Effect of Using Porcelanite as Partial Replacement of Fine Aggregate on Roller Compacted Concrete with Different Curing Methods

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ABSTRACT

Roller-Compacted Concrete is a no-slump concrete, with no reinforcing steel, no forms, no finishing and wet enough to support compaction by vibratory rollers. Due to the effect of curing on properties and durability of concrete, the main purpose of this research is to study the effect of various curing methods (air curing, 7 days water curing, and permanent water curing) and porcelanite (local material used as an Internal Curing agent) with different replacement percentages of fine aggregate (volumetric replacement) on some properties of Roller-Compacted Concrete and to explore the possibility of introducing practical Roller-Compacted Concrete for road pavement with minimum requirement of curing. Specimens were sawed from slabs of (380*380*100) mm for determination of Ultrasonic Pulse Velocity (UPV) and Voids volume. Results show that using (5) % porcelanite improved the results of UPV and Voids volume of Roller-Compacted Concrete (with air curing) as compared with reference Roller-Compacted Concrete (with permanent water curing) by percentages ranging from(3.6 to 28.9)% and (-8 to -15.5)% respectively.

Key words: Porcelanite, UPV, Voids volume, internal curing, roller compacted concrete, curing methods.

تأثير أستعمال مادة البورسيلنايت كأستبدال جزئي من الركام الناعم على الخرسانة المرصوصة بالحدل وبطرق انضاج مختلفة.

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الخلاصة

الخرسانة المرصوصة بالحدل هي الخرسانة عديمة الهطول والتي لا يتم فيها أستعمال حديد التسليح أو القوالب ولا تحتاج الى عملية الانهاء وكذلك يجب ان تكون ذات رطوبة كافية لتحمّل الحدل بواسطة الحادلات الهزازة.نتيجة لتأثير الانضاج على خصائص وديمومة الخرسانة لذا فإن الهدف الاساسي من البحث هو دراسة تأثير طرق مختلفة من الانضاج (الانضاج بالهواء ،الانضاج 7 ايام بالماء، الانضاج الدائمي بالماء) وبأستخدام البورسيلنايت (مادة محلية تستعمل كعامل أنضاج داخلي) وبنسب استبدال مختلفة من الركام الناعم (استبدال حجمي) على بعض خواص الخرسانة المرصوصة بالحدل وتحري مدى امكانية انتاج هذه الخرسانة لرصف الطرق لتكون اكثر عملية وبأستعمال الحد الادنى من متطلبات عملية الانضاج .يتم نشر الواح خرسانة بأبعاد (380*380*100) مم لعمل نماذج لفحوص الامواج فوق الصوتية والمسامية.تظهر النتائج ان استعمال (5%) بورسيلنايت يقوم بتحسين نتائج فحوص الامواج فوق الصوتية والمسامية للخرسانة المرصوصة بالحدل (بأستعمال الانضاج بالهواء) بالمقارنة مع الخرسانة المرصوصة بالحدل المرجعية (بأستعمال الانضاج الدائمي بالماء) بنسب تتراوح بين (3.6 to 28.9)% و- (-8 to -15.5) % على التوالي .

الكلمات الرئيسية: البورسيلنايت,فحص الامواج فوق الصوتية ,المسامية ,الانضاج الداخلي ,الخرسانة المرصوصة بالحدل,طرق أنضاج,أستبدال حجمي.

1. INTRODUCTION

The American Concrete Institute (ACI) committees 211.3R, 2009, and 116R, 2010, define Roller Compacted Concrete (RCC) as “concrete compacted by roller compaction; concrete that, in its unhardened state, will support a roller while being compacted”. RCC is a zero-slump material that has to be compacted by roller to achieve the required density. RCC can be exposed directly to traffic, **European Ready Mixed Concrete Organization (ERMCO), 2012.**

Keifer, 1986 refers to that RCC having no reinforcements, no finishing, and is cast using vibratory and roller compaction. The application of RCC is mainly in the construction of dams, rapid placement of paving for highways and runways and for multi-layer placement of foundation.

At the 1930s, a form of RCC paving was reported in Sweden, **Anderson, 1986**. In North America, the first RCC pavement was identified by Seattle Office of **U.S. Army Corps of Engineers (USACE)** constructed about 1942, **ACI 325.10R, 2001.**

RCC compared with conventional slump concrete has less water to achieve a zero-slump concrete; consequently, less cement is required to produce an equivalent water to cement ratio. Reducing water in the mixture leads to less shrinkage and no bleed water, and less cement is one means of reducing thermal induced cracking. Roller Compacted Concrete Pavements mixes compared with conventional Portland Cement Concrete (PCC) contain larger volume of fine aggregate to ensure a uniform concrete mix with less surface voids, **Hansen, 1996.**

Three common ideas in roads construction were used in design of RCC; using rigid pavement concrete, using pavers and rollers (asphalt) and using proctor and density test (soil), as shown in **Fig. 1**.

2. MATERIALS CHARACTERISTICS

2.1 Cement

Sulphate Resisting Portland Cement (SRPC) (Type V) under commercial name of (Al-jeser) was used for RCC mixes throughout work. The physical properties, chemical analysis of the cement used and the compounds of cement calculated according to Bogue's equations, **ASTM C 150, 2005,** are given in **Tables 1** and **2.** The results conform to, **Iraqi specifications (IQS) (No.5:1984)**.

2.2 Coarse Aggregate

Aggregate predominately retained on the No.4 (4.75mm) sieve, in this work crushed coarse aggregate with a nominal size of (19 mm) was used and it was obtained from Al-Nibaai region. The gravel was sieved through sieve size of (25 mm) and washed with water, air dried, separated into different sizes, and stored in containers. Some properties of coarse aggregate are illustrated in **Table 3** according to (**IQS, No.45:1980**). The design overall gradation of aggregate is selected by using, **ACI 211.3R, 2009, ACI 325.10R, 2001,** and **State Commission of Roads and Bridges (SCRB) , 2003,** (type II binder course) dense gradation which is usually used for asphalt concrete pavement in Iraq and using the centerline of them. **Table 4** and **Fig. 2** illustrate the combined gradation used throughout the investigation.

2.3 Fine Aggregate

Al-ekhaider natural sand of 4.75 mm maximum size was used as fine aggregate in RCC mixes. The fine aggregate was sieved through sieve size (9.5 mm) to separate the aggregate particles of diameter greater than (9.5mm). The fine aggregate was then cleaned with water on sieve size 0.075mm (No.200 BS.) and after that it was air dried and separated into different sizes to be ready for use. Some properties of natural fine aggregate are illustrated in **Table 3** according to (**IQS, No.45:1980**).The grading of fine aggregates is shown in **Table 4**.

2.4 Porcelanite Aggregate

Porcelanite stone was used in this research in all mixes (except for reference mix). It was brought from Al-Rutba town in Al-Anbar Governorate and tested by **Iraqi Geological Survey Board (IGSB)**. It has a white color and is characterized by high permeability and low density. The large lumps were firstly crushed into smaller size manually with a hammer in order to use it as a partial replacement of fine aggregate with maximum size 4.75 mm, by screening on electrical sieve shaker. The replacement was (5, 8, 12, 16 and 20) % as a volumetric partial replacement percentages of the same sieve analysis and grading curve of fine aggregate. The required quantity of the porcelanite aggregate was washed with water in order to remove dust associated with crushing process of porcelanite stone. The porcelanite aggregate was soaked in water in the laboratory temperature for a suitable time period to bring the aggregate particles to saturation, which is recommended by, **ACI 211.2, 2004.Tables 5 and 6** show some physical and chemical analysis of fine porcelanite aggregate respectively.

2.5 Water

The water used in RCC mixes was potable water for both casting and curing of specimens.

3. PREPARATION OF RCC SLAB SAMPLES

3.1 Roller Compactor and Mould

The slab specimens used in this research were cast in steel mould having internal dimensions (380×380 mm) and depth of (100 mm). This mould consists of a steel plate base of (650×600×10 mm) surrounded by four steel angles with sections of (100×100×10 mm) and weight of (51 kg), as shown in **Fig. 3.**

The roller compactor apparatus, manufactured in a local workshop, is designed to simulate steel roller which is usually used in the field for compaction. It consists of steel skeleton as shown in **Fig. 4** and a solid cylinder (150 mm) in diameter, (330 mm) in length and (15 kg) in weight. The total weight of this apparatus is (36 kg). It is supplied with a container to carry the additional steel weights up to design load.

3.2 Mix design and proportions of RCC

RCC specimens are designed by modified proctor test according to, **ASTM D1557, 2002** (method C). This proportioning method involves establishing a relationship between the dry density and moisture content of the mix by compacting the mix in cylinder steel mould of (152.4mm) diameter and (116.4mm) height. A moisture-density test is used to determine the optimum moisture content which gives maximum dry density of RCC mixtures for each mix. The optimum moisture content is defined as the amount of water present in the mixture design that allows for maximum compaction.

In addition to reference RCC mixture, different percentages of saturated porcelanite content are used (5, 8, 12, 16, and 20) % by volumetric replacement of oven dried fine aggregate and different percentages of moisture content are used to determine the dry density-moisture content relationships and (14%) of cement content by weight of air dry aggregate, according to, **Shamil, 2011** results.

After determination the proportions of the mixes, the specimens are prepared. The total weight of aggregate which filled the above mould is approximately (3.5kg), for safety it is taken equal to be (4.5kg); this weight is separated by 7 sieves which are used in this work according to the retained percentage of these sieves multiplying the total weight of aggregate (4.5kg) by the retained percentage of each sieve.

The mixture is placed into the cylinder in five layers and each layer is compacted with (56) blows of a modified Proctor hammer of (4.5 kg) falling from (450 mm) height. When compaction is finished, the extension collar is removed and the surface of concrete is leveled with the mould, first weighting the mould with concrete, second the wet weighting of mixture is determined.

The above procedure is repeated with other percentages of moisture content. The specimen is withdrawn from mould by using loading jack and the wet specimen of mixture in the mould is weighed, the wet density can be calculated by using Eq. (1) as shown below:

$$\gamma_{wet} = Wm / Vol. \qquad (1)$$

The dry density can be found from Eq. (2):

$$\gamma_d = \gamma_{wet} / (1 + \omega) \qquad (2)$$

After that, the relationship between dry density and moisture content is plotted to find the optimum moisture content then the maximum dry density is calculated for every percentage of porcelanite as shown in **Fig. 5**. A total of 24 cylinder specimens were prepared for this research.

3.3 Casting of RCC slab specimens

3.3.1 Mixing

The same materials, gradation of aggregate and mix proportions which used in hammer compacted method; was used in casting RCC slabs. The retained percentage of aggregate on each sieve stayed the same, but the total aggregate content in this method was calculated to conform to the new volume of slab according to, **ACI 211.3R, 2009**. After mixing, the concrete was poured into the steel mould to construct slab specimen which was prepared for compaction.

3.3.2 Compaction

The mixture was placed in the slab mould and subjected to initial compaction on a vibrating table for 3 cycles of 30 seconds time interval. Such procedure is in agreement with that of, **Shamil, 2011**.The influence of this compaction is to create some initial compactive effort to the freshly laid surface, which is usually the case when using paving machine.

After initial compacting, the concrete mix is compacted using the roller apparatus. The mould was fixed in front of the roller compactor and subjected to three stages of rolling based on the work done by, **Sarsam, 2002,** to each stage15 passes were applied. This number of passes is suitable to achieve the good rolling with little effort, and the rolling action is taken in x-x direction, then the same sequence has been repeated in the y- y direction to insure the compaction of the slab sides as shown in **Fig. 6**. This process is used in three stages on slab specimen to obtain the designed dry density.

First stage: A total load of (1.1 kg/cm width) (using roller compactor weight) is implemented with 15 passes of the roller in each direction. The concrete is settled in a level position and completely fills the slab mould. This can represent the initial compaction in the field.

Second stage: The total load is increased to (3.2 kg/cm width) (using 69kg standard loads + roller compactor weight) with 15 passes in each direction. This may simulate the intermediate field compaction.

Third stage: The total load is increased to (5.3 kg/cm width) (by using 138kg standard loads + roller compactor weight) with 15 passes of the roller in each direction. At this stage, the slab surface is smooth and level. This represents the finishing compaction in the field.

3.3.3 Curing

After compaction, the slab specimens are leveled by hand trawling, and covered with polyethylene sheet and sealed with tape in the laboratory for about (24) hrs at laboratory temperature to prevent evaporation of moisture from the fresh concrete. After that, the specimens were cured with different curing methods according to, **Abed, 2014**, as followed:

- Water curing is for 1 day and then put in air until test.
- Water curing is for 7 days and then put in air until test.
- Permanent (continuous) water curing.

3.3.4 Obtaining Sawed Specimens

According to, **ASTM C42, 2004,** wet concrete diamond sawing process is used to cut the slabs to obtain cubes of (100 × 100 × 100 mm) and beams of (100×100×380 mm).

4. TESTS OF RCC SPECIMENS

4.1 Determination the Ultrasonic Pulse Velocity (UPV) test of RCC specimens

Ultrasonic Pulse transit times are measured by direct transmission method. This test is carried out according to, **ASTM C597, 2002,** on beam and cube specimens for the three different direction. Portable ultrasonic concrete tester known as (PUNDIT) with frequency 55 KHz and accuracy of 0.1 μ sec, is used for this purpose. Specimens were kept under curing method conditions until testing. The loading rate used in the test was 0.3 N/mm² per second. The test was conducted at ages of 7, 28, 56 and 90 days. The pulse transit path length is measured accurately and the time of its travelling was recorded. The pulse velocity is calculated by using Eq. (3).

$$V = L / T \quad (3)$$

4.2 Determination the Voids volume test of RCC specimens

Voids volumes are calculated according to, **ASTM C642, 2006**, in Eq. (4) as follows:-

1- The specimen is weighted and dried in an oven at a temperature of (100-110) °C for 24 hrs. . After removing the specimen from the oven, it is allowed to cool and is weighed and designated as (**A**).

2- The specimen is placed in suitable receptacles, covered with tap water and boiled for 5 hrs. . After that the specimen is allowed to cool for not less than 14 hrs. The specimen is surface dried by removing surface moisture with a towel, and weighed. This weight is to be the soaked, boiled, surface-dried mass (**C**).
3- The specimen is suspended by a wire and the apparent mass in water is determined. This weight is considered to be the apparent mass (**D**).

$$\text{Volume of permeable Voids, \%} = [(C-A)/(C-D)] \times 100 \quad (4)$$

5. DISCUSSIONS

Fig. 7 and **Fig. 8** show the relationship between the UPV and voids volume respectively with age of the RCC specimens for all mixtures of reference and internally cured RCC with (5, 8, 12, 16 and 20) % porcelanite as lightweight aggregate (LWA) replacement of fine aggregate and cured by different methods (air curing, 7 days water curing and permanent curing).

UPV (non-destructive) test is carried out in order to investigate the properties of concrete and also investigates the homogeneity of concrete due to internal curing (IC) agent (porcelanite aggregate) because of the sensitivity of the UPV as an indicator of changes in concrete properties. UPV results can be relied upon. The idea is testing the range of filling pores of the cement paste with cement hydration products thus causing them to get smaller and decreasing the interiors voids, and then increasing the density of cement paste, **Hoff, 2002.**

Generally, high results of UPV were recorded for internally cured RCC with 5% porcelanite replacement as compared with that of reference RCC and other percentages of porcelanite replacement. This increasing in UPV can be attributed to improving the density and homogeneity of RCC due to IC water which keeps on cement hydration. The micro cracks are inhibited and hence the UPV will be improved, **BS1881: part 203, 1986.** The 5% porcelanite using 7 days and permanent curing shows higher UPV than reference RCC due to the effect of IC.

Internal curing with porcelanite aggregate as partial fine aggregate replacement in percentages of (8, 12, 16 and 20) % decreases UPV of concrete compared to 5% porcelanite replacement. The decreasing in UPV can be attributed to; firstly, high moisture content due to high percentage of saturated porcelanite aggregate. Secondly, porcelanite as porous material make UPV decrease due to the high voids within RCC.

Leslie and Cheesman, 1949, and **IS: 13311-Part I, 2002,** listed UPV ranges to indicate the homogeneity and quality of concrete as shown in Tables (2-9) and (4.12). All calculated UPV results show that the internally cured and reference RCC specimens in all methods of curing and for all ages are higher than that of (4.575 and 4.5 Km/sec) respectively. This means homogenous RCC with high quality can be obtained by these proportions, compaction and curing methods.

Apparently, introduction of highly porous LWA into the dense cement matrix increases the voids volume and thus permeability and diffusivity of concrete. The results demonstrated that the voids volume of the RCC specimens that were cured in different curing methods decreases with the progress of the age; this may be due to the fact of the continuous hydration process and the ability of the paste to fill voids in the mixes.

Porcelanite may have a positive effect on RCC properties, as mentioned before, like improving elastic compatibility with cement paste that will lower micro cracking, improving

Interfacial Transition Zone (ITZ) between porcelanite and cement paste matrix which effect on permeability, eliminate or reduce cracks due to autogenous shrinkage.

For all that, the replacement with 5% porcelanite gave the lowest voids volume that can be achieved and which is better than that of reference RCC and other percentages of replacements. The percentage of decrease in voids volume at 5% porcelanite percentage for 28 and 90 day ages using air, and permanent curing methods compared to reference RCC is in the range of (9.7-34.4) % and (13.7-31.6) % respectively.

Voids volume of RCC specimens having other percentages of replacement of porcelanite in all methods of curing show higher percentages of variations than that of reference RCC, the range of variations is in the range of (-0.9-135.3) %. This behavior may be due to increase in the quantity of porcelanite aggregate with the increases in percentage of replacement which consequently increase the IC water which forms large pores inside concrete and reduces the integrity of the ITZ. This will increase the voids volume of RCC concrete. The other possible reason is the increase in Porcelanite replacement percentage leads to increasing the voids volume of fine aggregate which increases voids volume of the paste.

6. CONCLUSIONS

The following conclusions can be drawn from analysis of the results of experimental work which has been done to assess the effect of using porcelanite on RCC:

1. Porcelanite aggregate (light weight cheap and local material) could be used as an internal curing agent by a partial replacement material of fine aggregate.
2. Best percentage of porcelanite used is 5% as a percentage (volumetric) replacement of fine aggregate. This percentage gave an improvement in UPV and Voids volume of RCC.
3. Three methods of curing (air, permanent and 7 day water curing) were used in this study. Permanent water curing has great effect on UPV and Voids volume of RCC specimens than other curing methods for the same RCC mixture.
4. The results of Voids volume and UPV of 5% porcelanite replacement RCC and using air are less than that of the reference RCC using permanent water curing. This result could be very beneficial in practical work in road application fields.
5. UPV of RCC is improved by internal curing with 5% porcelanite replacement and has the highest value compared to the other mixes which ranges between (4.81-5.34 Km/s), (4.87-5.15 Km/s) for reference RCC and (4.6-5.13 Km/s) for others.
6. Voids volume of RCC samples with porcelanite percentage 5% cured with three methods of curing is lower than that with reference RCC cured with permanent curing at all ages. Reference RCC exhibits lower Voids volume than specimens cured with other curing methods and at (8, 12, 16 and 20) % porcelanite replacement.

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NOMENCLATURE

A= mass of oven-dried specimen in air, gm
C= mass of surface-dry specimen in air after immersion and boiling, gm
D= apparent mass of specimen in water after immersion and boiling, gm
V= pulse velocity (m/sec).
L= distance between transducers, (m), and
T= transit time (sec).
Vol. = the volume of the cylinder mould, cm^3.
Wm = the wet weighting of mixture, gm.
γd = the dry density, gm/cm^3.
γwet = the wet density, gm/cm^3.
ω = the moisture content, %.

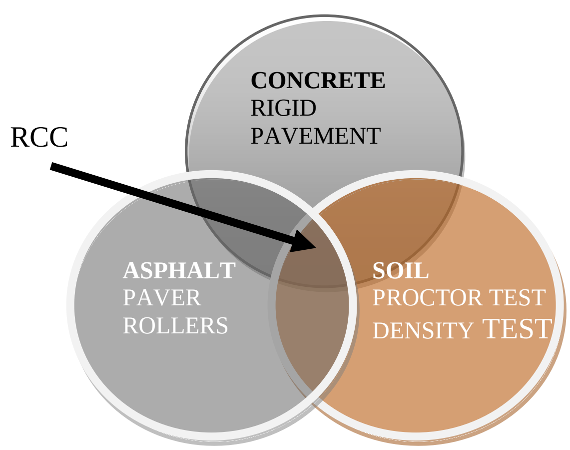

Figure 1. Multiple personalities, ***Adaska*** *and* ***Tull (PCA) (2011)***

Table 1. Physical properties of SRPC *

Properties Physical	**Test Result**	***IQS (No.5:1984) limits***
Specific surface area, Blaine method, m^2/kg *	324	≥ 250
Setting time , Vicat's Method Initial setting , hr. : min Final setting , hr. : min	 1:30 3:40	 ≥ 45 minutes ≤ 10 hours
Compressive Strength MPa 3-days 7-days	 18.5 23.2	 ≥15 ≥23

* Performed by the *IGSB.*

Table 2. Chemical composition and main compounds of SRPC *

Oxide composition	**% by weight**	***IQS (No.5:1984) limits***
SiO2	21.58	----
CaO	62.2	----
MgO	2.75	≤ 5.0
Fe2O3	4.76	----
Al2O3	3.94	----
SO3	2.23	≤ 2.5
Loss on ignition	2.5	≤ 4.0
Insoluble residue	0.71	≤ 1.5
Lime saturation factor	0.88	0.66-1.02
Main compounds (Bogue's equations) **		
C3S	49.57	----
C2S	24.47	----
C3A	2.38	≤ 3.5
C4AF	14.48	----

* Performed by *IGSB.*
** According to, *ASTM C 150, 2005.*

Table 3. Properties of coarse and fine aggregate*

Type of aggregate	Bulk Specific Gravity	Absorption	SO_3 %
coarse aggregate	2.56	0.6	0.06
fine aggregate	2.76	1.2	0.3

* Performed in laboratory of Building Materials-University of Baghdad.

Table 4. Grain size distributed used for RCC

Sieve Size (mm)	Finer by weight %	Grading *SCRB 2003*	Grading *ACI 325.10R & ACI 211.3R*
25.4	100	100	100
19.2	94	90-100	82-100
12.5	80	70-90	72-93
9.5	71	56-80	66-85
4.75	56	35-65	51-69
2.36	40	23-49	38-56
0.3	12	5-19	11-27
0.075	3	3-9	2-8

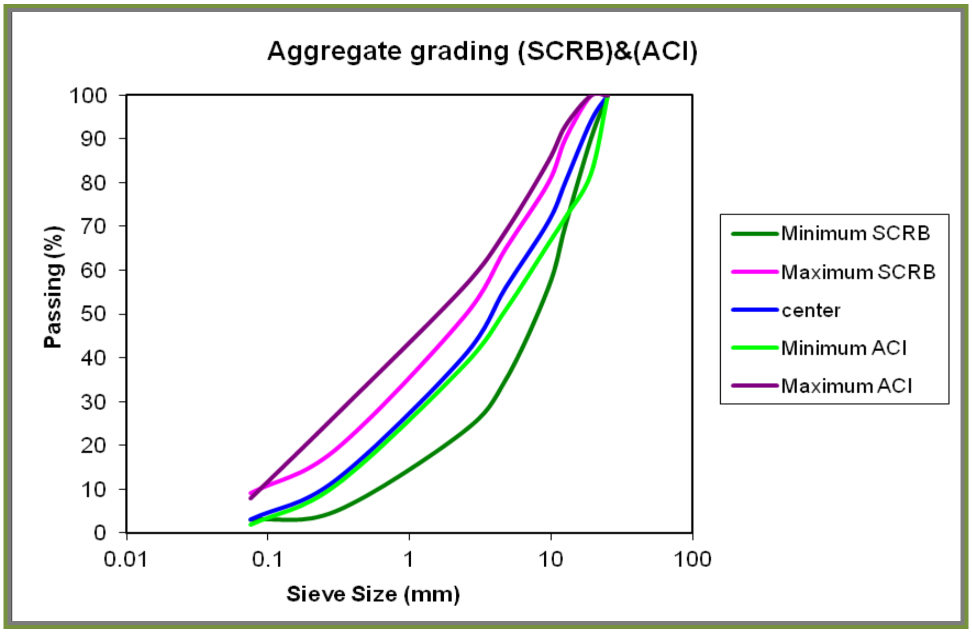

Figure 2. Grading of aggregate according to *SCRB (2003), ACI 325.10R (2001)* and *ACI 211.3R (2009).*

Table 5. Some physical properties for porcelanite aggregate *

Property	Test result
Specific gravity	1.68
Absorption, %	42
Dry rodded unit weight ,kg/m³	860**

* Physical properties testing were performed by *IGSB.*
** Within the limits of *ASTM C330 (2005)* (1120 kg/m³ max.) for fine aggregate.

Table 6. Chemical properties for porcelanite aggregate *

Oxide composition	% by weight
SiO2	70
CaO	8.2
MgO	2.75
Fe2O3	0.98
Al2O3	3.33
SO3	0.1
Loss on ignition	9.5

* Chemical properties testing were performed by *IGSB*.

Table 7. Velocity criterion for concrete quality grading, IS: 13311- Part I (2002)

Pulse velocity by cross-probing,Km/sec.	Concrete quality grading
Above 4.5	Excellent
3.5 to 4.5	Good
3.0 to 3.5	Medium
Below 3.0	Doubtful

Table 8. Suggested UPV for concrete, Leslie and Chessman (1949).

General condition	Ultrasonic pulse velocity (Km/sec)
Excellent	> 4.575
Good	3.66 – 4.575
Questionable	3.05 – 3.66
Poor	2.135 – 3.05
Very poor	< 2.135

Figure 3. Mould of slab specimen

Figure 4. Roller compactor apparatus

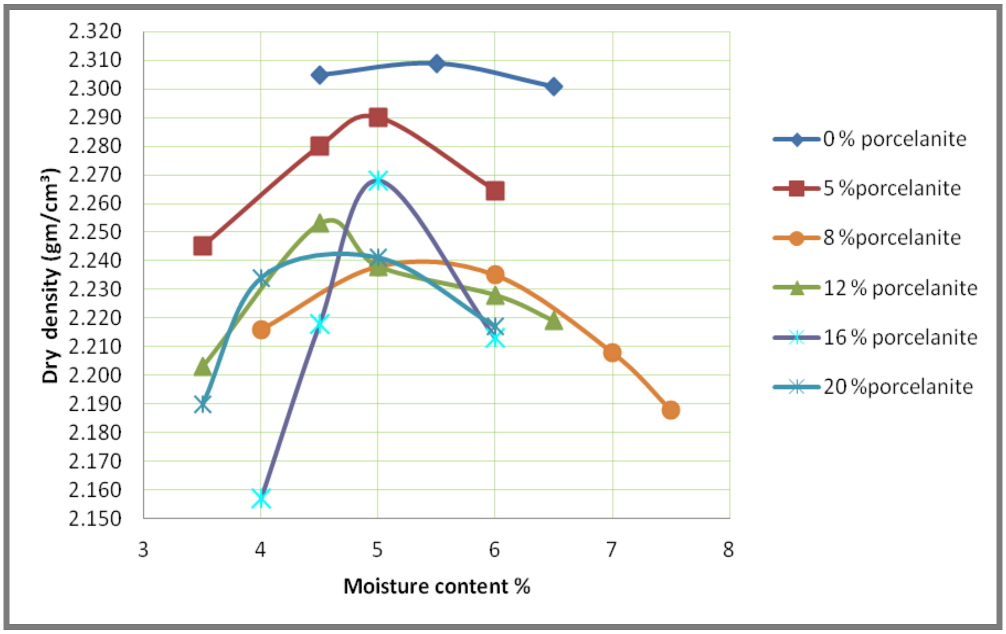

Figure 5. Dry density-moisture content relationships for different RCC mixtures

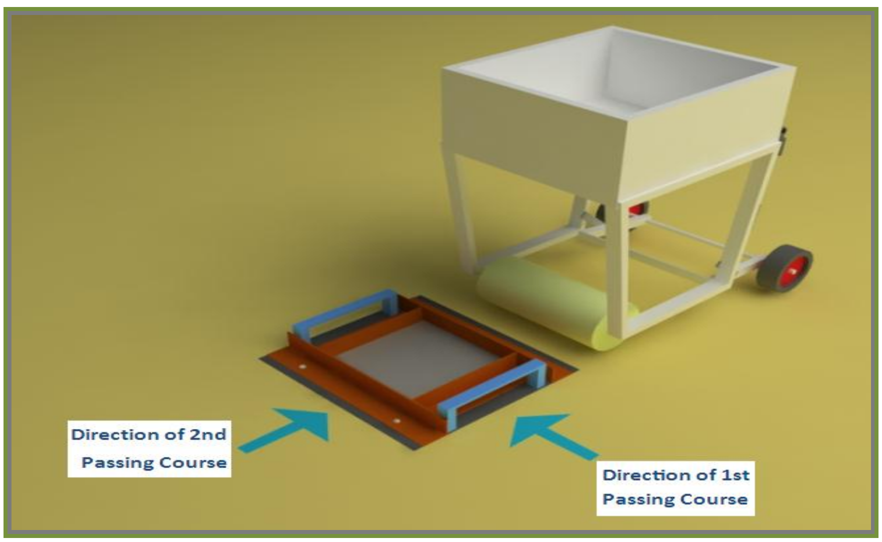

Figure 6. Direction of rolling compactor

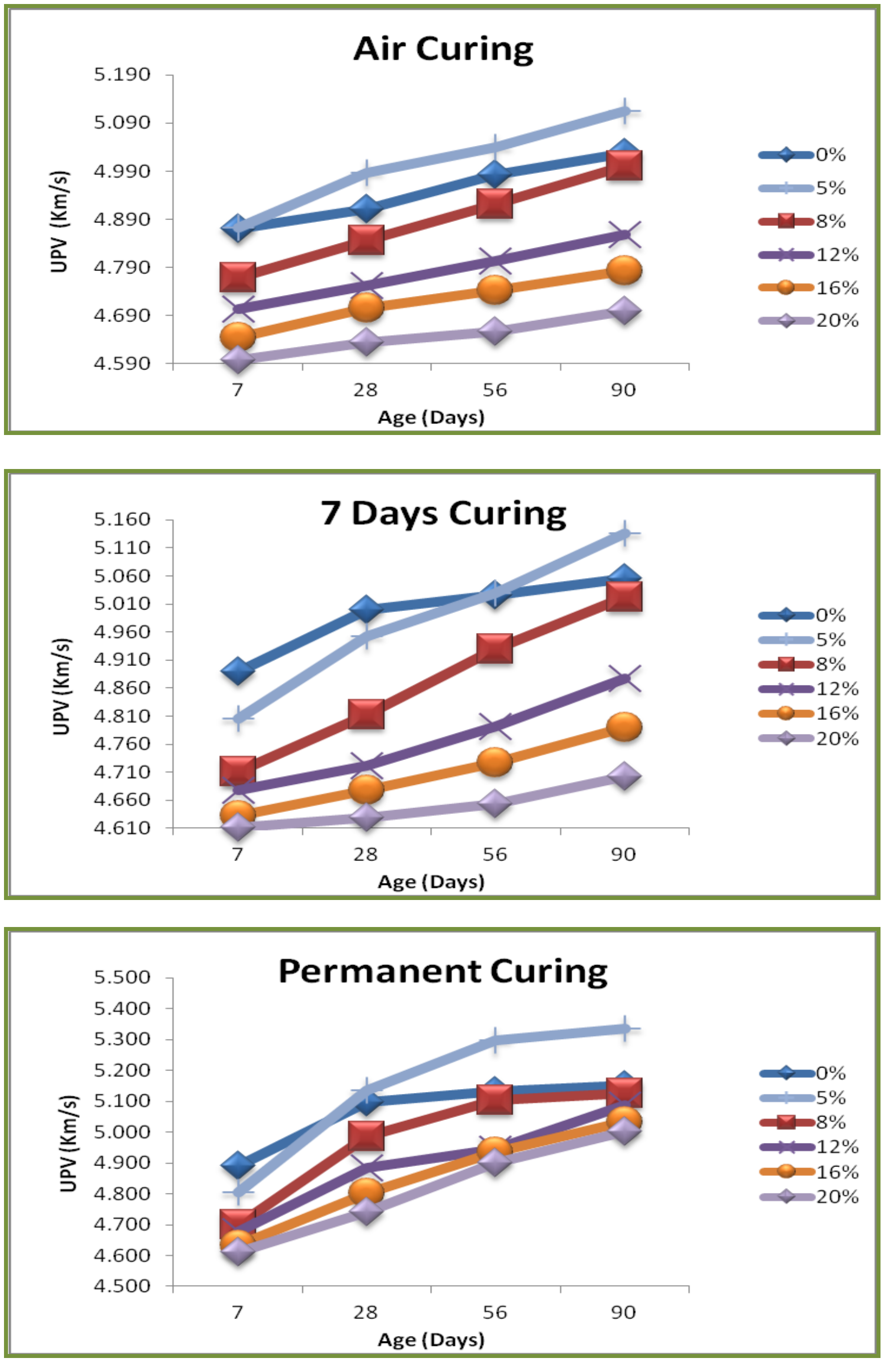

Figure 7. UPV development of RCC with porcelanite replacement percentages.

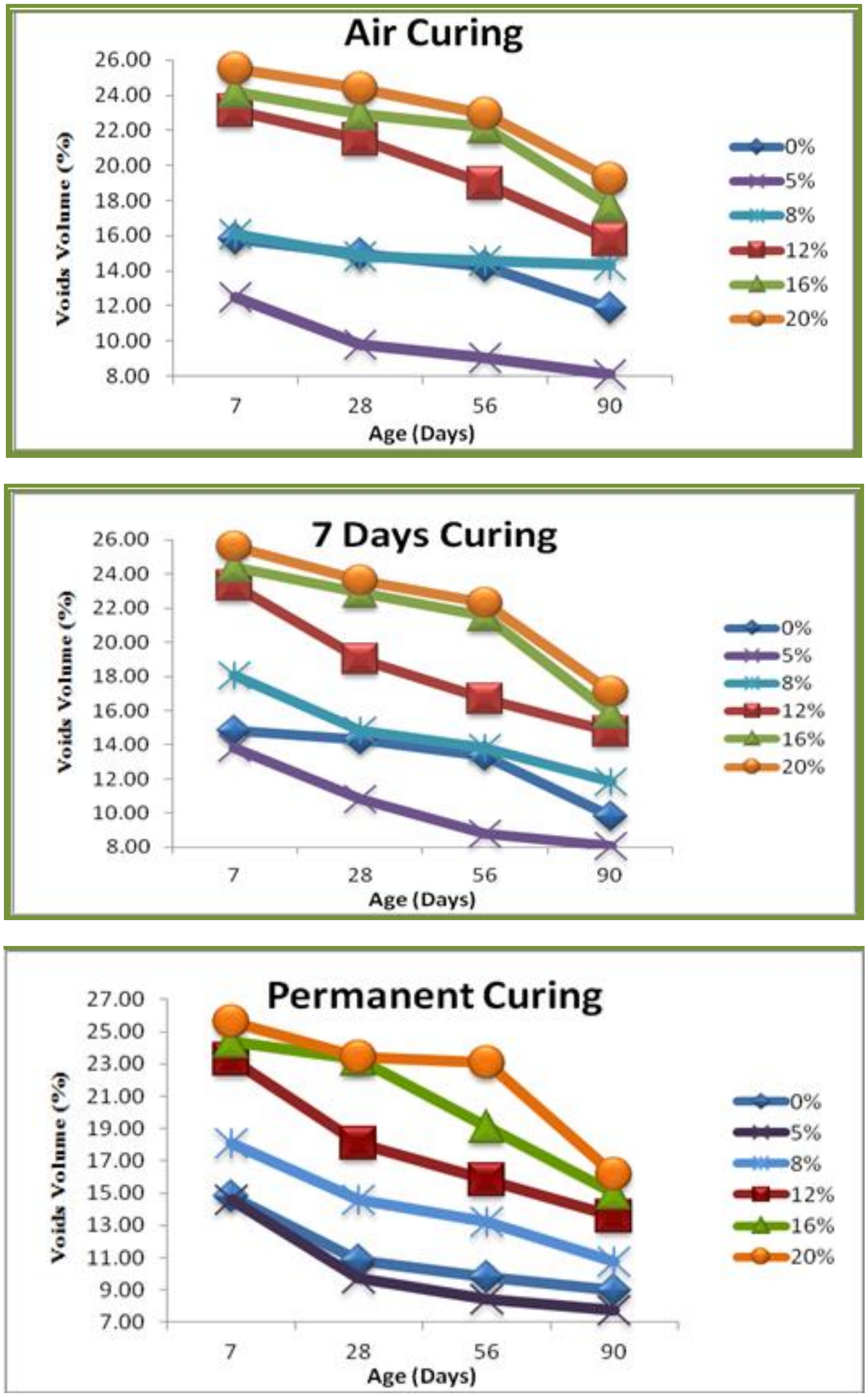

Figure 8. Voids volume development of RCC with porcelanite replacement percentages.