Assessing the Effect of Using Porcelanite on Compressive Strength of Roller Compacted Concrete

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ABSTRACT

Roller-Compacted Concrete (RCC) is a zero-slump concrete, with no forms, no reinforcing steel, no finishing and is wet enough to support compaction by vibratory rollers. Because the effectiveness of curing on properties and durability, the primary scope of this research is to study the effect of various curing methods (air curing, emulsified asphalt(flan coat) curing, 7 days water curing and permanent water curing) and different porcelanite (local material used as an Internal Curing agent) replacement percentages (volumetric replacement) of fine aggregate on some properties of RCC and to explore the possibility of introducing more practical RCC for road pavement with minimum requirement of curing. Cubes specimens were sawed from the slabs of (38*38*10) cm for determination of compressive strength. The results show that using (5) % porcelanite improved the compressive strength of RCC (with air curing) as compared with reference RCC (with permanent curing) by percentage ranging from(-2.9 to 6)%.

Key words: porcelanite, compressive strength, internal curing, roller compacted concrete, curing methods, volumetric replacement.

تقييم تأثير اضافة مادة البورسيلنايت على مقاومة الانضغاط للخرسانة المرصوصة بالحدل.

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الخلاصة

الخرسانة المرصوصة بالحدل هي الخرسانة العديمة الهطول والتي لا يتم فيها أستعمال القوالب أوحديد التسليح ولا تحتاج الى عمل الانهاءات ، ويجب ان تكون ذات رطوبة كافية لتحمّل الحدل بواسطة الحادلة الهزازة.بسبب تأثير الانضاج على خصائص وديمومة لذا فإن الهدف الرئيسي من هذا البحث هو دراسة تأثير طرق الانضاج المختلفة (الانضاج بالهواء، الانضاج بالمستحلب الاسفلتي (الفلنكوت) ، الانضاج 7 ايام بالماء، الانضاج الدائمي بالماء) وبأستخدام البورسيلنايت (مادة محلية تستعمل كعامل أنضاج داخلي) وبنسب استبدال مختلفة (استبدال حجمي من الركام الناعم) على بعض خواص الخرسانة المرصوصة بالحدل واستكشاف مدى امكانية انتاج هذه الخرسانة لرصف الطرق لتكون اكثر عملية وبأستعمال الحد الادنى من متطلبات عملية الانضاج.يتم نشر الواح خرسانة بأبعاد (38*38*10) سم لتشكيل مكعبات لفحص مقاومة الانضغاط.تظهر النتائج ان استعمال (5%) بورسيلنايت يقوم بتحسين مقاومة الانضغاط للخرسانة المرصوصة بالحدل (بأستعمال الانضاج بالهواء) مقارنة مع الخرسانة المرصوصة بالحدل المرجعية (بأستعمال الانضاج الدائمي) بنسبة تتراوح بين (6 – 2.9 -)%.

الكلمات الرئيسية: البورسيلنايت,مقاومة الانضغاط,الانضاج الداخلي ,الخرسانة المرصوصة بالحدل,طرق أنضاج,أستبدال حجمي.

1. INTRODUCTION

The American Concrete Institute (ACI) committee(s) 116R, 2010, and 211.3R, 2009, 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. It differs from conventional hydraulically-bound materials in that it can be exposed directly to traffic, **European Ready Mixed Concrete Organization (ERMCO), 2012.**

RCC is a lean no-slump, with minimal shrinkage, almost dry concrete that is compacted in place by vibratory roller. It is a mixture of aggregates, cement and water. Supplementary cementing materials such as fly ash can also be used. Cement contents range from 60 to 360 kg per cubic meter. Mixing is done with conventional batch mixers, continuous mixers, or in some instances tilting-drum truck mixers, **Kosmatka**, **et al., 2002**.

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

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

The design of RCC uses three common ideas in roads construction; 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 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 Mold

The slab specimens used in this research were cast in steel mold 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 weighted, the wet density can be calculated by using Eq. (1) as shown below:

$$\gamma wet = Wm / V \qquad (1)$$

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 contents 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.
- Water curing is for 1 day and after that the specimens are painted with flan coat and then put in air until test.
- Permanent (continuous) water curing.

3.3.4 Obtaining sawed cubes

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

4. DETERMINATION THE COMPRESSIVE STRENGTH TEST OF RCC SLAB

Compressive strength test was measured on 100 mm cube for the determination of average compressive strength according to, **B.S. 1881: part 116, 1983** using a compression testing machine with a capacity of (2000 KN).

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 compressive strength was determined by using Eq. 3 and the results are expressed to the nearest (0.5N/mm²).

$$Fc = \frac{P}{A} \qquad (3)$$

5. DISCUSSIONS OF COMPRESSIVE STRENGTH TEST RESULTS

Fig. 7 shows the relationship between the compressive strength and age of the RCC specimens for different porcelanite percentages cured in different methods (air curing, flan coat curing, 7 days water curing and permanent curing).

Concrete specimens using porcelanite exhibit an additional increase in compressive strength due to internal curing(IC) with increasing of curing age. This complies with studies carried out by, **Lam, 2005, Bentz, 2007,** and, **Sato, et al., 2011.**

In general, the results show that concrete mixes internally cured with saturated porcelanite aggregate give compressive strength obviously lower than that of reference concrete, independent of the exposure conditions, except concrete internally cured with (5%) porcelanite aggregate as partial fine aggregate replacement. It shows higher compressive strength than reference concrete, in all methods of curing and at 7,28,56 and 90 day age, by (15.2-30.8) (7.9- 22.2) (2-17.9) % and (2-9.8) % at air curing, flan coat curing,7days curing and permanent curing respectively.

The highest percentage of increasing in compressive strength value at 5% porcelanite percentage for all ages and different curing methods compared to reference mix is 30.8 % in air curing method and at age 28 days. Otherwise, the highest percentage of decreasing in compressive strength value at 20% porcelanite percentages is 46.2 % in permanent curing method at 56 days age.

In spite of the fact that the porcelanite aggregate is much weaker than the NWA (fine aggregate),the increase in compressive strength may be due to enhanced cement hydration because of using of saturated porcelanite which works as an IC agent, and this improves of the Interfacial Transition Zone (ITZ) and reduces shrinkage induced in micro cracking according to, **Lura, 2003, Lura, et al., 2005** and, **Piehl,** and **Monning, 2006,** who reported that ,the compressive strength increases due to existing IC water and this is caused by different influences:

- Increase in the degree of hydration and then increase in the hydration products which fill internal voids of concrete.
- Decrease in the porosity of concrete.
- Reduction of stresses and micro cracks due to shrinkage.

6. CONCLUSION

Depending on the results of the experimental work which has been done to investigate the effect of using porcelinite on RCC, the following conclusions can be drawn from analysis of these results:

1. Porcelinite aggregate (light weight locally available cheap material) could be used as a partial replacement material of fine aggregate as an IC agent.
2. Best percentage of porcelinite used is 5% as a percentage replacement of fine aggregate volume. This percentage gave improvement in tested properties of RCC.
3. Four methods of curing (air, permanent, flan coat and 7 day water curing) were used in this study. Permanent water curing has great effect on compressive strength, flexural strength (modulus of rupture), bulk density, porosity, absorption and UPV of RCC specimens than other curing methods for the same RCC mixture.
4. Compressive strength of RCC is improved by IC with 5%porcelinite replacement and has the highest value compared to the other mixes and ranges between (25.5-45 MPa), for reference RCC ranges between (23-41MPa) and for others (14.5-38 MPa).These results are for RCC using all methods of curing and for all ages.

5. The results of compressive strength, flexural strength and density show that the values of 5% porcelinite percentage replacement RCC and using air or flan coat curing (depending on exposure conditions) were equal or greater than of the reference RCC. This result could be very beneficial in practical work in road application fields. It reduces the time of work, the total cost of project and improves the properties of RCC.

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NOMENCLATURE

A = area exposed to load, mm^2.
Fc = compressive strength, MPa.
P = maximum applied load indicated by the testing machine, N.
V= 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, %.

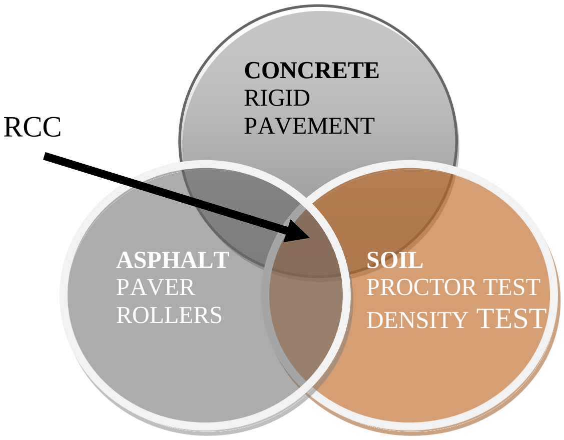

Figure 1. Multiple personalities, ***Adaska** and **Tull (PCA) (2011).***

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 *Iraqi Geological Survey Board (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

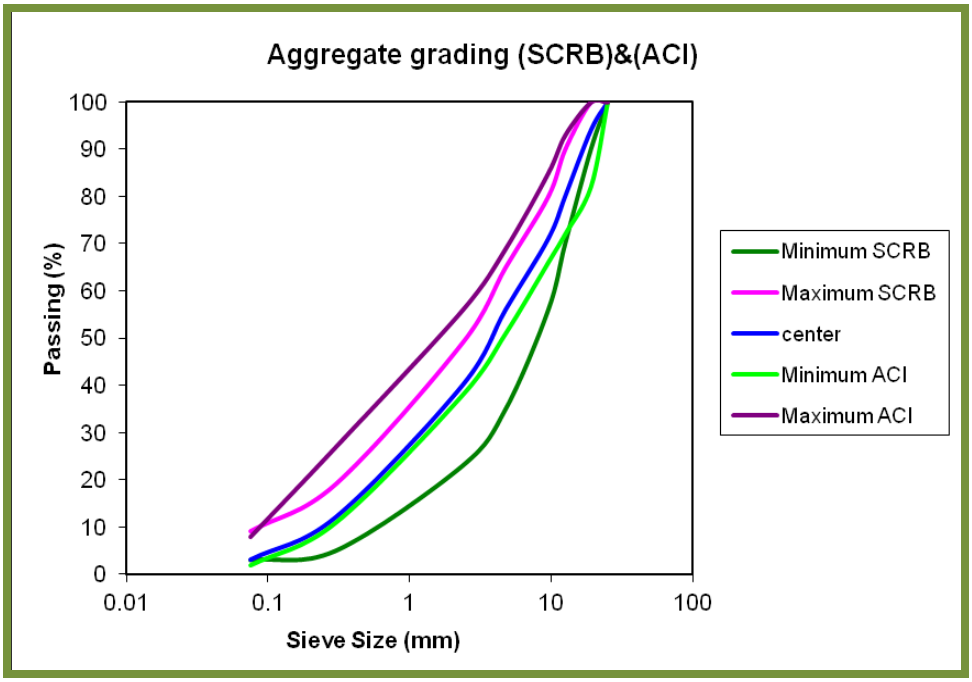

Figure 2. Grading of aggregate according to *SCRB (2003), ACI 325.10R (2001)* and *ACI 211.3R (2009).*

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**
SiO_2	70.03
CaO	8.2
MgO	2.75
Fe_2O_3	0.98
Al_2O_3	3.33
SO_3	0.1
Loss on ignition	9.5

* Chemical properties testing were performed by *IGSB.*

Figure 3. Mould of slab specimen.

Figure 4. Roller compactor apparatus.

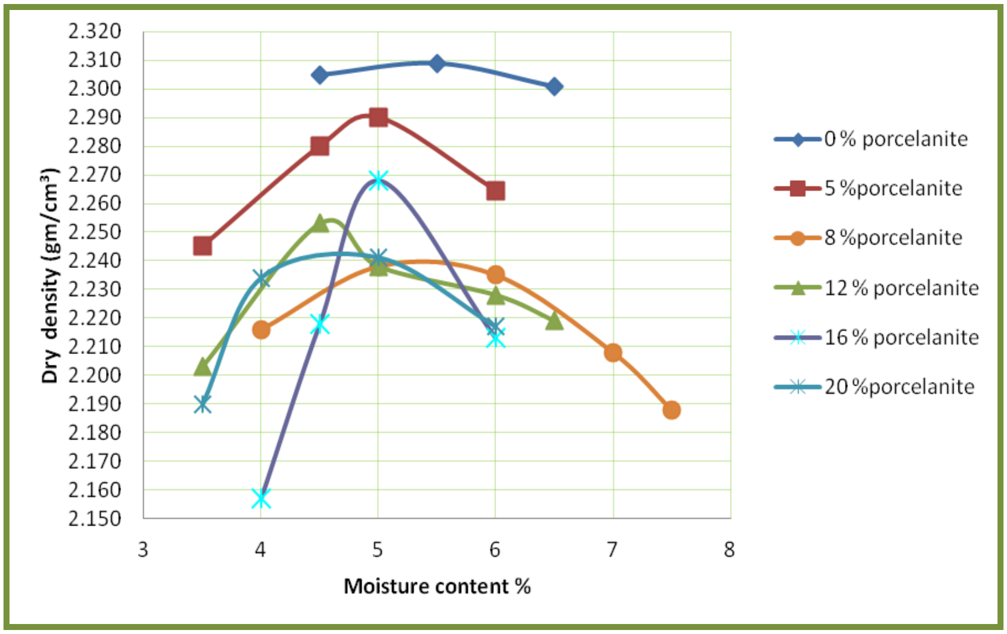

Figure 5. Dry density-moisture content relationships for different RCC mixtures.

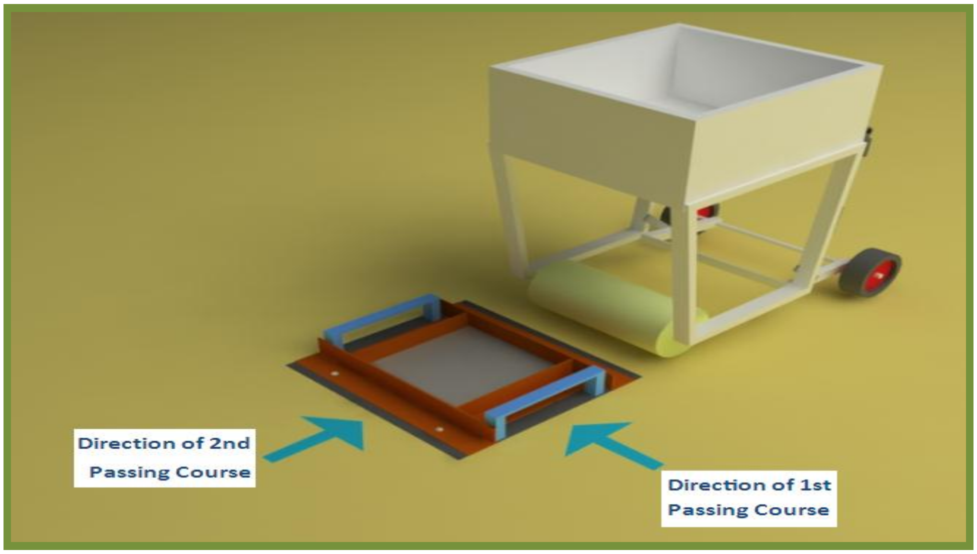

Figure 6. Direction of rolling compactor.

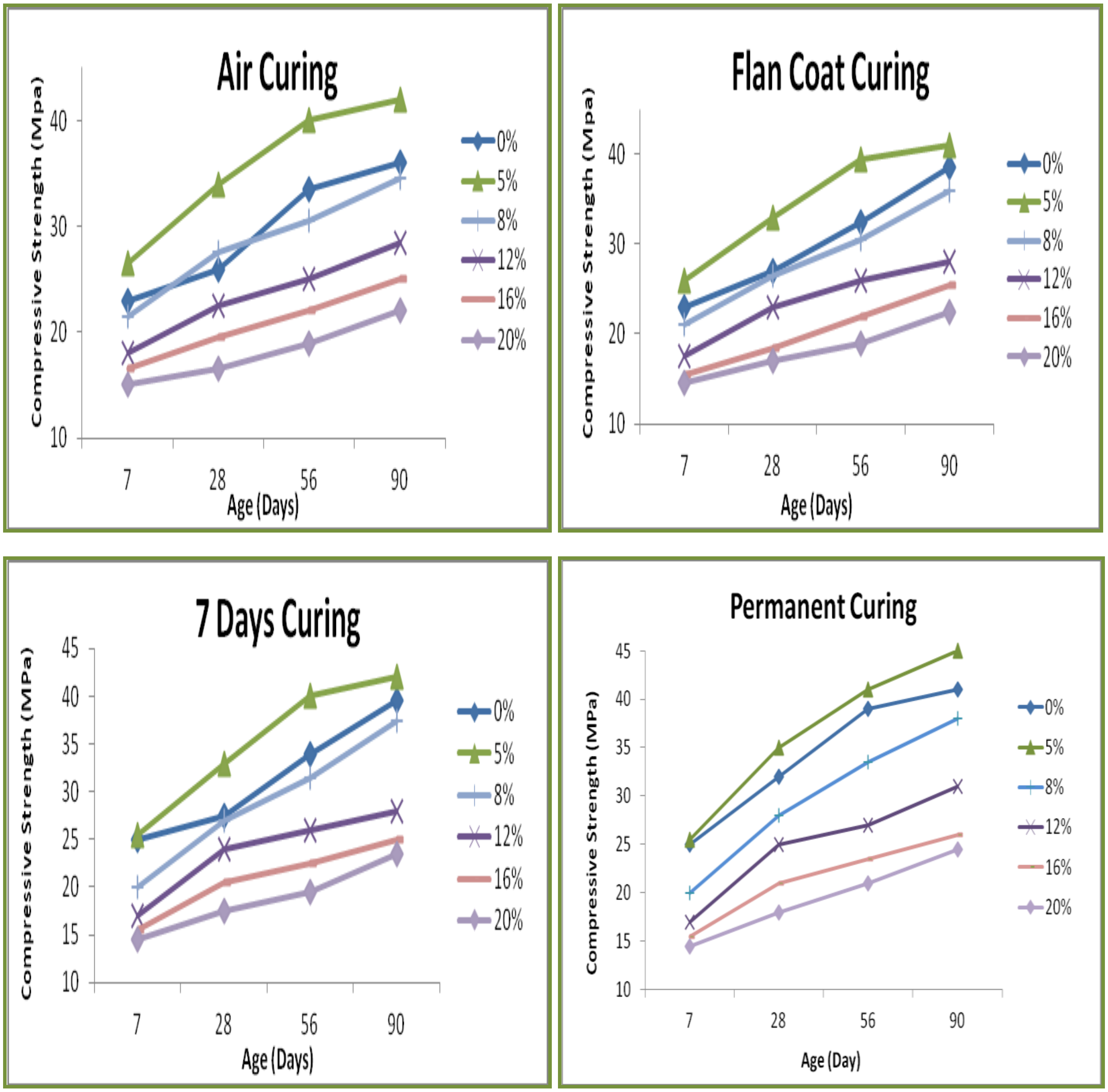

Figure 7. Compressive strength development of RCC with porcelanite replacement percentages.