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Properties of Roller-Compacted Concrete Pavement Containing Different Waste Material Fillers

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ABSTRACT

Waste materials might be utilized in various applications, such as sustainable roller compacted concrete pavements (RCCP), to lessen the negative environmental consequences of construction waste. The impacts of utilizing (brick, thermostone, granite, and ceramic) powders on the mechanical characteristics of RCCP are investigated in this study. To achieve this, the waste materials were crushed, grounded, and blended before being utilized as filler in the RCCP. After the mixes were prepared, compressive strength, splitting tensile strength, flexural strength, water absorption, density, and porosity were all determined. According to the research results, adding some of these powders, mainly brick and granite powder, enhances the mechanical characteristics of RCCP due to their pozzolanic activity and filler effect. Compared to the reference mixture, the usage of ceramic powder provided satisfactory results. When the thermostone powder is utilized in RCCP, unfavorable results occur, resulting in a reduction in the RCCP's mechanical characteristics.

Keywords: Roller compacted concrete, waste materials, recycled powder, sustainable concrete pavement.

خواص الخرسانة المرصوصة بالحدل الحاوية على انواع مختلفة من المواد المالئة

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لتقليل الاثار السلبية للمخلفات الانشائية, عادة ما تستخدم هذه المواد في مجموعة منوعة من التطبيقات.من اهم هذه التطبيقات هي الخرسانة المرصوصة بالحدل.في هذه الدراسة تم استخدام مسحوق الطابوق,الثرمستون,الكرانيت والسيراميك كمواد مالئة في انتاج الخرسانة المرصوصة بالحدل ودراسة تأثير استخدام هذه المواد على الخواص الميكانيكية للخرسانة المرصوة بالحدل. بسبب توفره محليا ورخص ثمنه تم استخدام مسحوق اللايمستون كمادة مالئة في الخلطات المرجعية.لاستخدام هذه المواد كمسحوق تم تكسير هذه المخلفات وطحنها الى مسحوق ناعم.بعد تحضير النماج تم قياس كل من مقاومة الانضغاط,الشد والانحناء كذلك تم قياس الامتصاص والكثافة والمسامية للنماذج. وفقًا لنتائج البحث ، فإن إضافة بعض هذه المساحيق ، خاصة مسحوق الطابوق والكرانيت ، حسن من الخصائص الميكانيكية للخرسانة المرصوصة بالحدل نظرًا لنشاطها البوزولاني وتأثير المواد المالئة. بالمقارنة مع الخليط المرجعي ، فإن استخدام مسحوق السيراميك قدم نتائج مرضية. اما عند استخدام مسحوق الثرموستون ادى ذلك الى انخفاض في الخواص الميكانيكية للخرسانة المرصوصة بالحدل.

الكلمات الرئيسية: الخرسانة المرصوصة بالحدل, المخلفات, الخلطات المرجعية, رصيف خرساني مستدام

1. INTRODUCTION

Due to the rising prevalence of industrial waste, several academics have concentrated on recycling solutions in recent years. Meanwhile, highways have received much attention since they play an essential part in a country's growth. A roller compacted concrete pavement (RCCP) is a zero-slump concrete pavement consisting of aggregates, cement, and water. After being prepared with standard asphalt paving machinery, this mixture is flattened and compacted using a vibratory roller. Factory floors, mine access roads and ports, military vehicle terminals, automobile parking lots, and warehouse floors may utilize the RCCP **(ACI 325.R10)**. Researchers have recently recognized the need to recycle industrial waste to reduce landfills and the need to utilize natural aggregates to avoid environmental harm. Construction waste materials are partially used in concrete pavements to replace cement and substitute natural aggregates. This approach may cut the cost of concrete manufacturing and be environmentally friendly. Researchers are working to improve sustainable road pavement innovation since this industry uses many raw materials, improperly disposes of waste, and emits many greenhouse gasses **(Zimmermann et al.,2005)**. Natural resource depletion is primarily due to construction operations, which account for 24% of global natural resource extraction and generate substantial waste. Resources and raw materials exploitation may also devastate the landscape, harm human health and the environment, as well as pollute water and air **(Bribian et al., 2010)**. Regarding environmental effects, the civil construction industry is undoubtedly a major source of greenhouse gas emissions, accounting for 40–50% of global emissions **(Monkizkhasreen et al., 2009)**. The preparation and assembly of construction materials and the energy consumed by machines to prepare and assemble them discharge pollutants into the environment. **(Yan et al., 2010)**.

The construction sector produces a vast amount of construction waste materials annually. Because these materials are hard to deal with and, as discussed earlier, they cause many environmental harm problems, figuring out a way to recycle construction wastes is essential. In this study, construction waste materials like (brick, thermostone, granite, and ceramic) have been utilized in RCCP production as filler materials, and the suitability of these materials has been investigated in terms of the mechanical properties of RCCP.

2. LITERATURE REVIEW

In recent years, recycled materials such as ceramics, coal, XLPE, and recycled polyethylene terephthalate have been studied for use in rigid and flexible pavements (PET). Crumb rubber and silica fume were used to replace aggregates and a part of cement in a research performed by **(Fakhri and Saberi, 2016)**. The mechanical properties of RCCP mixes were examined by increasing the amounts of crumb rubber that replaced aggregate by (5, 10,..., and 35 percent), and an eight percent of silica fume content replaced cement. The samples containing crumb rubber and silica fume cured for 28 days were all tested for mechanical properties; the results indicated a considerable increase in compressive strength **(Fakhri and Saberi, 2016)**. Building waste and recovered asphalt pavement were also used as aggregates for concrete paving, as were recycled concrete aggregates (RCA). The study results show that using these materials is beneficial in terms of waste management.

Moreover, when these waste materials are utilized in appropriate quantities and with a proper design, they may improve the mechanical qualities of concrete pavement **(Sereewatthanawut and Prasittisopin, 2020) and (Hossiney et al., 2010)**. In two additional experiments, shredded rubber was employed as RCCP aggregates. The mechanical characteristics of RCCP were examined by substituting different amounts of this material with natural aggregates. The tests revealed that this material might improve RCCP's energy absorption and ductility. However, the mechanical characteristics of this material deteriorated compared to RCCP reference samples; Silica fume was introduced to the RCCP mixes that contained shredded rubber to ease the problem **(Meddah et al., 2014, and (Meddah et al., 2017)**. The impact of XLPE waste on RCCP as a recycled aggregate was examined by replacing the natural aggregate with the XLPE with different percentages (5, 15, 30, and 50% replacement), and the mechanical properties of the RCCP mixes were also investigated by **(Shamsaei et al., 2017)**. XLPE waste was shown to increase the ductility of RCCP **(Shamsaei et al., 2017)**. In another case, **(Lopez-Uceda et al., 2016)** looked at the impact of roller-compacted concrete's mechanical qualities when recycled concrete aggregate (RCA) was used as coarse particles (RCC). 50% and 100% of the natural aggregate contents were replaced. The findings suggested that RCA could be used to substitute coarse aggregate in road building by 100 percent **(Lopez-Uceda et al., 2016)**. **(Shamsaei et al., 2019)** investigated the effect of substituting coal and ceramic waste powders for cement in RCCP at replacement percentages of 5 and 10% by weight. The results of the tests revealed that the mechanical characteristics of RCCP had deteriorated. The mechanical and durability properties of concrete pavement mixtures containing ceramic waste and micro-silica have been investigated. The mixtures were prepared by replacing part of cement with silica and part of natural aggregate with waste ceramic. The tests were conducted at temperatures of 20 to 800 degrees Celsius and in an acidic environment to test the durability of the RCC. Tests have shown that adding ceramic waste to concrete mixes increased their durability **(Zareei et al., 2019)**. Likewise, the freeze-thaw resistance of concrete mixtures, including ceramic waste, was examined. Fine aggregates had been replaced with various percentages of ceramic waste, including 20 percent, 40 percent..., 80 percent, and 100 percent.

As a consequence of the findings, it was discovered that incorporating ceramic waste might improve the durability of concrete mixtures **(Siddique et al., 2019)**. According to the experience of employing waste materials in RCCP, it is clear that waste materials such as (brick, thermostone, granite, and ceramic) have not yet been used as powder fillers in RCCP. Using some of these waste elements in RCCP may also affect the workability of this form of concrete pavement, requiring more research. The mechanical characteristics of RCCP, including these waste materials, are investigated in this research.

3. EXPERIMENTAL PROGRAM

3.1. Materials properties

3.1.1. Aggregate

In this study, the crushed stone aggregate was used as a coarse aggregate, and natural river sand was employed for fine aggregate. The fine and coarse aggregate grading were compared with the ASTM grading standards **(ASTM C33-18)**, and both coarse and fine aggregates were within acceptable limits, as shown in **Fig.** 1 and **Fig. 2**. The aggregate characteristics are shown in **Table 1**. The **(ACI 327R-14)** suggests a grading limit for combined aggregate used in RCC; in this study, these limits have been used to choose the grading of combined aggregate, as illustrated in **Fig. 3** . To avoid segregation, the nominal maximum size of coarse aggregate was limited to 19 mm. Also, The fine aggregate had a particle size of less than 4.75 mm (sieve No.4).

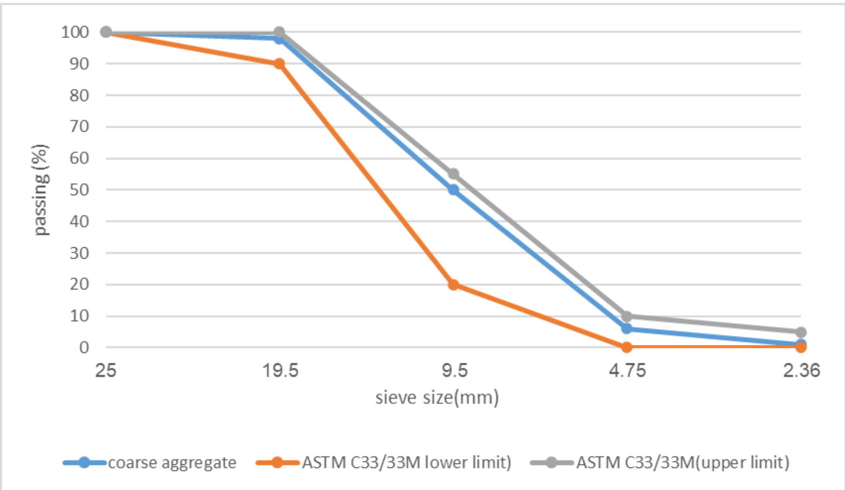


Figure 1. Gradation of coarse aggregates and ASTM C33 limitations.

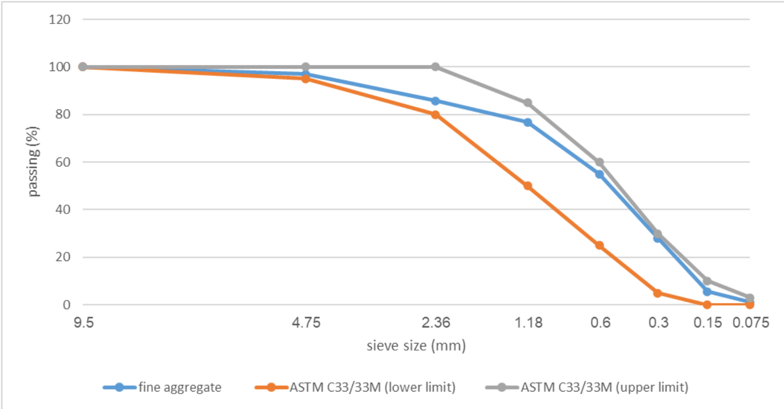


Figure 2. Gradation of fine aggregates and ASTM C33 limitations.

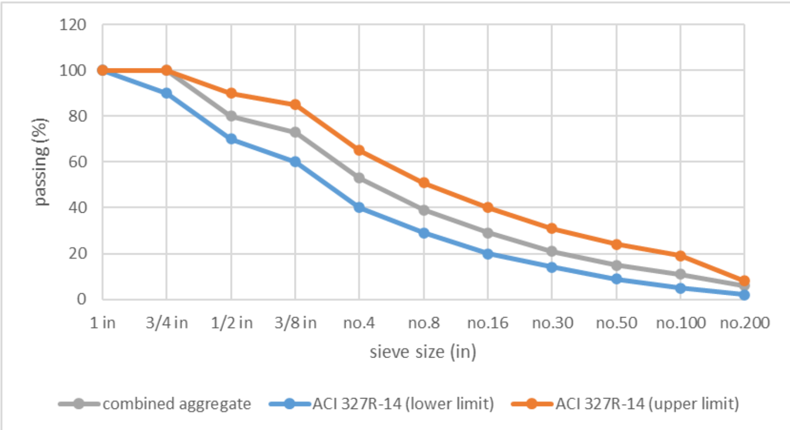


Figure 3. combined aggregate graduation and ACI 327R-14 limitation.

Table 1. Aggregate characteristics.

test	Coarse aggregate	Fine aggregate	ASTM (C33-18) limits
Bulk specific Gravity	2.62	2.592	--
Absorption of water (%)	0.23	1.23	--
Soundness by Sodium Sulfates%	1	2	10 % max. Fine agg. 12% max. Coarse agg.
SO_3 (%)	0.04	0.231	--
Abrasion by Los Angeles Test (%)	15	--	50% max.
Fractured aggregates (%)	95	--	--

3.1.2. Cement

Ordinary Portland cement (type I) was utilized in this experiment. **Table 2** summarizes the chemical and physical characteristics of cement.

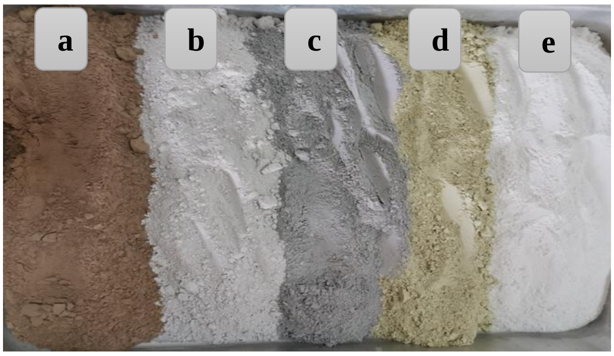
Table 2. Physical and chemical characteristics of cement.

	Test	Result	(ASTM C150 / C150M-20)
Physical Properties	Fineness, specific surface area by air-Permeability, m^2/kg	345	260 Min.
	Setting Time (initial), hr: Min	02:10	00:45 Min.
	Setting Time (final), hr: Min	03:45	6:15 Max.
	Autoclave expansion %	0.042	0.8 Max.
	Compressive strength, MPa		
	3 days	30	12 Min.
	7 days	37	19 Min.
Chemical properties	(SiO_2), %	21.27	
	(AL_2O_3),%	5.27	
	(Fe_2O_3),%	3.20	
	(CaO), %	62.40	
	(MgO), %	1.61	6 Max.
	(SO_3), %	2.01	3 Max.
	(I.R.), %	0.56	1.5 Max.
	(LOI), %	2.55	3 Max.

3.1.3. Powder Fillers

For this investigation, five types of mineral fillers were employed (material passing sieve No.200); limestone powder (LP), brick powder (BP), thermostone powder (TP), granite powder (GP), and ceramic powder (CP). Limestone powder is one of the options usually used as filler in RCCP. Because of its broad availability and inexpensive cost, this investigation used an RCC mixture with limestone powder filler was used as a reference mixture. The other filler employed in this study was waste materials brought from different construction sites and crushed and ground to a very fine powder to be used as filler.

Figure 4 shows the different types of fillers. The chemical analysis and particle size distribution of all types of powder fillers are shown in table 3. the particle size distribution analysis results are shown in fig. 5.



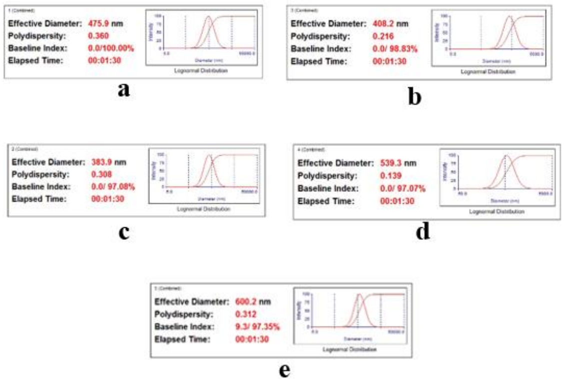


Figure 4. Different types of mineral fillers (a) ceramic powder, (b) thermostone powder, (c) granite powder, (d) brick powder, and (e) limestone powder.

Figure 5. partical size distribution analysis,(a) LP, (b) BP, (c) TP, (d) GP, (e) CP.

Table 3. chemical composition and particle size distribution of all types of fillers.

Criteria	LP	BP	TP	GP	CP
SiO2, (%)	5.05	68.35	5.14	64.8	51.7
AL2O3,(%)	1.62	13.7	8.64	14.42	18.2
Fe2O3,(%)	0.61	7.83	4.51	3.9	6.1
Cao, (%)	49.08	2.19	55.36	4.9	6.1
MgO,(%)	1.59	1.67	2.66	2.5	2.4
SO3, (%)	0.22	0.15	1.9	1.8	1.06
LOI, (%)	32.35	1.85	6.4	4.09	0.96
Particle size distribution (nm)	475.9	408.2	383.9	539.3	600.2

3.2. Mixture Proportioning

Five different mixtures of RCC were made. The reference mixture was made with limestone powder filler, and the others were made with different waste materials fillers. The **(ASTM D1557-12)** standard may be a viable method for achieving the appropriate water content and density for RCC. The materials utilized to make RCC mixes in this research were cement, coarse aggregates (crushed stone), natural river sand, and several types of filler (limestone powder (LP), brick powder (BP), thermostone Powder (TP), granite powder (GP), and ceramic powder (CP)). Following the recommendations of **(ACI 327. R, 2015)** and **(ACI 327. R, 2015)**, a cement content of 12 percent by weight of the total dry components was employed. According to the outcome of gradation tests, prescribed amounts of aggregates consisting of 50% coarse crushed stone, 44%

natural river sand, and 6% filler were employed. The optimum moisture content (OMC) and maximum dry density for each type of powder filler were determined by the modified proctor test following the (ASTM D1557-12), based on different water values provided by (ACI 327. R, 2015) and (ACI 211.3.R, 2002). The modified proctor compaction test (ASTM D1557-12) (Procedure C) was utilized to proportion RCC mixtures. This process used a range of molding water percentages, beginning at 4.5 percent and rising by 1% up to 8.5 percent. The data are plotted as curves with dry density (kg/m^3) and OMC values (percent), as shown in **fig. 6**. Constant quantities of 3000 gm crushed stone aggregate and 2640 gm natural river sand with 360 gm fines were combined with the amounts of cement and water for proportioning all RCC mixes using the modified proctor test.

3.3. Casting procedure

Two types of specimens were prepared to conduct destructive and non-destructive tests (cylinder samples and beam shape samples). The compaction procedure followed **ASTM (C1435/C1435M – 14)** using the vibrating hammer. Cylindrical samples (15 cm in diameter and 30 cm in height) were compacted in four layers. Additionally, beam-shaped samples (10 * 10 * 50) cm were

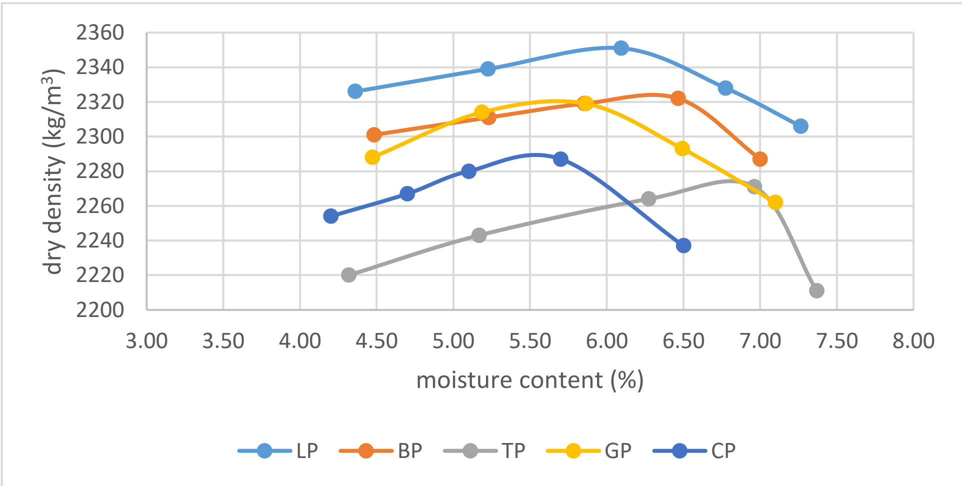


Figure 6. moisture content (%) with dry density (kg/m^3) relationship for different types of fillers.

compacted in two layers in prismatic molds. After completing the casting procedure, the samples were cured for 24 hours in the laboratory environment and covered with a plastic sheet to minimize water evaporation. The samples were then taken from the molds and stored at a temperature of about 23 ± 2 °C in a lime-saturated water bath until the prescribed testing duration (28 and 90) days. **Figure 7** illustrates some pictures of the casting procedure.

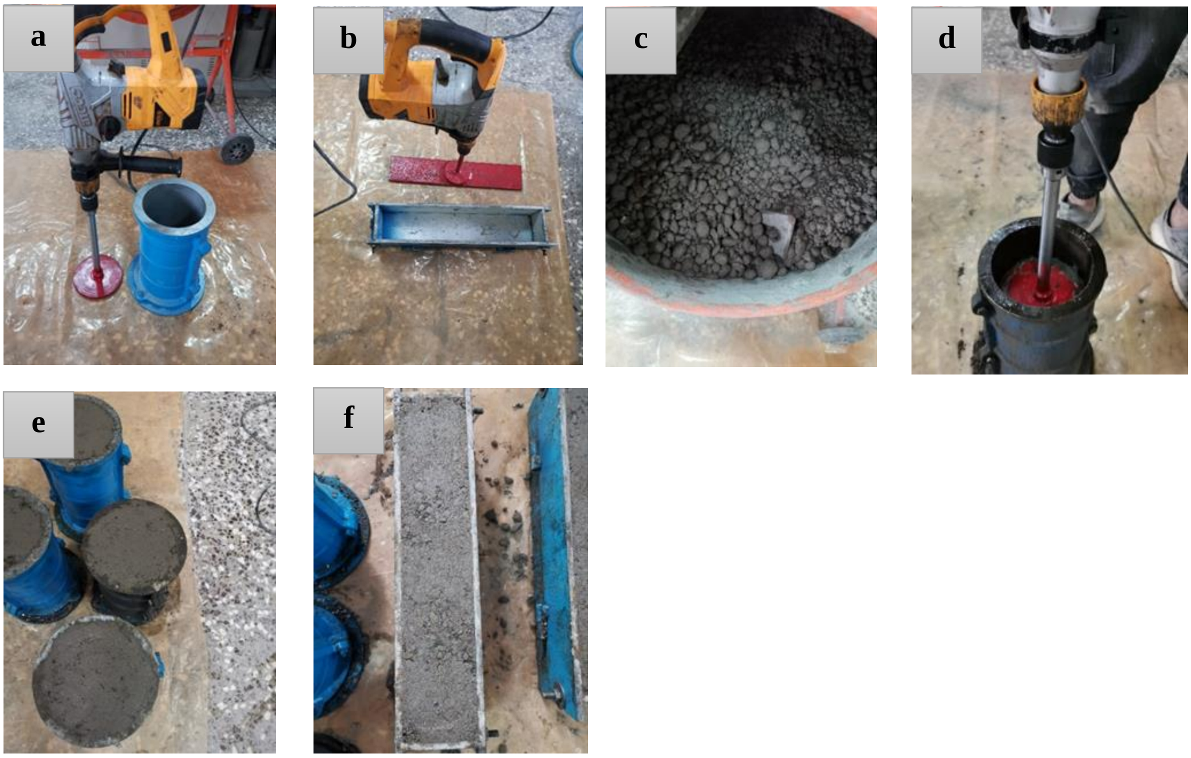


Figure 7. (a) and (b) vibrating hammer, (c) homogeneous mixture of RCC, (d) compaction procedure of RCC,(e) and (f) samples after compaction.

3.4. Mechanical properties

3.4.1. Compressive strength

Cylinder samples with dimensions of (15 cm in diameter and 30 cm in height) were used to determine the compressive strength. The samples had been cured in a curing water tank for (28 and 90) days. The test was conducted by **(ASTM C39-15)**. The compressive test machine of 3000 KN capacity was used to perform the test with a loading rate of 0.25 ± 0.05 MPa/s. **Figure 8** illustrates the compressive test procedure.

3.4.2. Splitting Tensile strength test

The test was carried out by **(ASTM C496-11)** on cylinder samples with dimensions of (15 cm in diameter and 30 cm height). The test was performed on cured samples at the age of 28 and 90 days. The compressive test machine with 3000 KN capacity was used with a loading rate of 0.7 to 1.4 MPa/min. **Figure 9** shows the sample testing in the loading machine.

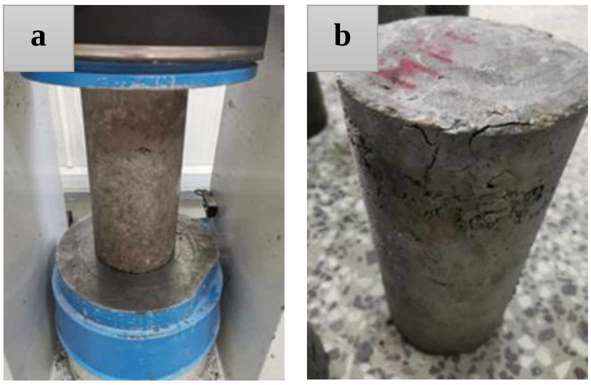


Figure 8. (a) cylinder sample in the compressive test machine, (b) the sample after failure due to compressive load.

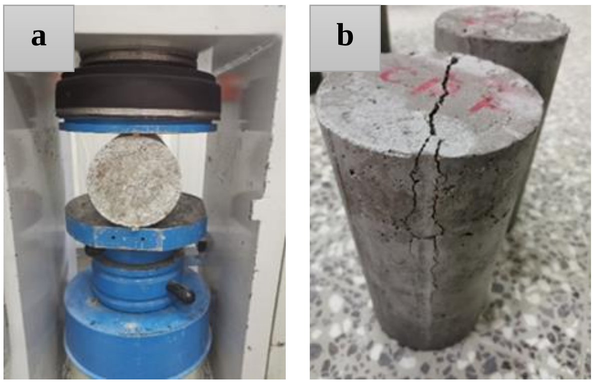


Figure 9. (a) cylinder sample testing for tensile strength, (b) the sample after failure.

3.4.3. flexural strength test

Flexural strength was determined for each mixture using beam shape samples with dimensions of (10*10*50) cm. The specimens were subjected to testing following **(ASTM C78-15)** (two-point loading). The specimens were put in the testing machine to touch the sample's surface. The test was performed on samples cured for 28 and 90 days. **Figure 10** shows the sample in the flexural test machine.

3.4. Density, porosity, and Absorption Tests

The procedure used to determine the density, porosity, and absorption of roller-compacted concrete samples is detailed in **(ASTM C642-13)**. The test was done on individual pieces of cylinders and prisms with a volume for each piece of more than 350 cm^3 obtained by cutting the cylinder and prism samples into individual pieces. The test was carried out on the samples cured for 28 and 90 days. **Figure 11** shows some pictures illustrating the test procedure.

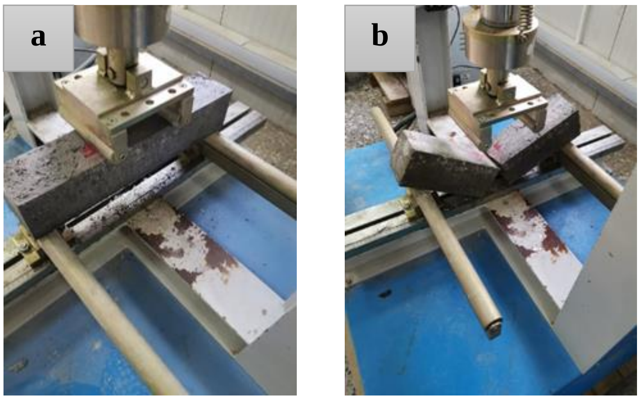


Figure 10. (a) the sample in the flexural testing machine, (b) the sample after failure.

Figure 11. (a) cutting the samples, (b) drying the sample for 24 hours, (c) taking the weight of SSD sample after immersed in water for 48 hours, (d) taking the weight for The sample in water.

4. RESULT AND DISCUSSION

4.1. Density and optimum moisture content

Table 4 illustrates the results of the modified proctor test. It can be noticed that the maximum dry density had decreased as the limestone powder filler was replaced with other types of filler. This decrease is attributed to the lower specific gravity of the other filler than limestone filler **(Mardani and Ramyar,2012)**. As seen in **fig. 6,** utilizing thermostone powder as a mineral filler results in the lowest fresh density, followed by ceramic powder. This is because thermostone and ceramic powder have lower specific gravity than the limestone powder they replaced as mineral filler. Also, as shown in **table 4** and **fig. 6**, the optimum water content has varied when limestone filler was replaced with other types of filler. The differences in optimum moisture content may be for the following reasons: higher surface area of one filler compared to another filler, absorption of water differ from one material to another for pozzolanic reaction, and different mineral fillers have a varying loss on ignition values, resulting in more unburned carbon, which reacts and absorbs some of the water **(Adamu et al., 2017)**.

Table 4 Optimum moisture contents and maximum dry densities for different RCC mixes.

Mix-ID	OMC %	γ Dry kg/m^3
LPF	6.1	2352
BPF	6.3	2325
TPF	6.8	2274
MPF	5.7	2322
CPF	5.5	2290

4.2. Compressive strength

The compressive strength of RCC is comparable to that of ordinary concrete (28 to 41 MPa). Practical construction and economic factors would likely demand increasing thickness above compressive strengths of (48 MPa), even though this has already been attained in specific projects. The enhanced compressive strength of RCC is due to the use of tightly graded aggregates in the mix. The lower W/C ratio of RCC mixes gives a lower porosity in the cement matrix, resulting in increasing the compressive strength of RCC. Each RCC mixture proportion has an optimum moisture content to attain the maximum dry density. This density usually provides the highest strength. **(ACI 327-R14)**.

Figure 12 shows the results of the compressive strength tests at 28 and 90 days for different RCC mixtures. The test results showed that the compressive strength at 28 days for all RCC mixtures with different mineral fillers is acceptable compared with the minimum limit specified in ACI 327.R14 (28 mpa), except for the RCC mixture with thermostone powder filler. The fineness of filler particles, pozzolanic activity, specific gravity and density, and stiffness of mineral filler all these factors can affect the compressive strength of concrete **(M. Adamu et al.,2016)**. Comparison with RCC mixture with limestone powder, the result shows that utilizing brick powder filler in RCC gives the highest compressive strength (34.36 mpa), which is higher than the compressive strength of RCC mixture with limestone powder by 18.19%. The compressive strength decreased slightly for RCC mixture utilizing granite powder as filler compared with RCC with brick powder filler, but still higher than RCC mixture with limestone filler by 13.24%. The RCC mixture that had manufacturing using ceramic powder as mineral filler shows a comparable compressive strength with the RCC mixture used limestone filler, just a slight decrease by 1.7%. The significant reduction in compressive strength occurs when using themostone powder as a filler in RCC; the compressive strength decreased to 19.53 mpa or 30.52% drop compared with RCC mixture with limestone filler. **Figure 13** shows the percentage variation of compressive strength compared with the RCC mixture with limestone filler. This increase or decrease in compressive strength could be because of the variation in the pozzolanic activity of different fillers. The brick and granite powder has the highest pozzolanic activity. For ceramic powder mixture, the result indicates that the compressive strength of the ceramic powder mixture is less than that of the limestone powder mixture. This could be because ceramic powder showed pozzolanic activity in the late ages.The pozzolanic reaction increases the quantity of calcium silicate hydrate (C–S–H) and the material's compressive strength. Additionally, it refines the pores and decreases the porosity of the paste, resulting in a denser pore structure **(Sukmana and Melati, 2019),(Ramezaniapour et al.,2010),(Pachipala,2017),(Arroudj et al.,2015), and (Abdullah D. J., at el.,2021)**. Another possibility is that the filler particles are responsible for the filler effect; finer particles might fill the space left by cement particles, increasing the packing density of cementitious materials **(Modarres et al.,2016)**. At the age of 90 days, the compressive strength of all mixtures continues to grow, especially for the mixtures containing pozzolanic materials (brick, granite, ceramic), as shown in **fig. 12**. the compressive strength of the RCC mixture contained ceramic powder became larger than the limestone powder mixture. The increase in strength could be due to the pozzolanic activity of the ceramic powder that might be more active as the age of the concrete had increased. Where some natural pozzolans could need more time to show better pozzolanic activity in consuming the portlandite $Ca(OH)^2$ and producing more binding materials (C-S-H gel) in concrete (**(Mardani and Ramyar,2012)** and **(M. Adamu et al.,2016)**.

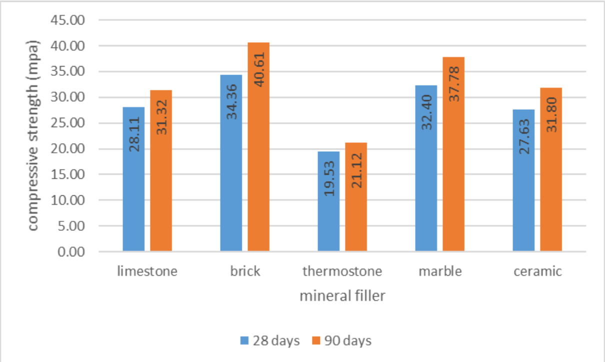


Figure 12. compressive strength of RCC mixtures with different types of mineral filler at 28 and 90 days.

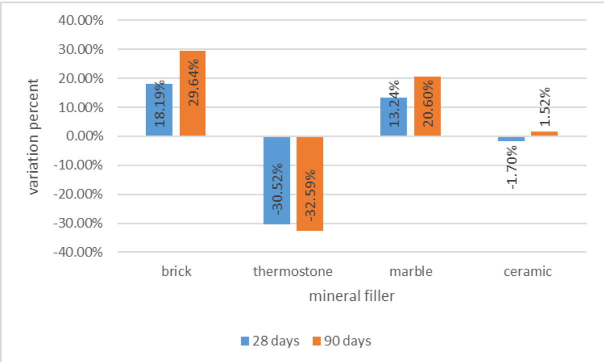


Figure 13. variation percentage of compressive strength of RCC mixtures compared with RCC mix with limestone

4.3. Tensile strength

The tensile strength result at 28 and 90 days is shown in **fig. 14**. from the results, it could be seen that the tensile strength was found to be in the range of 2.25– 3.85 MPa. The result of 28 days shows improvement in tensile strength for RCC mixtures with brick powder filler and granite powder filler. Using brick powder as a filler gave the best result compared with RCC mixture with limestone filler with an increase in tensile strength by 12.66%, and by using granite powder filler in the RCC mixture, the tensile strength increased by 7.22%. The decrease in tensile strength happened when the ceramic and thermostone powder filler were used in the RCC mixture. However, the reduction in strength was much lower in the RCC mixture with ceramic filler compared with the thermostone filler. The decrease in strength was 1.2% with ceramic filler; however, the reduction in strength was 33.09% when the thermostone filler was used. The variation in strength is shown in **fig. 15**. The tensile strength changing pattern results are the same as the compressive strength changing pattern. The variation in tensile strength using different types of filler could be because of the pozzolanic reaction of the filler **(Shi, C.,2001)**. It might also be attributed to the fillers' pore-filling capacity and microstructural refinement capabilities, which are dependent on filler fineness **(CD Atis et al.,2004)**. Previous research has shown that the splitting tensile strength of RCCP may range from 2 to 4 MPa depending on the RCCP mix design **(Jayaraman et al.,2019)**. In this regard, it can be concluded that all RCC mixtures with different types of filler gave a sufficient tensile strength above the minimum level.

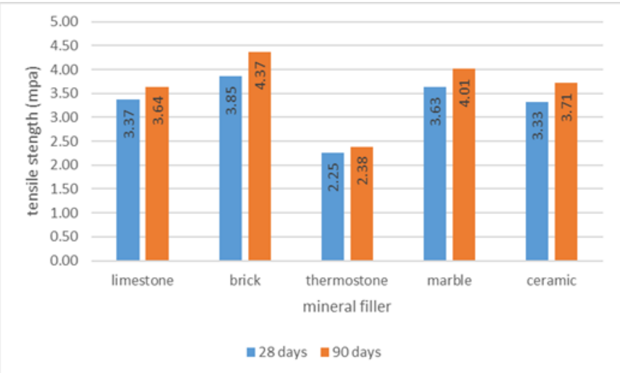


Figure 14. tensile strength of RCC mixtures at 28 and 90 days with different types of fillers

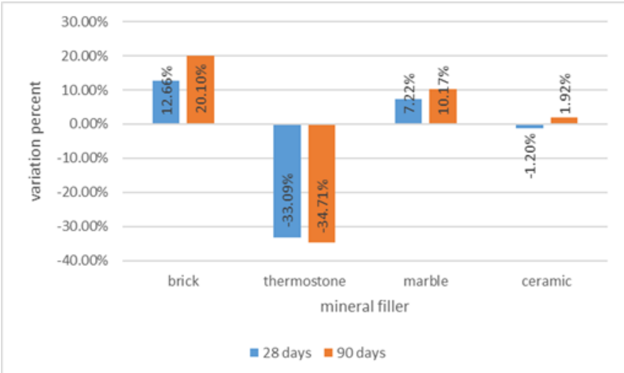


Figure 15. variation percentage of tensile strength of RCC mixtures compared with RCC mix with limestone filler.

4.4. Flexural strength

Flexural strength is usually related to the density and compressive strength of the RCC mixture. When the RCC pavements mixture is correctly designed, that will result in densely packing of aggregate in the mix, minimizing the occurrence of fatigue cracking. Due to the low W/C ratio of RCC, it has a high density and a strong binding to the aggregate particles. Consequently, depending on the mix design, the flexural strength of RCC is often relatively high—between (3.5 and 7 MPa)

(Jayaraman et al.,2019). The flexural strengths of the RCC produced are presented in **fig. 16** except for RCC mixture containing thermostone filler; it can be seen that the flexural strength for all RCC mixtures with different types of filler has been increased compared with the RCC mixture with limestone filler. However, except for RCC mix with thermostone filler, all other mixes produced with different types of filler have flexural strength above the minimum limit specified by the standard. **Figure 17** shows the percentage variation of flexural strength of all RCC mixtures compared with RCC mixture with limestone filler. However, the flexural strength of RCC mixture with thermostone filler was (3.48 mpa), which is near the minimum limit specified by the standard (3.5 mpa). As shown by the figure, the flexural strength of the RCC mixture with brick powder gave the best result with an increase in strength by 10.24% compared with the limestone filler mixture.

On the other hand, the RCC mixture with granite powder filler increased strength by 7.85% .this trend of strength increasing is the same in compressive strength and tensile strength. A decrease in strength happened with the RCC mixture containing thermostone filler by 27.9% compared with the RCC mixture containing limestone filler. These results could be due to the high fines and densely packed aggregates; hence the flexural strength is directly related to the density and f'c of concrete **(Khayat and Libre,2014)**. The flexural strength results are comparable to those mentioned in **(ACI 327. R, 2015)** and other researchers **(G. Li, 2004)**. Also, it could be because of the pozzolanic activity of the fillers .

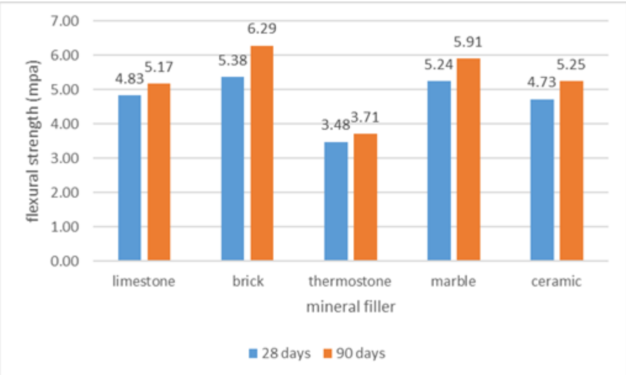


Figure 16. flexural strength of RCC mixtures at 28 and 90 days with different fillers.

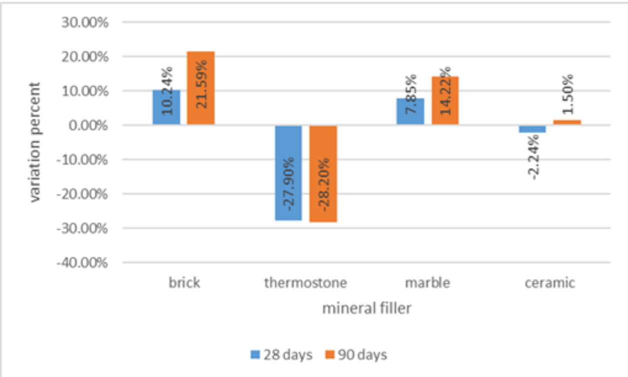


Figure 17. variation percentage of flexural strength of RCC mixtures compared with RCC mix with limestone filler.

4.5. flexural to tensile strength ratio

Concrete's tensile and flexural strengths are generally 10% and 15%, respectively, of its compressive strength **(Mehta,1986)**. Compressive to tensile strength is equivalent to that of normal concrete, with a range of 7 to 13%. The ratio is determined based on the aggregate, cement content, and age **(Elavenil and Vijaya,2013)**. The RCCP splitting tensile strength of the compressive strength for RCC mixes at 28 days was 11.98%, 11.22%, 11.53%, 11.20%, and

12.04% of the compressive strength with (limestone, brick, thermostone, granite, and ceramic) powder filler, respectively, as shown in **fig. 18**. In addition, the RCCP flexural tensile strength was 17.19%, 15.66%, 17.83%, 16.18%, 17.10% of the compressive strength for RCC mixtures with (limestone, brick, thermostone, granite, and ceramic) powder filler, respectively, as shown in **fig. 19**. To put it another way: This indicates that RCCP usually has high split tensile and flexural strength compared to conventional concrete. The flexural to splitting tensile strength ratio for RCCP was determined in this work, 1.43, 1.4, 1.55, 1.44, and 1.42 for mixes with (limestone, brick, thermostone, granite, and ceramic) filler, respectively. On the other hand, ACI suggests a range of 1.4 to 1.6 for this ratio. **Figure 20** shows the relation between flexural and tensile strength.

4.6. Density, absorption, and porosity

The density, absorption, and porosity results at the age of 28 and 90 days are presented in **fig. 21** and **fig. 22**. It can be observed from the results that the density increased when brick and granite powder was used in RCC mixture instead of limestone powder. Also, RCC mixture with ceramic powder gave a comparable result with the limestone powder mixture. The explanation for this might be related to the influence of nano fine filling the pores and the pozzolanic activity of various mineral fillers. This results in the creation of additional hydration products (C-S-H) gel and the refinement and decrease of pore porosity, resulting in a denser pore structure **(Sukmana and Melati, 2019),(Ramezaniapour et al.,2010),(Pachipala,2017),(Arroudj et al.,2015),** and **(Salih, and Abed,2016)**. However, when thermostone powder is used in RCC mixture, the density decreases compared with the limestone mixture; this could be due to the lower density of thermostone powder filler than limestone powder. The absorption and porosity of the RCC mixture with brick and granite powders filler was the lowest compared with other mixtures due to the filler effect and pozzolanic activity. Also, ceramic powder mixture gave an acceptable result compared with limestone powder mixture. At 90 days of curing, the density results for all RCC mixes have increased in conjunction with a decrease in absorption and porosity. The brick, granite, and ceramic showed the highest density with the lowest absorption and porosity. The explanation for this might be related to the influence of micro fines filling the pores and the pozzolanic activity of these powders, which results in the creation of extra hydration products (C-S-H) gel and refinement and decrease porosity, resulting in a denser pore structure.

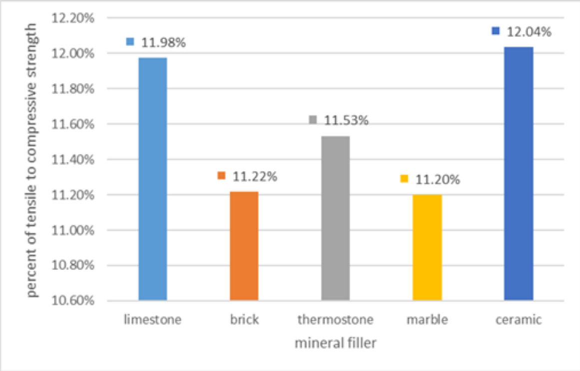


Figure 18. splitting tensile strength to compressive strength ratio for different mixtures of RCC with different kinds of fillers.

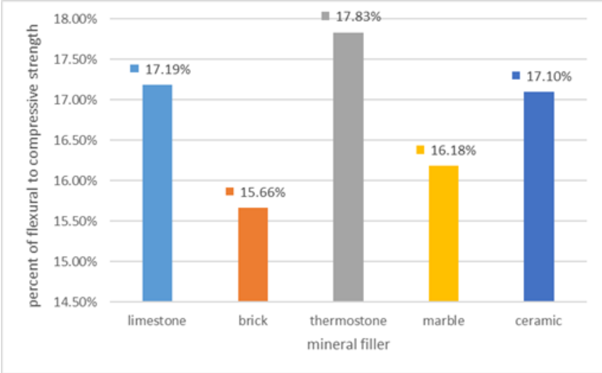


Figure 19. the ratio of flexural strength to compressive strength for different mixtures of RCC with different kinds of fillers.

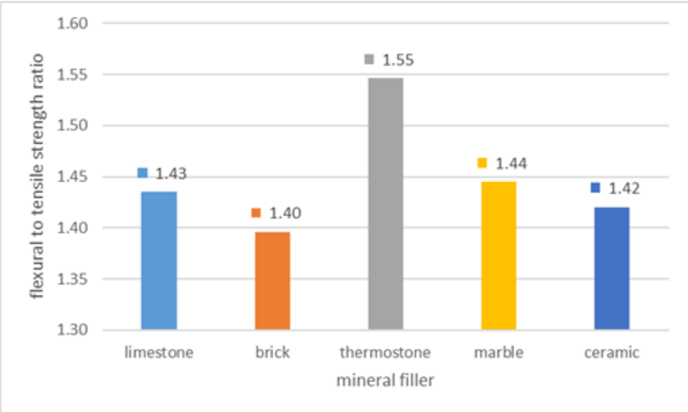


Figure 20. flexural strength to tensile strength ratio for different RCC mixtures with different kinds of fillers.

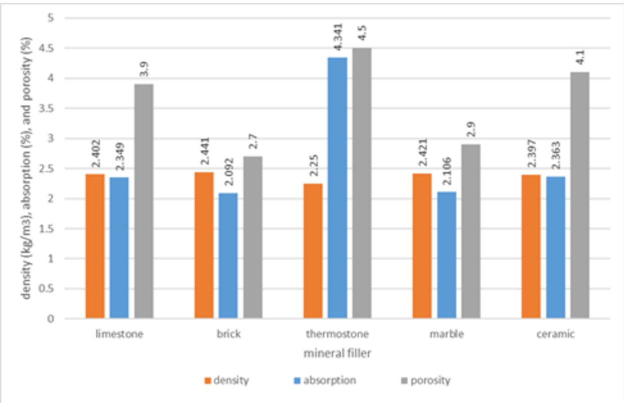


Figure 21. density (kg/m3),absorpation (%), and porosity (%) of different RCC mixture at 28 days.

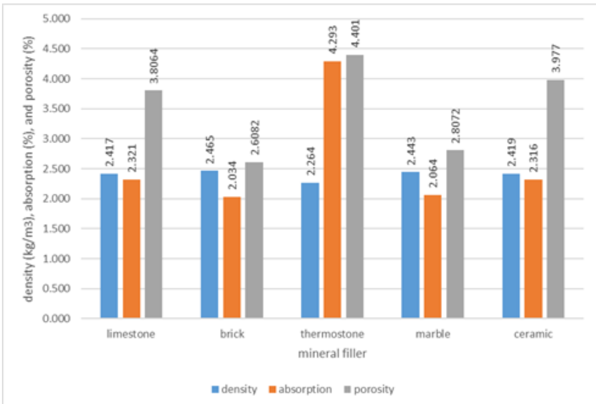


Figure 22. density (kg/m3),absorpation (%), and porosity (%) of different RCC mixture at 90 days.

5. CONCLUSION

The use of recycled powders in roller compacted concrete is investigated in this work. It is hoped that the results of this study would encourage further research and the use of recycled powders. The following conclusions may be reached based on the preceding results.

1. Recycled powders, such as (BP, GP, and CP), have SCM properties and have a greater silicon dioxide concentration and a lower calcium oxide percentage than cement. Using these powders increases the pozzolanic reaction of cementitious materials, while including recycled powders reduces the quantity of hydration products. The reactivity of recycled powder increases as fineness increases.

2. The suitability of using recycled powder has been investigated in terms of mechanical properties. Based on the result, the use of BP and GP gave a favorable outcome compared with limestone powder.

3. The use of ceramic powder gave an acceptable result regarding the ACI 327 R-15 limits. Moreover, at later ages, the mechanical properties of the mixtures containing ceramic powders have been improved due to the pozzolanic activity of CP.

4. The feasibility of using thermostone powder in RCC has been investigated. Based on the result, the mechanical properties of the RCC mixtures containing TP reduced compared with the reference mixture. Regarding the ACI 327 R-15 limits, the result was not acceptable.

5. The density of RCC improved when BP and GP were used. However, the CP gave a comparable result with the reference mixture. The absorption and porosity have improved and reduced when BP and GP have been used due to the pozzolanic activity and filling effect of these materials.

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