at 28 days and cement content for different Water content of RCC.

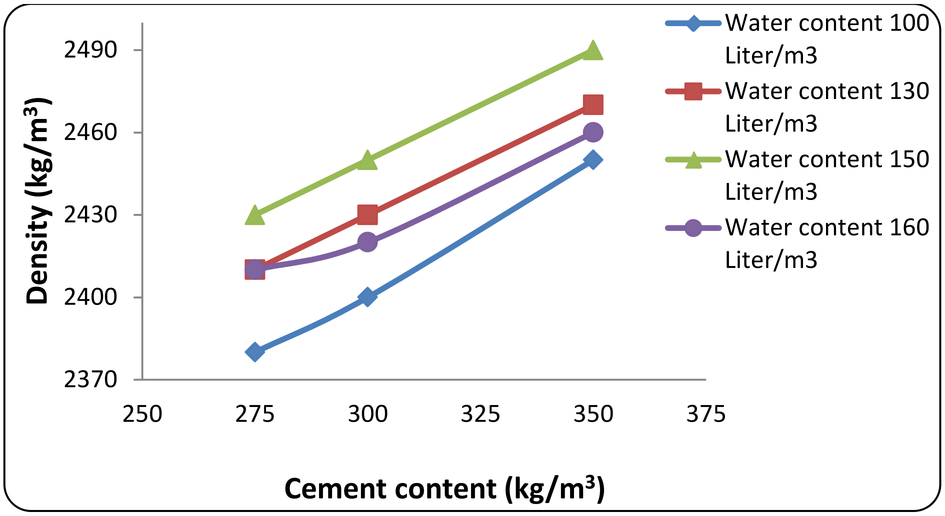

Figure (6) Relationship between density at 28 days and cement content for different Water content of RCC.

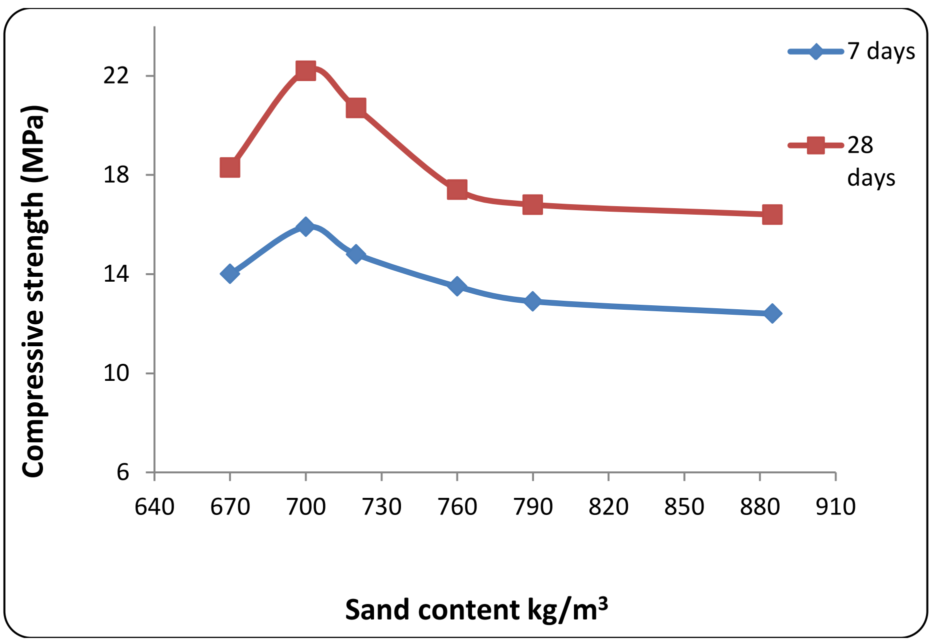

Figure (7) Relationship between compressive strength and sand content at 7 and 28 days of RCC.

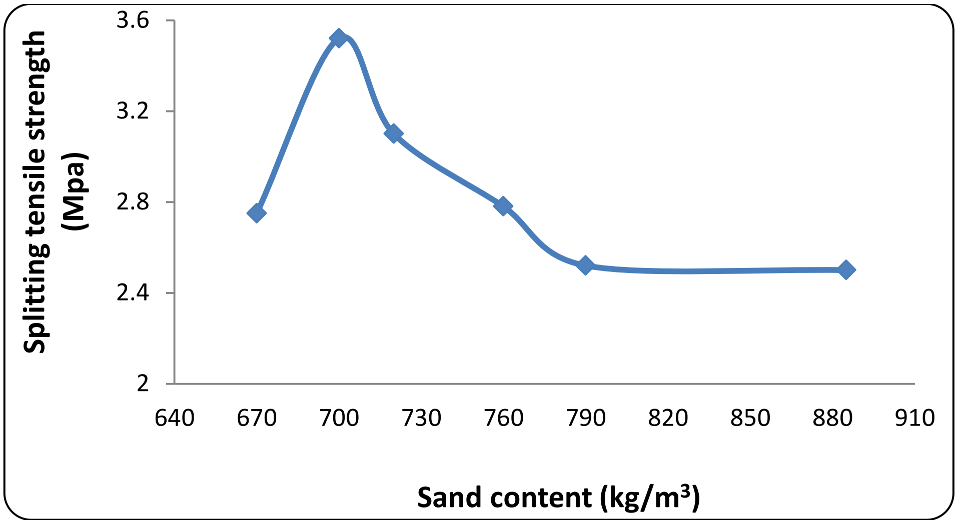

Figure (8) Relationship between splitting tensile strength at 28 days and sand content of RCC.

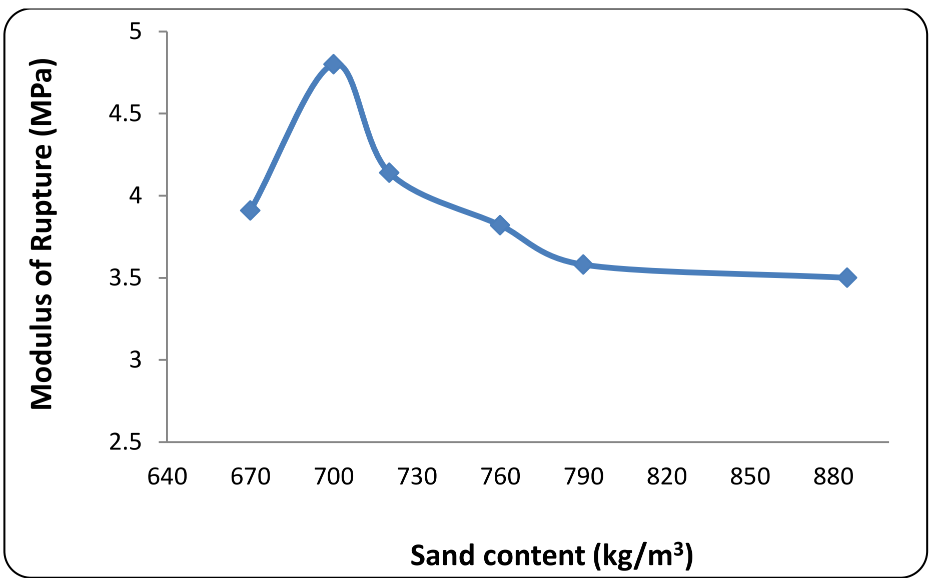

Figure (9) Relationship between modulus of rupture at 28 days and sand content of RCC.

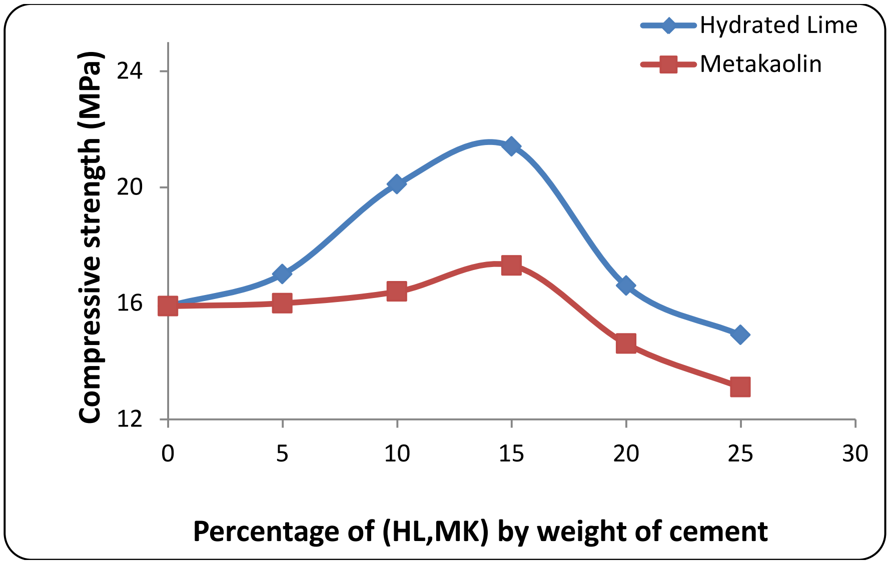

Figure (10) Effect of (HL,MK) content on compressive strength of RCC at 7 days

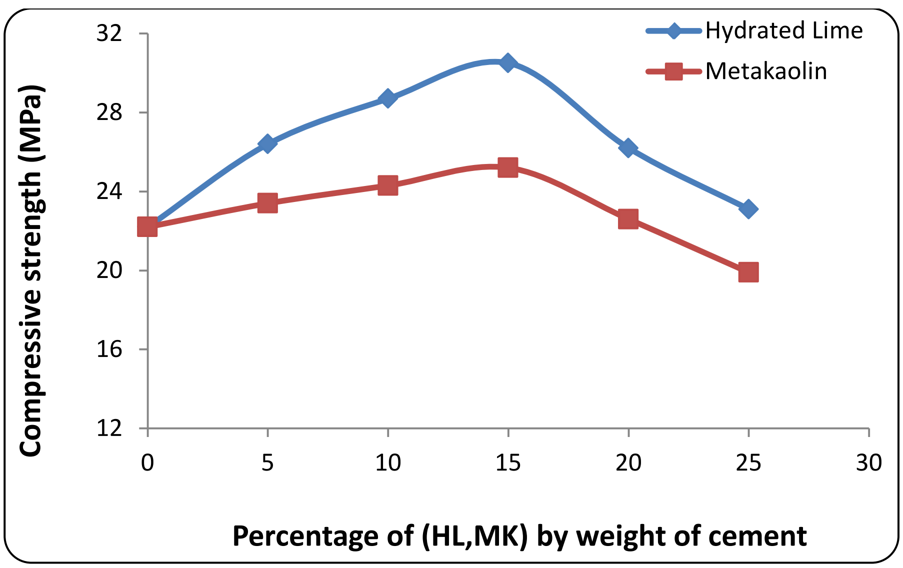

Figure (11) Effect of (HL,MK) content on compressive strength of RCC at 28 days.

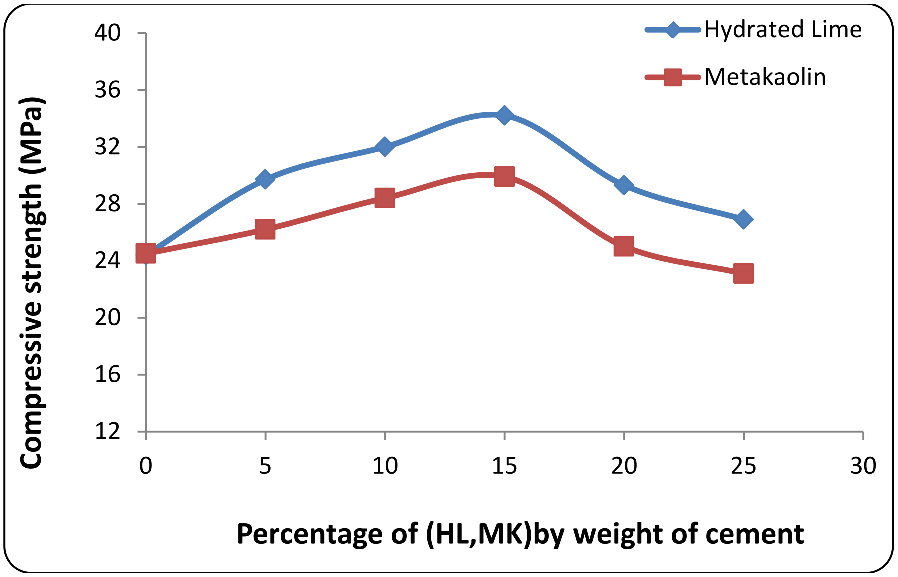

Figure (12) Effect of (HL,MK) content on compressive strength of RCC at 90 days.

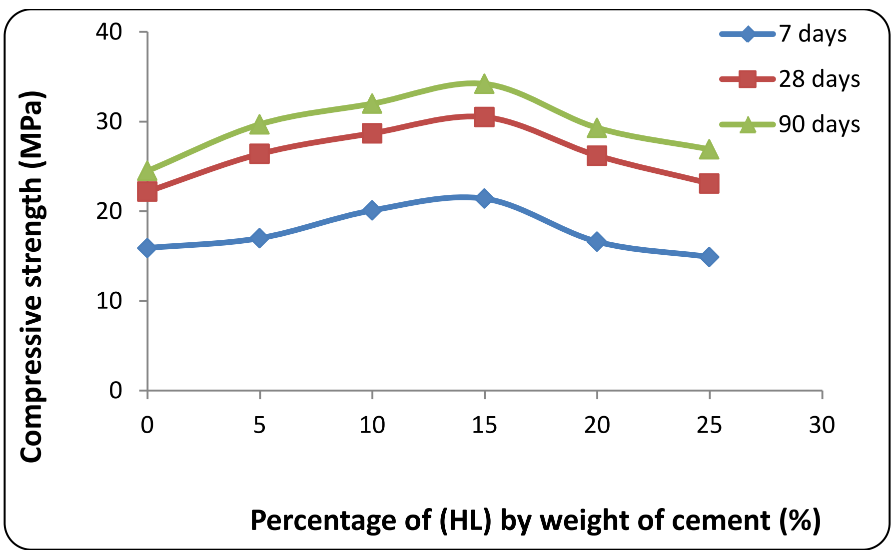

Figure (13) Effect of (HL) content (%) on compressive strength of RCC at 7,28 and 90 days.

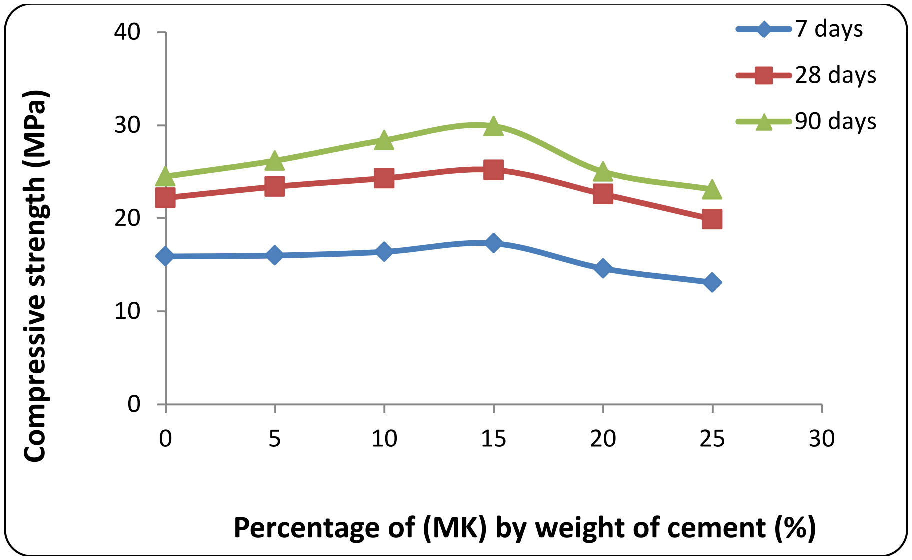

Figure (14) Effect of (MK) content (%) on compressive strength of RCC at 7,28 and 90 days

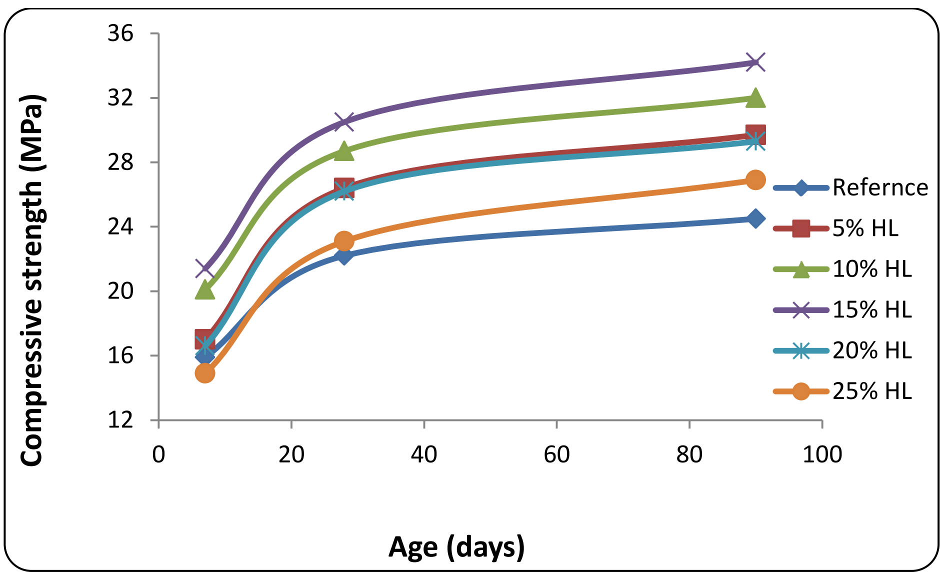

Figure (15) Effect of (HL) content (%) on compressive strength of RCC at 7,28 and 90 days.

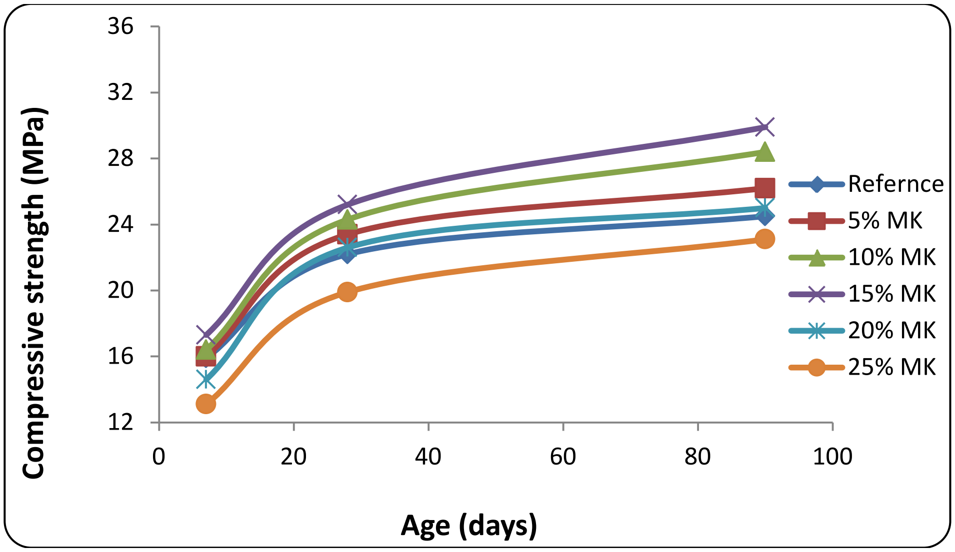

Figure (16) Effect of (MK) content (%) on compressive strength of RCC at 7,28 and 90 days

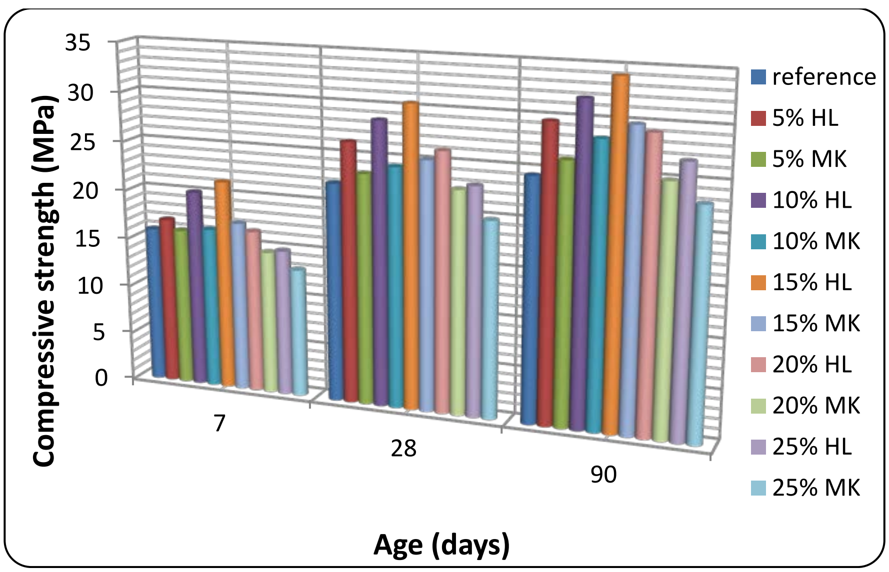

Figure (17) Effect of replacement levels of pozzolanic materials and ages on compressive strength of RCC.

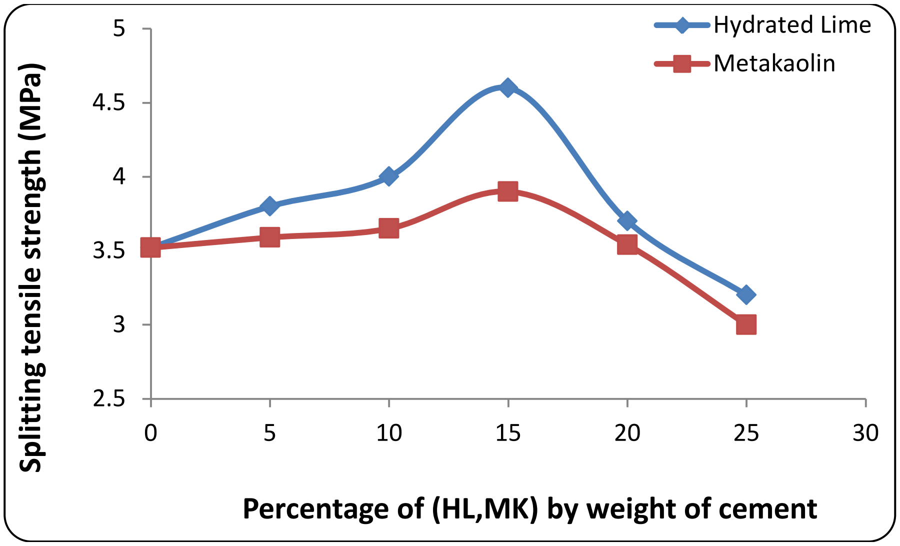

Figure (18) Effect of (HL,MK) content on splitting tensile strength of RCC at 28 days.

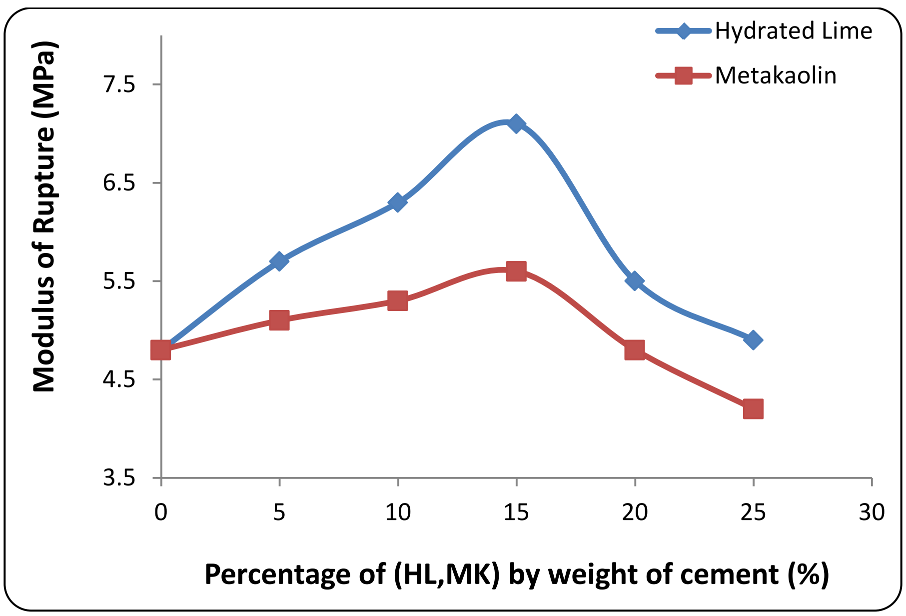

Figure (19) Effect of (HL,MK) content (%) on modulus of rupture of RCC at 28 days.