Effect of Compaction Methods on the Properties of Roller Compacted Concrete

Dr. Hisham Khalid Ahmed.
Building and Construction Engineering Department, University of Technology
E-mail: hish1950@yahoo.com.
Azal Thair Abdulrazzak
Building and Construction Engineering Department, University of Technology

Received on: 5/2/2014 & Accepted on: 13/5/2014

ABSTRACT

Roller compacted concrete (RCC) is a technology characterized mainly use of roller for compaction. This construction method permits considerable reduction in costs and construction time of dams and roads. The main aim of this work is to investigate the influence of compaction methods on the properties of RCC. the experimental program included preparing cylindrical specimens with (diameter of 150 mm by height of 300 mm) for measuring the compressive strength, splitting tensile strength and absorption. And it also includes prism specimens with (100*100*400) mm for measuring the modulus of rupture. These specimens were compacted by using different compaction methods, dynamicly (modified proctor hammer compaction (CBR test), vibrator table, and vibrator table with CBR test) and statically (compacting pressure (compacting pressure 10 MPa, 15 MPa and 20 MPa).
Results show that the compaction methods have a noticeable effect on the properties of RCC. The results also indicated that using vibrator table with CBR show an increase in the compressive strength, splitting tensile strength and modulus of rupture by 23%, 14% and 13%, respectively as compared with compacted by vibrator table only. The results also show that using compacting pressure 20 MPa show an increase in the compressive strength, splitting tensile strength and modulus of rupture by 31%, 27%, and 39%, respectively as compared with that made by compacting pressure 10 MPa.

Keywords: Roller compacted concrete, compaction, compressive strength, splitting tensile strength, Modulus of rupture.

تأثير طرق الرص المختلفة على خواص الخرسانة المرصوصة بالحدل

الخلاصة:

تعتبر الخرسانة المرصوصة بالحدل من التقنيات التي تمتلك بالدرجة الاكبر خاصية استعمال الحادلات لرص الخرسانة, ان استعمال هذه الخرسانة يوفر الوقت و الكلفة في إنشاء السدود و الطرق.
إن الهدف الرئيسي من هذا البحث هو دراسة تأثير طرق الرص المختلفة على خواص الخرسانة المرصوصة بالحدل.

https://doi.org/10.30684/etj.32.10A.10
2412-0758/University of Technology-Iraq, Baghdad, Iraq

تضمن المنهاج العملي تحضير نماذج فحص اسطوانية بابعاد (قطر 150 ملم و ارتفاع 300 ملم) لغرض قياس مقاومة الانضغاط و مقاومة شد الانشطار و الامتصاص و استخدام مواشير ذات ابعاد (100* 100* 400)ملم لغرض فحص معامل التصدع. و قد تم استعمال طرق مختلفة لرص النماذج الخرانية بصورة ديناميكية (الرص بالمطرقة, المنضدة الهزازة, المنضدة الهزازة ثم الرص بالمطرقة معاً) و بصورة ستاتيكية (بتسليط ضغط بمقدار 10 ميكاباسكال, 15 ميكاباسكال, 20 ميكاباسكال). و قد بينت النتائج بان لطرق الرص المختلفة تأثير ملحوظ على خواص الخرسانة المرصوصة بالحدل, كما اشارت النتائج بان استعمال طريقة المنضدة الهزازة مع الرص بالمطرقة يؤدي الى زيادةفي مقاومة الأنضغاط, الأنشطارومعامل التصدع بمقدار 23%, 14%, 13% على التوالي مقارنة بتلك التي تم رصها بواسطة المنضدة الهزازة وكذلك بينت النتائج ان استعمال طريقة تسليط الضغط بمقدار 20 ميكاباسكال يؤدي الى زيادة في مقاومة الانضغاط, الانشطار, ومعامل التصدع بمقدار 31%, 27%, 39% على التوالي مقارنة بتلك التي تم رصها بتسليط ضغط 10 ميكاباسكال وطريقة تسليط ضغط 20 ميكاباسكال لرص النماذج تعطي تحسن جيد في الخواص الميكانيكية للخرسانة المرصوصة بالحدل.

INTRODUCTION

Roller Compacted Concrete (RCC) takes its name from the construction method used to place the concrete; RCC is being used in many parts of the world such as Canada, U.S.A. and France [1].

RCC is based on zero slump concrete mix with very low water content in order to facilitate compaction using vibratory rollers. The roller compacted concrete technique achieves significant time and cost savings in the construction of concrete dams and pavements [2].

The term "Roller Compacted Concrete" is also defined by **ACI committee 116-R [3]** as "concrete compacted by roller compaction ; concrete that , in its unhardened state , will support a roller while being compacted, and the properties of hardened (RCC) can be similar to those of conventionally placed concrete" .

The concept of roller compacted concrete had probably its beginning at the engineering foundation conferences held in 1970 and 1972 in USA **[4].**

RCC has been successfully placed in lift thickness ranging from a minimum of 150 mm (compacted thickness). Lift thickness can vary depending on mix proportions, placement rates and compaction procedures [5]. Each lift is compacted with vibrating steel. Wheel roller, these compacters range from relatively small to light asphalt rollers. Compaction in thick lifts after spreading in thin layers is effective provided proper dozer equipment and technique are used and mixture is proportioned for a workabilitybin 10 to 30 sec range [6].

A few investigation have been made about the effect of compaction methods on the mechanical properties of roller compacted concrete [7, 8].

In this field a recent study was carried out (Abdulla) [9] to evaluate physical and mechanical properties of RCC using roller loading to simulate the field condition and using hammer compaction method.

The main aim of this research is to study the effect of different compaction methods (hammer compaction (CBR test), vibration by vibrating table, vibration with hammer compaction and static compaction with different of compacting pressure) on the mechanical properties of roller compaction 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 (2). The test results have shown that the cement conforms to the provisions of Iraqi Specification No. 5 (1984) [10].

Aggregate

The aggregate which is used is combined aggregate, 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 [11], the final grading of combined aggregate is shown in Table (2).

Water

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

Mixes

In order to select the mixture proportion for RCC the design method recommended by ACI committee 207-5R-99[4] was used.

Trial mixes were carried out to determine the optimum water cement ratio W/C ratio is that which produces a maximum compressive strength.

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

1. Cement content = 250 kg/m^3
2. Fine aggregate = 800 kg/m^3
3. Coarse aggregate = 1300 kg/m^3
4. Water content= 112 Kg/m^3

The workability of the concrete mix was measured by Vebe apparatus (Vebe time = 18 sec).

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.

Preparation of specimens

The specimens of RCC were prepared by using cylinder steel moulds of size (150 × 300mm) and prisms of size (100 × 100 × 400mm). For compaction of the specimens, using different compaction methods, by dynamically and by static load.

a.Dynamically

Modified Proctor test method

Soil compaction equipment was used automatically to compact the specimens for proctor and CBR hammer. The moulds rested on uniform rigid base plate of apparatus, and then the concrete was placed in three equal layers if the cylinder moulds were used and in two layers for prisms. The automatic blow pattern ensures optimum compaction for each layer of concrete. The rammer of 4.5 Kg weight itself travelled across the mould, each layer received 56 blows according to ASTM-D1557[12] (modified Proctor test) method.

Vibrating table:

The mould field in equal layers, the frequency of vibration of vibrating table used in 3000 cycles per minute. Because of the concrete mix is very dry, it may be necessary to exert pressure or its top surface during vibration. Each layers compaction for 20 seconds.

modified Proctor test and vibrating table

b.Compaction by static load

The required load (10, 15, 20 MPa) was applied on each layer of concrete, using ELE universal testing machine with capacity of 2000 kN.

Curing

After that the specimens were demoulded, and then it placed in tap water for curing 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[13]. This test was conducted at 7 and 60 days of age.

Splitting Tensile Strength

The splitting tensile strength was carried out according to ASTM C-496-04[14], standard cylinders of 150mm diameter × 300mm height were used. This test was conducted at ages 7 and 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)[15], using flexural strength test machine of 300 kN capacity. Since fracture occurs within the central one third of the beam for all specimens. The flexural strength was determined by two – loading points method. This test was conducted at age 60 days.

Water Absorption

The water absorption test was carried out according to B.S.-1881- 122-1983[16].

Results and Discussion

Compressive strength

The effect of using different compaction methods (dynamic compaction and static compaction) on compressive strength of roller compacted concrete specimen are given in table (3) and figure (1) and (2). Generally it can be seen that for all specimens the compressive strength increases with age as a results of the progress in hydration process. Besides the results show that the compressive strength at 90 days age of specimens made by using dynamic compaction (modified Proctor test method-(CBR hammer)) is higher than the compressive strength of the specimen made by using vibrator table by 12%, while the percentage increase in compressive strength of specimens compacted by vibrator table with CBR hammer by value 23% compared with specimens compacted by vibrator table.

The figures shows also that the compressive strength at 90 days age of specimen obtained using static compaction method by compacting pressure 10 MPa is lower than that compacted by 15 MPa and 20 MPa by 14.6 % and 31% respectively. This reduction may be due to the presence of voids as results of insufficiently compacted pressure to obtain fully compacted concrete, these voids are reflected in their reduction in compressive strength [17]. From the results in figures (1 and 2) it can be clearly seen that the compressive strength at early age and later age of specimen made by using vibrator table with modified Proctor test is approximately the same with compressive strength of specimen made by compacting pressure 20 MPa. While the compressive strength at all ages of specimens compacted by vibrator is higher than specimen compacted by pressure 10 MPa with average value about 9%.

Splitting Tensile Strength

The effect of different compaction methods on splitting tensile strength are presented in table (3) and figures (4) and (5). As can be seen from figures, the trends of curves are approximately similar to that of compressive strength. Splitting tensile strength at age 90 days of specimen made by using (vibrator table with CBR hammer) is higher than the splitting tensile strength of specimens made by vibrator only, CBR test by 14% and 9%, respectively.

From the results, it is observed that there is an increase of splitting tensile strength at 90 days age of specimen made by compacting pressure 20 MPa in comparison with the specimens made by compacting pressure 10, 15 MPa, this increase was 27% and 16 %, respectively. The results also show that the splitting tensile strength of specimens using vibrator table with CBR hammer is similar to that made by compacting pressure 20 MPa.

Splitting tensile strength as a percentage of a compressive strength at different age of RCC specimens compacted by different compaction methods are indicated in table (4). Generally it can be seen that strength ratio vary from 0.11-0.13, these results are in agreement with that reported by ref. [9].

Modulus of Rupture

The effect of different compaction methods on the modulus of rupture (ultimate flexural strength) are shown in figures (5) and (6) and table (3). It can be observed from the results that the modulus of rupture at age 90 days of specimen made by using (CBR hammer with vibrator) is higher than that made by vibrator, CBR hammer by 13% and 10 % respectively. It can be noted that the specimens of RCC made by using compacting pressure 20 MPa showed an increase in modulus of rupture at age 90 days of value 39%, 19% respectively over that made by using compacting pressure 10 MPa and 15 MPa, and have approximately same value as that made by dynamic compaction method (vibrator table with CBR hammer).

The relationship between modulus of rupture of RCC specimens compacted by different methods is indicated in table (6). It can be seen that the strength ratio of modulus of rupture to compressive strength at different ages from 0.21-0.24. These results are in agreement with finding by others [9].

Water absorption

The results obtained from measurement of water absorption of RCC specimens using different compaction methods are shown in table (6). It can be seen that the percentage of the absorption for specimen compacted by pressure 10 MPa is greater than that of other compaction method this may be attributed to the presence of voids as a result of insufficiently compacted pressure to obtain fully compacted concrete[17].while the lowest overall absorption is for the specimens compacted by (vibrator table with CBR hammer) and that by compacting pressure 20 MPa. Generally these results show that the compaction method has a little effect on the water absorption of RCC.

Dry density:

The results of dry density at age of 28 days for RCC specimens using different compaction methods is shown in table (6).

The results also indicated that the dry density of RCC made by using vibrator table with CBR hammer is higher than other dynamic compaction methods (table vibrator only and CBR hammer only). The dry density of that made by compacted pressure 20 MPa is higher than other static method (compacting pressure 10 MPa, 15 MPa). These results of high dry density are reflected in high compressive strength of RCC specimens.

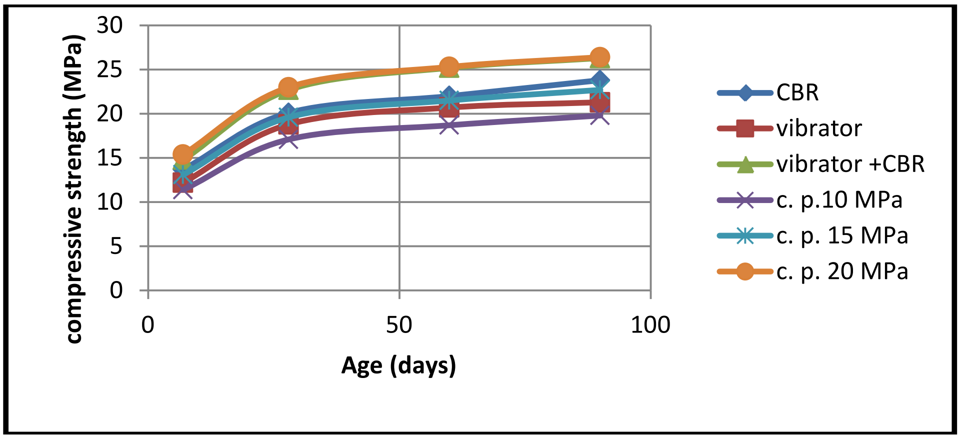

Figure (1): Relationship between compressive strength and age of RCC.

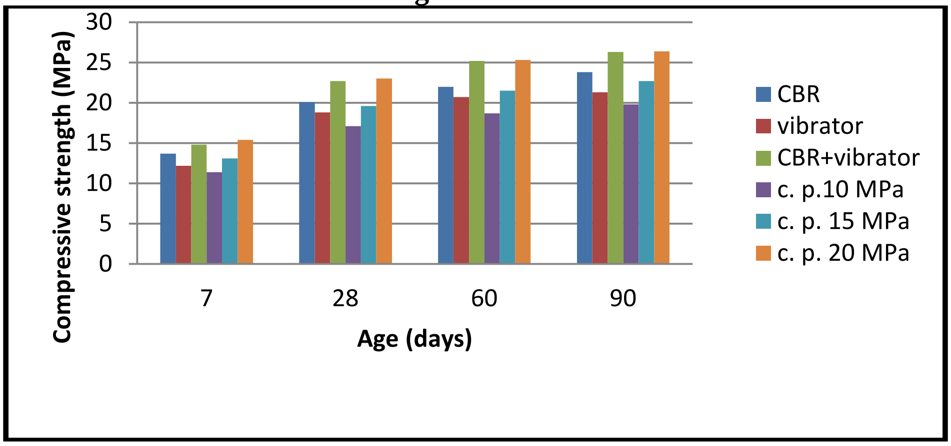

Figure (2): Effect of compaction methods on compressive strength of RCC.

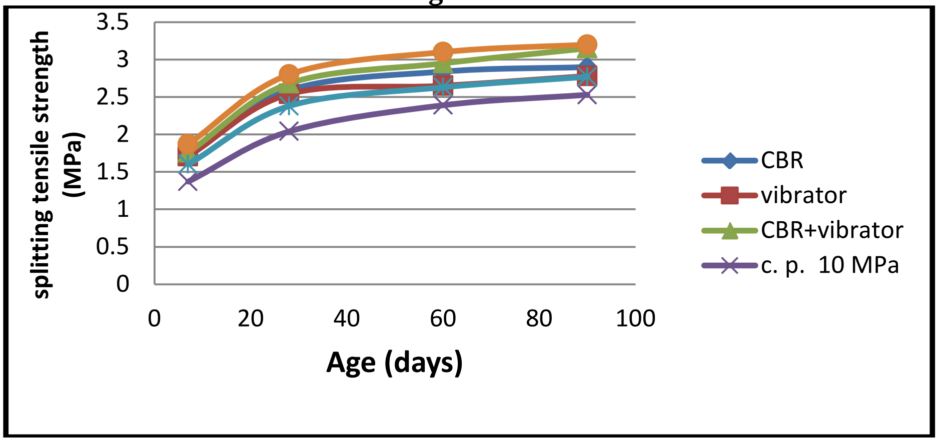

Figure (3): Relationship between splitting tensile strength and age of RCC.

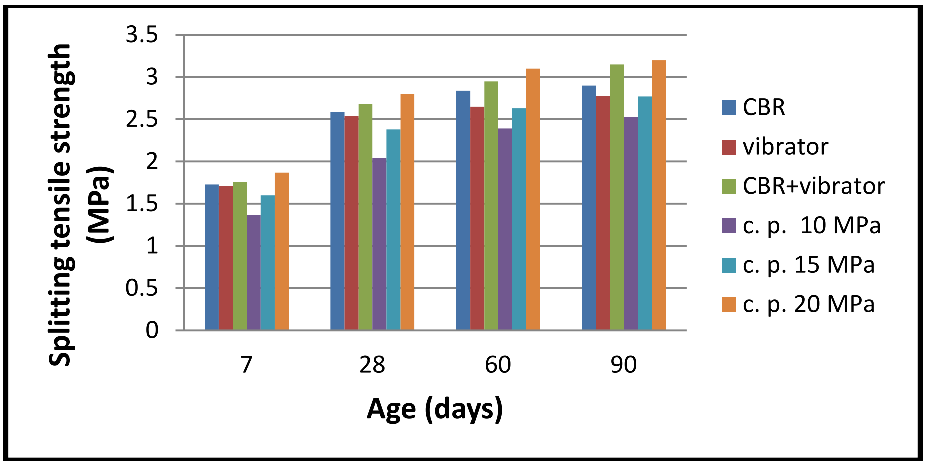

Figure (4): Effect of compaction methods on splitting tensile strength of RCC.

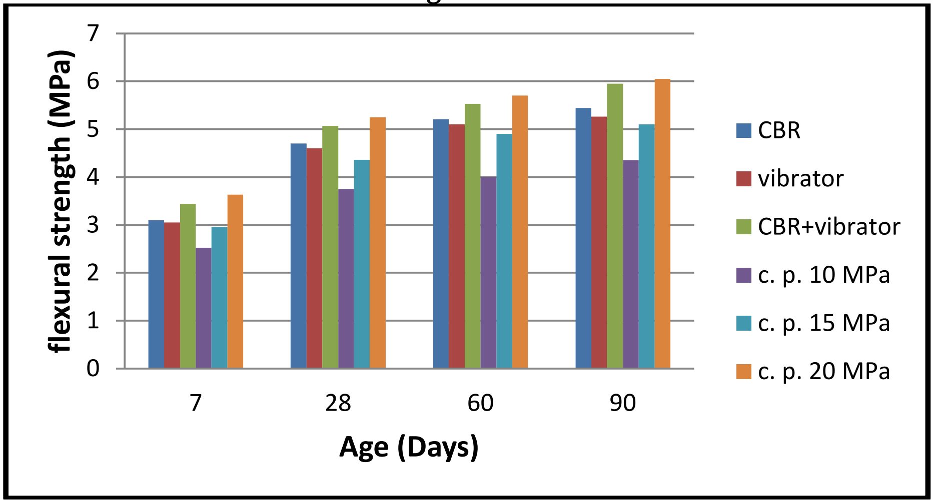

Figure (5): Relationship between flexural strength and age of RCC.

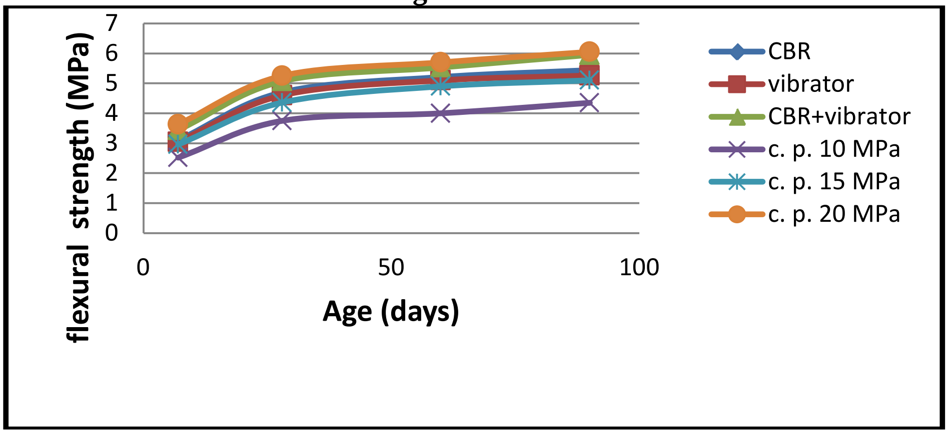

Figure (6): Effect of compaction methods on flexural strength of RCC.

Table (1): Cement Characteristics.

Chemical Analysis		Compound Composition%		Physical Properties	
Oxide	% by weight				
CaO	62.80	C_3S	58.1	Specific surface area, Blain's method, m²/kg	323
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/mm² 7 days N/mm²	 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% passing
19	99	85-100
12.5	71	77-95
9.5	51	67-85
4.75	37	50-70
2.36	34	38-56
1.18	30	28-48
0.6	28	18-38
0.3	12	12-28
0.15	8	8-18
0.075	7	2-8

* SO_3 content in Coarse aggregate = 0.08
* SO_3 content in Fine aggregate= 0.03

Table (3): Mechanical Properties of RCC Using Different Compaction Method

Method of compaction	Compressive Strength (MPa)				Splitting Tensile Strength(MPa)				Modulus of Rupture (MPa)			
	Age –(days)											
	7	28	60	90	7	28	60	90	7	28	60	90
CBR hammer	13.7	20.1	22	23.8	1.73	2.59	2.84	2.9	3.1	4.7	5.21	5.44
Vibrator	12.2	18.8	20.7	21.3	1.71	2.54	2.65	2.78	3.05	4.6	5.1	5.26
Vibrator+CBR	14.8	22.7	25.2	26.3	1.76	2.68	2.95	3.15	3.44	5.07	5.53	5.95
Compacting pressure 10 MPa	11.4	17.1	18.7	19.8	1.37	2.04	2.39	2.53	2.52	3.75	4	4.35
Compacting pressure 15 MPa	13.1	19.6	21.5	22.7	1.6	2.38	2.63	2.77	2.96	4.36	4.9	5.1
Compacting pressure 20 Mpa	15.4	23	25.3	26.4	1.87	2.8	3.1	3.2	3.63	5.25	5.7	6.05

Table (4): Relation between Splitting Tensile Strength and Compressive Strength of RCC of Different Compaction Method

Compaction Method	Strength ratio- Age-days			
	7	28	60	90
C.B.R. hammer	0.13	0.13	0.13	0.12
VIB	0.14	0.14	0.13	0.13
CBR+VIB	0.12	0.12	0.12	0.12
C.P. 10 MPa	0.12	0.12	0.13	0.13
C.P .15 MPa	0.12	0.12	0.12	0.12
C.P. 20 Mpa	0.12	0.12	0.12	0.12

Table (5): Relation between Modulus of Rupture and Compressive Strength of RCC of Different Compaction Method

Compaction Method	Strength ratio- Age-days			
	7	28	60	90
C.B.R.	0.23	0.23	0.24	0.23
Vibrator	0.25	0.24	0.25	0.25
CBR+VIB	0.23	0.22	0.22	0.23
C.P. 10 MPa	0.22	0.22	0.21	0.22
C.P .15 MPa	0.23	0.22	0.23	0.22
C.P. 20 MPa	0.24	0.23	0.23	0.23

Table (6): Absorption and Dry Density of RCC at 28 days.

Method of Compaction	Absorption (%)	Dry Density (kg/m^3)
CBR Hammer	3.61	2435
Vibrator Table	3.90	2425
CBR Hammer with Vibrator Table	3.50	2460
Compacting Pressure 10 \ (MPa)	4.00	2430
Compacting Pressure 15 (MPa)	3.59	2430
Compacting Pressure 20 (MPa)	3.50	2458

Conclusions:

Based on the results and discussions, the following conclusions can be drawn:

1-The results show that there is a considerable effect of compaction methods on mechanical properties of RCC.

2-Using vibrator table with CBR hammer improve the properties of RCC. The compressive strength, splitting tensile strength and modulus of rupture of RCC specimens at age of 90 days is higher than that made by CBR hammer only.

3-The specimens of RCC made by using static compaction method by compacting pressure 20 MPa show an increase in compressive strength at age of 90 days of value 31%, 16 % over that made by using compacting pressure 10 MPa and 15 MPa, respectively.

4-The splitting tensile strength and modulus of rupture of RCC at age of 90 days were obtained using compacting pressure 20 MPa shows a significant increase by 27 %, 39 % respectively compared to that of compacting pressure 10 MPa, while the increase was 16%, 19% as compared with that made by compacting pressure 15 MPa.

5-The results show that the RCC by static method (compacting pressure 20 MPa) have approximately the same value as that made by dynamic method (vibrator table with CBR hammer).

6-The results show that the compaction methods have a little effect on water absorption of RCC.

REFERENCES

[1] Vorbieff, G., and Whitaker, C., "State of the Art of RCC Pavements in Australia", CIA Conference, July, 2003, pp. (1-9). Available at www.concreteroads.net/rcc/RCCpaperJuly2003.

[2] U.S.A. Army Corps, "Roller Compacted Concrete", Technical Engineering and Design Guides as Adopted from the U.S.A. Army Corps of Engineering, New York, ASCE, 1994, pp. (100).

[3] ACI – 116 R-90, "Cement and Concrete Terminology ". ACI Manual of Concrete Practice, part (1), 1990, pp. (1-14).

[4] ACI Committee 207-5R-99, "Rolled Compacted Mass Concrete", ACI Manual of Concrete Practice, part (1), 1999, pp. (1-49).

[5] Hansen K.D., "Roller Compacted Concrete: A Civil Engineering Innovation", Concrete International, March, (1996), pp. (49-53).

[6] Riyadh M. J., "Some Factors Affecting Properties and Behavior of Roller Compacted Concrete in Embankment", Ph.D. Thesis, Department of Civil Engineering, University of Baghdad, January 2005, pp. (65-68).

[7] Sarsam S.I., "Evaluation of Roller Compacted Concrete Pavement Properties", Engineering and Development, Scientific Journal of Al-Mustansyreiah University, Vol. (6), No. (1), March, 2002, pp (59- 74).

[8] Al-Janabi, M.,A. "Behavior of Heavy-Duty Roller Compacted Concrete Pavements Reinforced with Fibers". M.Sc., thesis, Building and Construction Engineering Department of the University of Technology, sept. 2012.

[9] Abdullah, S., G., "Effect of Additives on the Properties of Roller Compacted Concrete", M.SC., Thesis, Department of Civil Engineering, University of Baghdad, February 2011.

[10] Iraqi Standard Specification, No.5, (1984), "The Portland Cement".

[11] ACI Committee 325-10R-95, "*Roller Compacted Mass Concrete Pavements*", ACI 325-10R-95, American Concrete Institute, Michigan, USA, 1995, pp.(1-32).

[12] ASTM D-1557, " Standard test method for Moisture-Density Relations of Soils and Soil-Aggregate Mixtures Using 10Ib (4.54- kg) Rammer and 18-in. (457-mm) Drop " Annual Book of ASTM Standards American Society for Testing and Materials, vol.04.08, 2002, pp.206-210.

[13] ASTM C39-04."Standard Test Method for Compressive Strength of Cylindrical Concrete specimen", Annual Book of ASTM Standards American Society for Testing Materials, Vol.04.02, 2004.pp.24-29.

[14] ASTM C496-04."Standard Test Method for Splitting Tensile Strength of Cylindrical Concrete specimen", Annual Book of ASTM Standards American Society for Testing Materials, Vol.04.02, 2004.pp.259-262.

[15] ASTM C78-03, "Standard Test Method for Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading), Annual Book of ASTM Standards American Society for Testing and Materials, vol.04.02, 2003.

[16] B.S.1881:122,"Method for Determination of Water Absorption". British Standards, London, 1983.

[17] Ahmed, H.K. and Al-Shimeri, K.A, "The Effect of Pozzolana Addition on the Physical Properties of Roller Compacted Concrete" Proceeding of fourth International Scientific Conference of Salahaddin University- Erbil, October,2011, Vol (2), pp.(344-350).