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SUSTAINABLE DESIGN OF PERVIOUS PAVER BLOCKS USING CEMENT KILN DUST (CKD) AND RECYCLED ASPHALT PAVEMENT (RAP)

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Abstract

The main aim of the study is to make Sustainable and cost-effective development of pervious paver blocks made with CKD (Cement kiln dust) and RAP (Recycled asphalt pavement). In the present study, two different types of aggregates (CKD and RAP) were used: RAP aggregates and fresh aggregates (FA) that were procured from a nearby quarry. RAP was acquired through the uncontrolled milling of bituminous concrete (BC) pavement that was 8 years old and from a Gokul warehouse in Gwalior (M.P.). CKD was acquired as a cementitious replacement for the usage of industrial wastage for sustainability from the Rashi Prism factory in Satna (M.P.) A total of 70 specimens (14 types) + 5 replicas were made for testing in the lab. Two of the five replicates were tested for porosity, density, infiltration rate, and clogging impact; three were tested for strength properties (Compressive strength, Cantabro abrasion). According to the findings of the study paver blocks made from CKD are reliable as well as cost-effective. The finding concludes that paver blocks made by the replacement of CKD and RAP are sustainable, durable and affordable.

Keywords

Pervious, Paver block, CKD, RAP, Sustainable, Cost-effective

1. Introduction

The construction of a reliable road system is crucial to a country's economic growth and social progress. Typically, the quantity of building supplies needed is quite large. Man makes use of soil for a wide range of construction-related tasks because it is the most inexpensive material at his disposal. Construction sites often lack access to graded soil, forcing engineers and scientists to make do with industrial waste that degrades the environment or presents disposal challenges. Use of waste materials in construction, such as fly ash, granulated blast furnace slag, cement kiln dust, etc., requires specific consideration in this setting (1). The granular material layer is an essential part of a flexible pavement structure since it affects the stresses and strains everywhere else. Fatigue and rutting in asphalt concrete are two major causes of failure in flexible pavement (2). Materials from asphalt and aggregate pavements that have been previously used and subsequently reclaimed are known as reclaimed asphalt pavement (RAP). High-quality, well-graded aggregates coated with asphalt cement can be found in RAP after it has been crushed and screened, and this material is mostly produced during pavement restoration and reconstruction (3). RAP quality might vary depending on the source of the old pavement it was recycled from and the qualities of the constituent materials and asphalt concrete type utilized in the original pavement. Sometimes new granular material, soils, or even garbage is added to heaps of recycled pavement. A variety of factors, including the frequency with which the pavement has been resurfaced, the extent to which it has been patched and/or cracked sealed, and the presence or absence of previous seal coat treatments, will affect the makeup of RAP. Specific gravity measurements of RAP indicate that it has a high silica content and low levels of CaO, falling within the range of 1.94 to 2.30. It is necessary to monitor the quality of recycled asphalt pavement (RAP) to ensure that it is suitable for its intended purpose after processing, since RAP may originate from a variety of sources. One prominent example is "in-place" recycling of asphalt roads. The usual particle size distribution and other physical, chemical, technical, and mechanical features of RAP have been determined via extensive research(4).

The mining and heavy industrial industries, which include cement, power, steel, and others, are responsible for an increasing amount of waste. The expense of waste removal is rising as well. Without the creation and implementation of new and beneficial use choices that are both commercially viable and environmentally friendly, the accumulation of by-product materials is unavoidable. Cement kiln dust (CKD) is a solid waste product of Portland cement kilns' pre-heater by-pass systems caused by the presence of trace amounts of volatile components in the kiln's feed and fuel. The raw feedstock is only partially calcined, and the result is a fine, grey powder that resembles Portland cement. The main chemical components of CKD are lime, silica, alumina, and iron. The raw materials and collection technique employed by the cement mill have an impact on the chemical and physical properties of CKD. Patients with chronic kidney disease (CKD) may be eligible for free lime. It's possible that coarser CKD particles collected closer to the kiln contain more free lime. More sulfates and alkalis are concentrated in smaller particles in CKD. The cementitious qualities of cement kiln dust make it a desirable commodity. Because to the inclusion of lime (CaO), CKD may have a high cementitiousness. Cement kiln dust (CKD) may thus be used as an alternative to Portland cement, blast furnace slag cement, Portland pozzolan cement, and mixed cement. It may be pelletized or agglomerated for more particular applications. Stabilizing municipal sludge, red mud, mining tailings, and dredge materials are all made easier by CKD's high alkalinity. It is an excellent match for the alkaline environments in which these organisms may develop due to its alkaline qualities and its ability to absorb moisture. Highway construction also makes use of CKD (5).

Recent years have seen a rise in awareness of environmental issues and the importance of sustainable development. As society's trash and byproducts accumulate, more and more people and organizations are looking for ways to cut back, repurpose, and recycle. Concrete is the most commonly used construction material in the world - it constitutes to as much as twice the total of all the other building materials combined, due to its versatility, economy and workability. An astounding 12 billion metric tonnes of concrete is produced every year which uses approximately 1.6 billion metric tonnes of cement annually. In fact, it is often said that modern civilization is literally built on concrete. The research and development of Controlled Low Strength Materials (CLSM) has recently attracted a lot of attention. Portland cement and other cementitious materials are essential to the creation of CLSM. Cement kiln dust (CKD) is a substantial by-product of the cement manufacturing process that might potentially be used as a

substitute for Portland cement in the production of CLSM with the desired properties. Reduced environmental risks from CLSM's usage of CKD point toward a future when this byproduct is put to good use in the service of sustainable development. Cement manufacturers dump over 12.9 million metric tons of CKD every year, the vast majority of which is unrecyclable. The cement production process generates a byproduct called clinker, a fine powder that looks exactly like Portland cement.

Figure 1.1 shows the two powders

The method used in the kiln and the efficiency of the dust collection system typically yield four distinct types of dust from the cement manufacturing process. There are two common kiln techniques: the wet process and the dry process. The feed materials might be either a slurry to be processed in the wet process kilns or dried and ground to be processed in the dry process kilns. There are potentially two ways to collect CKD for either procedure. The first is the dust, which can be recycled by the kiln's dust collection system. The second procedure either recycles or disposes of all CKD. Free lime, one of CKD's chemical characteristics, is often concentrated in the coarser particles collected near the kiln. Concentrations of sulfates and alkalis tend to be higher in finer particles. Similarly, the calcium content of CKD from wet process kilns is often smaller than that of dust from dry process kilns. CKD has been included in asphalt concrete as a mineral filler. It has been estimated that between 15 and 25 percent less asphalt cement is required if CKD is combined with the asphalt binder before the hot mix aggregate is added. Factory-made CKD aggregates may be either agglomerated or palletized, depending on the application. Roads paved with asphalt and concrete might benefit from an oil-absorbing artificial aggregate made from CKD during the warmer months. As a cement modifier for low-ductility mastic asphalt, CKD shows potential when used with asphalt binder. CKD has the potential to replace Portland cement in the production of cement-like silicate materials (CLSM) due to its dual activity as a cementitious material and pozzolan activator(6).

2. Aim

- Sustainable and cost-effective development of pervious paver block made with CKD (Cement kiln dust) and RPA (Recycled asphalt pavement)

3. Objectives

- The development of pervious paver blocks using (RAP) recycled asphalt pavement in three weight ratios of 0%, 50%, and 100% that are environmentally friendly as well as financially feasible.
- Sustainable and affordable development of permeable paver blocks constructed with industrial waste CKD (Cement kiln dust), which has cementious ratio in 10% and 20% by weight.

4. Literature Review

(Ahmed et al., 2023)(7)This research looks into how the engineering qualities of pozzolanic concrete, which is used in block production, change when Portland cement is partially replaced by cement kiln dust. The end result may be less cement used and fewer greenhouse gas emissions. Cylindrical concrete samples were made from five different combinations of 71.13% pozzolan and 14.16% water, with either zero, five, ten, fifteen, or twenty percent of the OPC fraction (14.71 wt.%) substituted by CKD. Density, compressive strength (UCS), voids, and water absorption were measured after 28 days of curing, and these measurements were taken at 7, 14, 28, 56, and 91 days of curing for each sample. The number of voids per day decreased and the amount of water absorbed increased with worsening CKD. The UCS was largest in the 15% CKD group, regardless of age at cure. X-ray diffraction analysis reveals a much larger concentration of the hydrated calcium silicate phase in the CKD 15% sample compared to the control.

(Radhakrishnan&Vignesh,2023)(8)

Bituminous materials are used for the majority of road surfaces around the world. Massive quantities of natural virgin aggregates are required for road construction and maintenance. The cost and the environment are both affected by the depletion of resources used in building the road. Therefore, it is important to cut back on the amount of virgin aggregate used to build bituminous pavements. Recycling asphalt pavement (RAP) and marble debris are two examples of eco-friendly materials that may be used in road construction. Sustainable Development Goal (SDG) 12 is the topic of this study, and more specifically target 12.5, which is all about recycling and reusing resources. However, no studies on the combined use of RAP and sustainable materials in bituminous paver blocks were found. In this experiment, the bituminous mixtures were tested for durability and compared to a standard mixture. After casting bituminous paver blocks using eco-friendly components, their performance was evaluated with standard laboratory tests like the compression test, Cantabro loss test, and wheel rut test. The bituminous blocks passed all of the tests with flying colors, therefore they may be used for servicing the pavement constructions. According to the research, combining RAP with sustainable materials in pavement blocks can create a low-impact, low-maintenance system, making it an important strategy for achieving SDG 9.

(Chiara et al., 2022)(9)A study was done using samples gathered from five different locations in Italy to evaluate the performance of RAP as aggregate in concrete. Physical properties (particle size distribution, water absorption, porosity, wettability), microstructure (using microscopy), dimensional stability (drying shrinkage of mortar and concrete with 100% of RAP as aggregates), and durability (using freezing-thawing cycles) are just some of the aspects of RAP that have been studied. The differences between RAP and regular concrete aggregates were discussed at length. The use of RAP as recycled aggregate for concrete might be beneficial, but it would need to be well characterized to ensure performance and durability.

(Sumit Nandi&Ransinchung,2021)(10)Over the last several years, recycling concrete paver blocks has surpassed any other kind of concrete recycling in popularity. The environmental effect of waste management is reduced, and the manufacture of heirloom-quality objects is aided as a result. Concrete paver blocks containing either coarse or fine fractions of unprocessed recovered asphalt pavement (RAP) were analysed to see how their performance varied from one another. As a byproduct of asphalt recycling, RAP (reclaimed asphalt pavement) is created. The effect of RAP% and wet curing age was evaluated using an ANOVA with multiple comparisons for this investigation. All performance tests, with varying loads, showed that concrete blocks infused with RAP were durable and reliable. The dose of RAP used as a natural aggregate replacement and the durability of RAP concrete may be enhanced by the use of staged mixing and time-controlled dual-source compaction, which combines synchronized impact pressure and vibratory compaction energy. An economic and environmental impact analysis suggests that precast concrete paver blocks built from recycled RAP fractions may be successful in the long run.

(Bittencourt et al., 2021)(11)Recently, there has been a rise in academic interest in using recycled asphalt pavement (RAP) aggregate into cementitious material. This curiosity stems mostly from the fact that flexible pavement maintenance results in the buildup of a great deal of unused RAP aggregates, which can lead to serious environmental difficulties due to the paucity of landfilling space for this waste. Therefore, the goal of this study is to help find a solution by advancing the use of RAP pervious concretes. There were five mixtures examined for their physical, mechanical, and hydraulic (as determined by an infiltration and clogging test) properties, all of which included natural and/or RAP aggregates. Both an experimental mixture (in which up to 100% RAP was substituted for natural aggregate) and a control mixture (in which only natural aggregate) were created. While the use of RAP aggregate improved the infiltration performance of pervious concretes (infiltration rate more than 2.9 103 m/s), it significantly degraded the mechanical behavior of the resulting materials. Although the strength of the tested combinations was lower than what would be required for structural pervious concrete, they were nevertheless adequate for use in non-structural applications like as bike lanes, sidewalks, and soon.

(Saleh et al., 2020)(12)The research team behind this project hopes to find out whether cement kiln dust (CKD) and poly(styrene) (PS), two troublesome waste products, may be used to create lightweight bricks with physico-mechanical characterizations acceptable for future building applications. Portland cement, iron slag, and crushed waste glass make up the two basic components (CKD and PS), and their relative amounts were modified to enhance the mechanical properties of the final product. Compressive strength, density, porosity, and water absorption were among the mechanical and physical properties investigated on the samples. Scanning electron microscopy (SEM), energy dispersive X-ray spectroscopy (EDX), and Fourier transform infrared fluorescence (XRF) were used to investigate the microstructure. PS does not improve survival in CKD, as shown by experimental research using mechanical resistance. The strongest composite, in comparison to CKD, was made of iron slag, Portland cement, ground waste glass, and shredded PS waste. The modified cementitious product has been evaluated and found to be of sufficient quality for use in outside shielding and interior non-load-bearing walls in construction projects in accordance with national and international regulations.

(Suchorab et al., 2018)(13)In this chapter, we explore the possibilities of cement kiln dust (CKD) in the building industry, namely in concrete manufacturing. Cement kiln dust (CKD) or bypass dust is a solid particle that must be filtered out by pollution control machinery due to the high alkalinity of the exhaust gases. Cement factories using rotary kilns release CKD as a byproduct of the manufacturing process. The strength and durability of CKD concrete was studied through a combination of literature review and original research. Concrete treated with CKD has been hydrophobized, therefore the scientists have also looked into the material's resilience to frost and salt. Our research shows that CKD utilization is a promising field of study; however, it is essential to keep in mind that adding no more than 5% CKD to concrete compositions is reasonable and has no negative effects on concrete parameters; adding 10% CKD is acceptable up to the point where all final product parameters begin to decrease; and adding 20% should be avoided at all costs.

(Gorman et al., 2016)(14)Recycled asphalt pavement (RAP) has seen a lot of experimental study up until this point. In order to optimize the ratio of new to recycled components and to determine how long it will take for the drum to completely melt, finite-element techniques have recently been shown to be an effective modeling tool. The thermal conductivities of RAP and its components must be precisely known before the modeling can begin. This requirement drove the current experimental effort, which included recycled asphalt pavement (RAP) particles, RAP particles stripped of their asphalt binder, and pure asphalt binder of varying ages. Sand, as well as the waste rock left behind from processing taconite, was analyzed. It has been suggested that the tailings could make a good aggregate. Three factors were found to be connected to the solid media conductivity results: "(a) the size distributions of the solids, (b) the overall density of the sample, and (c) the porosity of the sample. The solid media tested had conductivities that ranged from around 17 to 30 W/m °C. The binder's thermal conductivity was found to be between 0.17 and 0.19 W/m °C".

(Modarres & Hosseini, 2014)(15) This paper looked at the effects of incorporating rice husk ash (RHA) into roller compacted concrete (RCC) made from virgin and RAP. Cement was replaced with RHA in the RCC combinations at a rate of 3-5%. Several options, including RAP in its entirety, RAP mixed with fine original aggregate, and RAP mixed with coarse original aggregate, were evaluated. Compression tests and three-point bending setups were the most common experimental methods. RCC composites have their modulus of rupture, energy absorption, and fatigue response determined by flexural testing. Only samples that had been cured for 120 days were subjected to the fatigue test; the other tests and analyses were conducted at 7, 28, and 120 days. Using RHA improved both maximum dry density and optimal moisture content (OMC). Using RAP of varied sizes also reduced the OMC and the maximum dry density. Substituting 3% RHA for cement increased the material's adaptability. However, raising the RHA level to 5% decreased the energy absorption. RAP-containing RCC blends had a shorter fatigue life than the standard mix. Additionally, fatigue life was increased when RAP was used to replace the coarse material. The energy-absorbing capacity and fatigue response of RCC mixtures were found to be highly correlated (R2 > 0.90). The more energy-absorbent mixture performed better under repeated loadings at stress ratios of 0.72. Furthermore, the fatigue life was discovered to be inversely proportional to the porosity of the material. Improvements in fatigue resistance and reduced porosity, notably after 120 days of curing, were attributed to the use of 3% RHA. In contrast, increasing the RHA content to 5% increased porosities and decreased fatigue lives.

(Isaac et al., 2013)(16)HMA and WMA now account for close to 85% of all RAP usage due to the genre's recent surge in popularity. Several studies have been conducted throughout this time period, however they have all concentrated on RAP concentrations of 50% or below. This report details laboratory research on the effects of RAP contents between 50 and 100% on WMA's rutting, moisture damage, durability, cracking, and mixing homogeneity. For most uses on today's roads, mixtures containing more than 50 percent RAP are not beneficial due to the lack of a RAP surplus and the performance statistics reported in this research. When tested for its effectiveness as a base pavement layer, WMA blended with 50% RAP met or exceeded expectations in all categories, including durability and cracking.

5. Methodology

In the present study, two different types of aggregates (CKD and RAP) were used: RAP aggregates and fresh aggregates (FA) that were procured from a nearby quarry. RAP was acquired through the uncontrolled milling of bituminous concrete (BC) pavement that was 8 years old and from a Gokul warehouse Gwalior (M.P.) with an expected maximum particle size of 13 millimeters. The substance was composed of large RAP aggregate particles that stuck together because to the liquefaction of asphalt. This content had to be disentangled from its aggregated condition before it could be used. Once the RAP aggregates were equally baked for 30–40 minutes at 80 C, they were broken up into smaller pieces using a wooden hammer. To make good use of RAP aggregates in pervious paver blocks (PPB), this technique was consistently employed. Furthermore, 10% to 20% by weight of industrial waste cement kiln dust (CKD) is used as a replacement for cement. The current study opted for a c/a ratio of 0.25 and a w/c ratio of 0.30. Table 1 displays the results of producing pervious paver blocks with two different gradations. "These grades are G1 and G2, respectively. G2 was chosen to have a finer texture than G1, whereas G1 was picked from a prior study by (34). Virgin aggregates and RAP were combined in three different ways: 100% VA, 50% VA + 50% RAP, and 100% RAP." "The weight of the aggregates was used to replace RAP". "The mix ratios for the various aggregates and gradations are denoted as G1 0, G1 50, G1 100, and G2 0, G2 50, and G2 100." RAP usage has been denoted in the mix by the numbers 0, 50, and 100. Table 4 provides information on the mix proportion as well as the fundamental characteristics of FA and RAP. Specific gravity, density, and cantabro abrasion values of RAP aggregates are reduced when an asphalt binder coating is present on their surface. Material abrasion during milling operations increases water absorption. Additionally, the RAP aggregates are contaminated by fines and dust, which is another factor in the water absorption.

"The aggregates were sieved into various sizes to facilitate the development of a porous, open network for the purpose of evaluating pervious paver blocks". "Table 1 and Figure 2 show that two different aggregate gradations were utilized. "These gradations were 6.3 mm passing 2.36 mm retained and 12.5 mm passing 6.3 mm retained". "When the aggregates were batched in the saturated surface dry state, no super plasticizer was applied". "The binding material used was ordinary Portland cement (OPC), often known as OPC 43. This study opted for a c/a ratio of 0.25 and a w/c ratio of 0.30".

5.1 Material used - Cement, Coarse aggregate and water

- Waste material used for replacing aggregate and cement making it economical and sustainable.
- Coarse aggregate replaced by RAP (Recycled asphalt pavement) in three percent 0%, 50% and 100% ratio by weight.
- Cement replaced by industrial waste CKD (Cement kiln dust) which have cementious properties in two percent 10% and 20% ratio by weight.
- Coarse aggregate divided into two grades G1 and G2.

G1 = 12.5mm → 6.31 mm

G2 = 6.3 mm → 2.36 mm

Figure 1.2 shows the sieving of FA

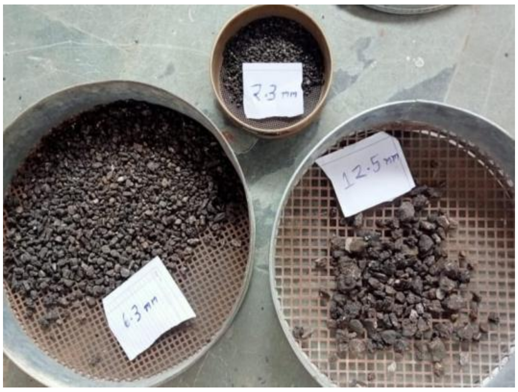

Figure 1.3 shows the sieving RAP

Table: 1

"Details of gradations used in the study"

	"Aggregate size, mm"	
"Gradation"	12.5 - 6.3	6.3 - 2.36
G1	100	0
G2	50	50

5.2. CEMENT KILN DUST (CKD)

Project was completed using Rashi prism factory, Satna -produced CKD and Ordinary Portland Cement (OPC), a consistent standard was identified. The w/c ratio for the OPC was set at 0.30. Both a 10% and a 20% cement weight replacement ratio for making paver blocks were studied. various chemical compositions of CKD, OPC, and CKD, with OPC and CKD serving as replacements in varying amounts. Both the OPC mortar (OPCM) and the CKD mortar (CKDM) were tested for their physical properties, such as their flow, density, Ultrasonic Pulse Velocity (UPV), and porosity (apparent porosity and 2D image analysis). In addition to employing image analysis methodology to assess whether or not the strength of the examined samples correlates with their color features, we also measured their compressive strength.

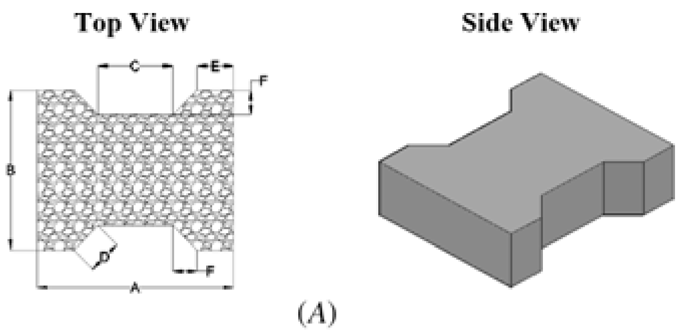

Figure 1.4 shows the sides of paver block by which area of paver block finded

5.3. PREPARATION OF PCPB

-"The production of PCPB has been standardized. Cement paste encapsulating aggregate blending method best characterizes this technique". "After adding all of the aggregate and 20–25% of the total calculated water content, the concrete mixer was run for 15-20 seconds in this procedure". The aggregate was bound together with the appropriate amount of cement. Once the remaining water was added, the mixture was mixed for about 2 minutes before being poured into the molds. The PCPB samples were compacted using a vibrating table. In the manufacturing, paver bricks are typically vibrated for 15-20 seconds to get them ready for use. Overnight, we let the prepared samples to dry in the mold. The dry samples were demolded following a 29-day cure period in water. Keep in mind that there are four different PCPB preparation shapes. Measurements of different PCPBs' diameters and areas were taken for this study.

A total of 70 specimens (14 types) + 5 replicas were made for testing in the lab. Two of the five replicates were tested for porosity, density, infiltration rate, and clogging impact; three were tested for strength properties. The averages are presented in the text that has been released. The coefficient of variation for the all measurement is under 10%.

6. Tests

1. Density and Porosity
2. Cantabroabrasion loss (%)
3. Infiltration rate (mm/sec.)
4. Compressive strength

6.1. HARDENED DENSITY AND POROSITY

The structural and functional activities of PCPB are best characterized by its density and porosity, two essential pore properties. "Hardened concrete samples were tested for density and porosity using the ASTM C1754/C1754M-12, Standard Test Method for Density and Void Content of Hardened Pervious Concrete (Withdrawn 2021)". The pore parameters were determined after the dry weight of each sample was determined. After taking the necessary measurements, the volume was recorded. "A hardened sample's density is defined as its dry weight per unit volume". Researchers were able to determine porosity by immersing samples for 30 minutes. Tapping the outside of the PCPB samples helped release the trapped air. When the conditioning time was over, we measured how much the sample weighed when immersed, and we used the method given in ASTM C1754 to determine the porosity value. (35)

6.2. CANTABRO ABRASION TEST

PPB's longevity is an important quality. The aggregates are held together by the cement paste in a honeycomb pattern. Maintaining a low rate of material loss due to abrasion is crucial to preserving the stability of this structure. One simple technique for testing the stability of a finished mixture is the Cantabro loss (CL) method. The Los Angeles (LA) test protocol calls for placing the ready PPB samples into an abrasion machine without utilizing steel balls. The mass lost by the PPB after 300 revolutions at 30 revolutions per minute are represented as a percentage of the Cantabro attrition loss. (36)

6.3. FAILURE LOAD AND COMPRESSIVE STRENGTH

For this study, we made every PCPB sample through a compression test under controlled displacement. Every minute, one millimeter of pressure was added. To determine the PCPBs' compressive strengths, we calculated their surface areas and recorded the failure loads. Indian Standard (IS) 15658:2006, also known as the CED 5: Flooring, Wall Finishing, and Roofing, was used to conduct the evaluation of the precast concrete blocks. (37)

6.4. INFILTRATION RATE

The density and porosity of the hardened specimens of each test were initially determined. Steel ring of 50 mm in height and 75 mm in inner diameter was used for the measurement. The ring is secured to the PCPB sample in Figure 5A before plumber's putty is applied to the underside of the rim to seal it from water leakage. A 15 mm head was attempted to be maintained while 250 ml of water was added to the ring. After the water was poured into PCPB for the first time, we timed how long it took to evaporate from the surface. "The infiltration rate of PCPB was determined using C1701/C1701M-17a, Standard Test Method for Infiltration Rate of In Place Pervious Concrete, which took into account the ring's diameter and the amount of time required for the water to permeate the PCPB".(38)

6.5. COMPRESSIVE STRENGTH TEST

"The compressive strength (CS) of the PPB was measured using a displacement-controlled compressive testing device. The rough edges of the paver stones were smoothed with gypsum paste to produce a flat loading zone". The rate of force application was 1 mm per minute. PPB samples' CS were determined using both their failure loads and their overall surface areas. According to IS 15658: 2006, the observed compressive strength is multiplied by 1.18 to account for the PPB's skewed aspect ratio.(39)

7. Results

7.1. Density and porosity

Gradation G1

- 0% RAP 10% CKD
- 0% RAP 20% CKD
- 50% RAP 10% CKD
- 50% RAP 20% CKD
- 100% RAP 10% CKD
- 100% RAP 20% CKD
- Ideal (100% RAP 100% FA)

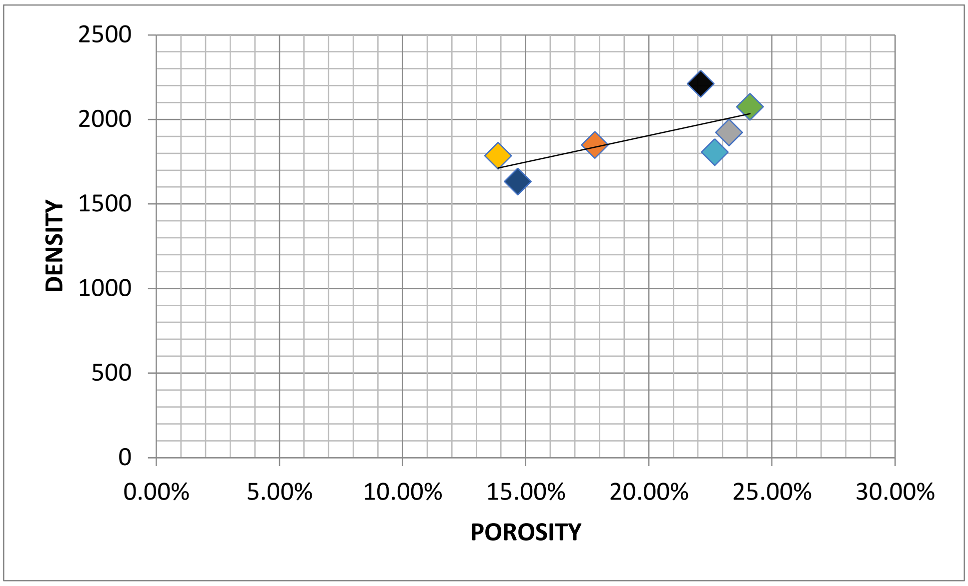

Figure 2.1 Shows the density and Porosity of G1 gradation

Gradation G2

- 0% RAP 10% CKD
- 0% RAP 20% CKD
- 50% RAP 10% CKD
- 50% RAP 20% CKD
- 100% RAP 10% CKD
- 100% RAP 20% CKD
- Ideal (100% RAP 100% FA)

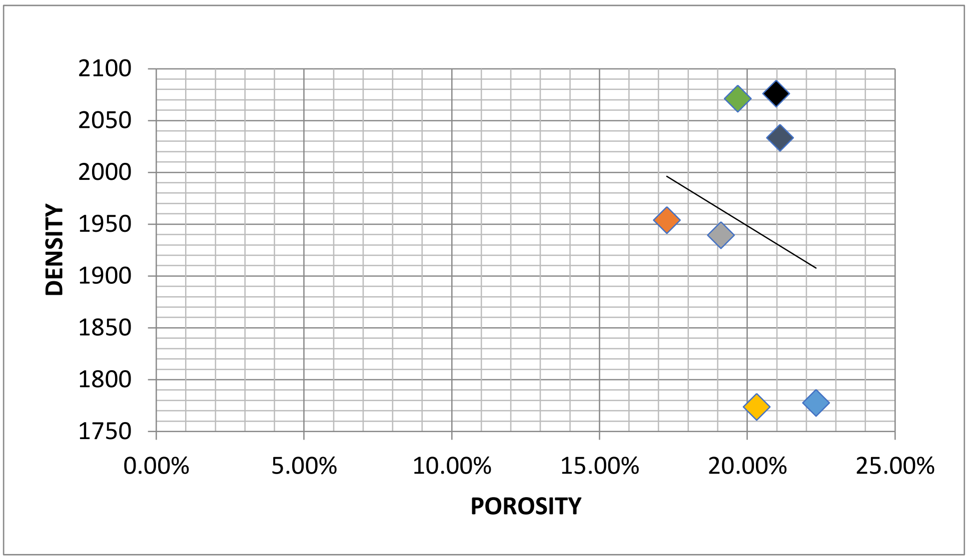

Figure 2.2 Shows the density and Porosity of G2 gradation

The above table describes the density and porosity of G1 paving stone blocks. Two of the blocks had a porosity of 13.88% and 14.68%, respectively, which is below the PC requirement. However, water percolation was seen in these blocks, pointing to the presence of a connected void system as will be shown by the infiltration rate results. Results were similar when using the coarser aggregates of the G2 grading rather than the finer ones of G1. "The density of G2 and G1 graded blocks were found to be nearly identical for the same combination composition (w/c and c/a)". In addition, G2 graded mixtures were shown to have higher porosity than G1 graded mixtures. Because of the blocked bottoms of the blocks containing the G2 graded mixtures with different c/a and w/c ratios, only the mixture with these specific ratios was dispensed.

7.2. Cantabro abrasion loss%

Gradation G1

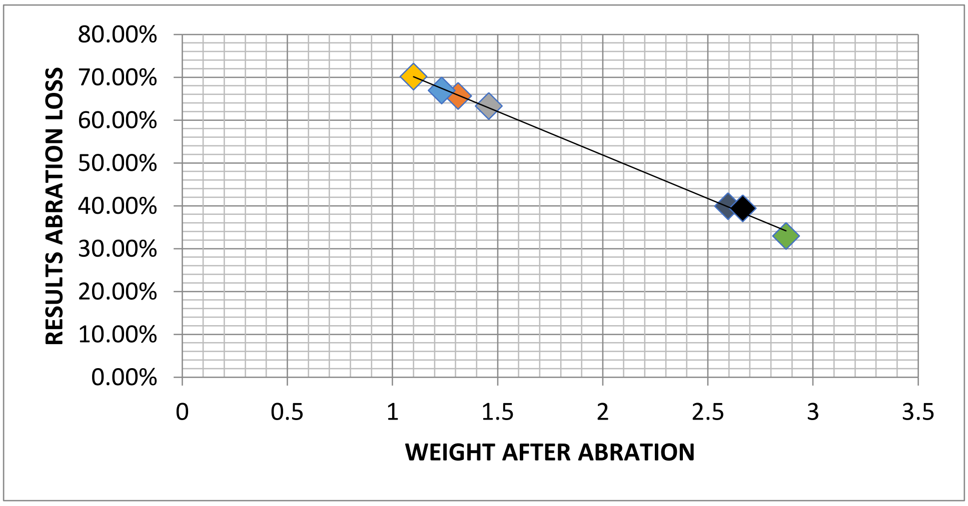

Figure 3.1 Shows the cantabro loss % of G1 gradation

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