SEMARAK ILMU PUBLISHING

Journal of Advanced Research in Applied Sciences and Engineering Technology

Journal homepage: https://semarakilmu.com.my/journals/index.php/applied_sciences_eng_tech/index
ISSN: 2462-1943

Analysing the Effect of using Waste Ceramic Aggregates as Coarse Aggregate and Concrete Dust as Filler in Pavement to the Permeability

Kalpana M.[1,*], Venkatesan G.[1], Padma S.[1]

[1] Department of Civil Engineering, Saveetha Engineering College, Chennai, Tamil Nadu 602105, India

ARTICLE INFO

Article history:
Received 21 January 2024
Received in revised form 20 September 2024
Accepted 7 October 2024
Available online 20 December 2024

Keywords:
Permeable pavement; Ceramic waste; Geo textile; Asphalt mix; Coarse aggregate

ABSTRACT

The recent degradation of the common environment is a result of the swift advancement of human demands on the climate. Around the world, there have been a lot of construction, demolition, and repair projects that have increased the amount of waste. Waste items contribute to the landfill and also cause unfavourable environmental and public contamination. On the other side, paver materials from common resources are used for construction. In the past thirty years, there has been an unquestionable increase in asset use, which has led to asset double dealing. Therefore, we can see a solution by using waste material in place of developing asphalts. Porous asphalts are used in pedestrian and vehicular routes to facilitate surface spill penetration. Porous asphalts can capture suspended materials, thereby filtering contaminants from storm water, in addition to reducing surface overflow. The purpose of the test investigation is to determine the likelihood of using ceramic waste as a replacement to coarse aggregate with concrete dust as filler material when developing porous asphalt. Ceramic waste with a 12.5mm diameter that is used appropriately can be used to develop penetrable asphalt. The experimental trial with 30% replacement of coarse aggregate can be used as a substitute for conventional mix because the experimental results are almost identical to those of the conventional sample. The trials evaluated using 40% ceramic waste in place of coarse aggregate can be used to build parking lots and a pathway because it is lower in weight and has more voids. The trial mix of 50/50 failed to bear the load used during the experimental trials, hence it cannot be used as a replacement.

1. Introduction

A vital source of life, water paves the way for development and good living. Water conservation benefits the ecosystem. It requires less energy to process and supply water, which lowers pollution and preserves fuel supplies [1-3]. Saving water now ensures that there will be water available for recreational uses in the future. Thirty percent of the freshwater supply on Earth comes from groundwater, which accounts for 1.69 percent of all water on Earth, including seas and glaciers [4-7]. The total volume of freshwater stored in snow and ice, including that at the north and south poles,

* *Corresponding author.*
E-mail address: kalpana@saveetha.ac.in

https://doi.org/10.37934/araset.54.1.123137

is roughly equal to the volume of groundwater stored on a worldwide scale. It can act as a natural reservoir to fend against surface water shortages, such as those that happen during droughts [8-11]. By refilling the ground water with the help of rainwater runoff, water shortages can be controlled. Most regions have been paved over as a result of urbanization to make travel easier [12-15]. Some of the layers that make up the pavement structure include the permeable sub-base, permeable base, permeable bedding layer, and permeable surface. The thickness of these layers is designed to withstand traffic loads, distribute stresses on the subgrade, and allow water to seep through them [16,17]. By using permeable materials to pave pedestrian and vehicular paths, storm water runoff can be absorbed. Permeable pavement surfaces include interlocking pavers, porous asphalt, paving stones, and permeable concrete. In contrast to traditional impervious paving materials, permeable paving technologies allow storm water to percolate and infiltrate through the pavement and into the aggregate layers and/or soil below [18-20]. In addition to reducing surface runoff, permeable pavement solutions can capture suspended particles and filter contaminants from rainwater. With the use of permeable pavements, we will be able to reduce runoff, improve water quality, and manage storm water at its source. Permeable pavement is extremely practical and easy to utilize. In order to decrease the amount of surface runoff, they don't need extra space. They can be used to direct water infiltration into the earth as well as detain and retain water. Permeable pavements function exceptionally well, although there are worries regarding efficiency loss during their design life owing to clogging [21-23]. According to test results reported in the literature, permeable pavements are efficient at lowering runoff volume and eliminating impurities from storm water in urban areas, and their usage ought to be encouraged. The data suggest that after 20 years of use, permeable pavements may lose 80% of their capacity for infiltration [24-26].

Bituminous permeable paving roads have the potential to be very significant in the majority of pavement designs. It provides a quick, affordable, realistic, and long-term solution to surface water flooding. Permeable pavement is a fresh bituminous pavement substitute that quickly removes extra water from the road's surface [27-29]. The permeability and water infiltration characteristics of the pavements can be improved with a bitumen density of 6% and a void ratio of 20%. Surface contaminants in infiltrated water are reduced by the use of geotextiles and fibres. According to reports, permeable pavements reduce harmful substances like lead by 79 percent and the total amount of suspended particles by 64 percent. With either no particles or extremely few fines in the aggregates, the base and sub base of the pavement are comprised of open granular materials, which, after compaction, have a fairly large void ratio. The results of the study conducted by other research fellows give a justification for the reduced retention of copper as well as the considerable retention levels of zinc, cadmium, and lead by weight in percentage [30-32]. It is also stated that the permeable pavement retained an average of 0.28 kg of sediment in every rainfall event, compared to 4.1 kg for conventional pavement. Run-off water will be decreased to 42 percent and hydrocarbons will be captured at a rate of 90 percent if there is no heterogeneity in pavement performance. Utilizing ceramic waste in place of coarse aggregates can help enhance recycling of waste materials while gradually reducing the use of natural resources. By using ceramic aggregates to create permeable pavements, storm water runoff is decreased and infiltration capacity is increased [33-35]. The optimal replacement percentage that would provide for good infiltration and pavement longevity will be demonstrated through experimental research of permeable pavements using ceramic waste materials in varied replacement percentages for coarse aggregates. When the workability of ceramic coarse aggregates in various compositions was evaluated, it was found to range from medium to high at a ratio of 0.6 w/c. The usage of ceramic waste in pavement construction will help to increase the building's ability to absorb water [36-38].

To comprehend how asphalt is used to make the pavement permeable, a parking lot construction is considered. It is constructed with assumptions little to no trucks, residential traffic with a few trucks, and heavy traffic with heavy trucks, respectively, can use a minimum thickness of 2.5, 4, and 6 inches of compacted porous asphalt surface. A 1-inch-thick layer of clean, smaller, single-size crushed stones is frequently added on top to support the surface for paving. This layer provides a more secure working surface for construction by filling up the bigger void space at the surface of the coarse aggregate layer. The porous asphalt layer, filler coarse layer with recycled ceramic aggregates, rock ballast layer, stone reservoir layer, and geotextile layer are the five layers that make up permeable pavement design. The constructed parking lot is analysed to determine how fine aggregate and binder specs can be used to build permeable pavement [39,40]. Due to the interlocking effects between the aggregate and binder, the proportion of fine aggregates has a significant impact on the mix's performance. As binders age, they all become more rigid. Even though the layers contain the same amount of air voids, the binder at the upper surface ages faster than the lower layer. Cohesion is improved by high-viscosity binder, which also results in increased strength, reduced drain-down, better durability, and higher rutting resistance. Less than 14 percent of the permeable pavement's composition should be made up of fine aggregate, and less than 3 percent should be made up of filler material. Only when the air void content is more than 14% is infiltration conceivable [41,42].

The primary advantage of using permeable pavement is to improve the hydrological properties of a road. Recent modifications to storm water legislation around the country now call for greater on-site storm water infiltration and detention. One advantage of permeable pavement is its ability to filter pollutants out of surface water before they enter sewage systems or outflow rivers. Numerous studies have shown that porous asphalt has the potential to remove up to 90% of hydrocarbons, including oil and grease, significant percentages of total metals, and 90-80% of all suspended particles from automobiles. This significant drop in pollutants is positive, but it also highlights the need for routine pavement cleaning to preserve the pavement's permeable qualities. The porous asphalt can be put down over currently present impervious surfaces as a permeable friction course overlay. Porous asphalt can reduce traffic by 50% since it is more flexible than other porous pavements. When making permeable asphalts, less fine aggregate should be used. Ceramic waste materials can be used to replace until the ideal rate is reached, depending on the results of the tests for the coarse aggregates. The best outcomes are not achieved when ceramic waste is used as a trade-in for fine aggregates. The usage of geo-material layers as sub-bases enhances the strength and filtration of storm water [42,43].

The research's methodology entails testing permeable pavement with ceramic waste as aggregate in place of some of the coarse aggregate and concrete dust as filler. Geotextile fabric is used to increase the pavement's ability to absorb water [44,45]. It is experimented with to combine ceramic waste, coarse aggregate, concrete dust, and geotextile fabric with 60/70 grade bitumen. Based on numerous research papers and experiments, the replacement percentage of coarse aggregate is thought to be 0, 30, 40, and 50. The major component of this task is the choice of materials, therefore finding an alternative approach to dispose of building trash will help to maintain a sustainable environment. The building sites are where the ceramic waste is collected. To obtain aggregates measuring 12.5mm, the obtained materials are broken and sieved. Its characteristics are tentatively quantified, and they are compared to those of typical coarse aggregates. It is examined to determine whether using waste ceramic materials as a partial exchange for coarse aggregates in porous asphalts is reasonable [46-48]. By using ceramic waste as aggregates, porous asphalt can further expand its penetration limit and reduce surface spillover. As a result, distinct rates of substitution of ceramic waste aggregates in coarse aggregates are prepared and investigated. In penetrable asphalt, the relative attributes of such creations are identified [49,50].

2. Materials Collection

In this experimental work it is decided to use ceramic waste aggregate as a replacement to coarse aggregate, concrete dust as filler material, 60/70 grade bitumen as binder material and geo-textile as base layer. The physical and chemical properties of these materials are crucial since they will determine how the entire composite combination behaves. Based on their qualities and features under various scenarios and conditions, suitable materials are chosen.

2.1 Materials Used

i. Ceramic waste aggregates in replacement proportions for coarse aggregates
ii. Bitumen/Asphalt as binder material with grade 60/70
iii. Concrete dust as filler material
iv. Non-woven Geo-textile as base layer for infiltration purpose

2.2 Ceramic Waste Aggregates

Materials made of ceramic are weak, hard, solid under pressure, and weak when subjected to shearing and strain [51,52]. They resist compound disintegration, which can place when certain materials are exposed to severe or acidic environments. Ceramic materials' high liquefying points, incredible hardness and strength, significant solidity and durability, low electrical and warm conductivity, compound inactivity, and resistance to various synthetics are among their properties that are taken into account, as well as their low water retention limit. Ceramic rubbish collected from a construction job nearby. The ceramic pieces were separated from other garbage and crushed using a metal sledge from a quarry. According to established principles, crushed ceramic waste tiles were sieved into coarse aggregates. Ceramic waste aggregates are used as a partial replacement for coarse aggregates because they cannot be used as a full replacement for general. To analyse the strength characteristics of the permeable pavement, ceramic waste materials are employed as a partial replacement for coarse aggregate in three different proportions. The nearby site is where the used ceramics are gathered and it is presented in Figure 1. It was simpler to gather the materials because there were many structures on our campus that needed repair and rehabilitation [53-55]. Using a crusher, the gathered materials are reduced in size. By performing a sieve analysis, the crushed ceramic aggregates are divided into various sizes. The 20mm ceramic aggregate was collected for use in this experiment and has rough edges and an uneven form. After reviewing the study papers written by various scholars it was decided to take three different aggregate replacement percentages into consideration.

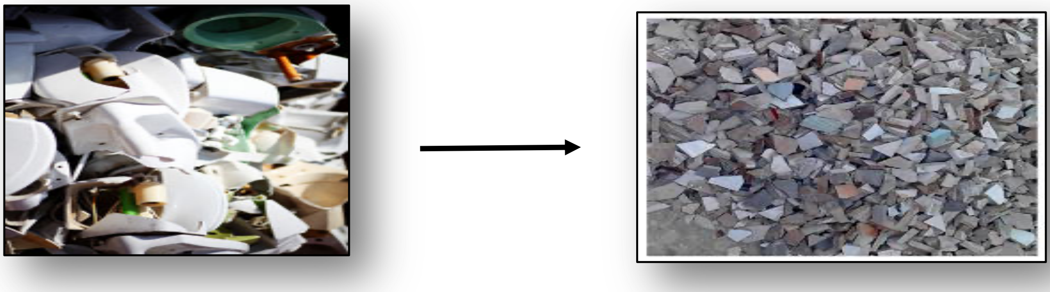

Fig. 1. Ceramic Waste Materials

Figure 2 displays the percentages of ceramic waste used. The replacement percentages for the coarse aggregate as ceramic waste are 0, 30, 40, and 50, respectively.

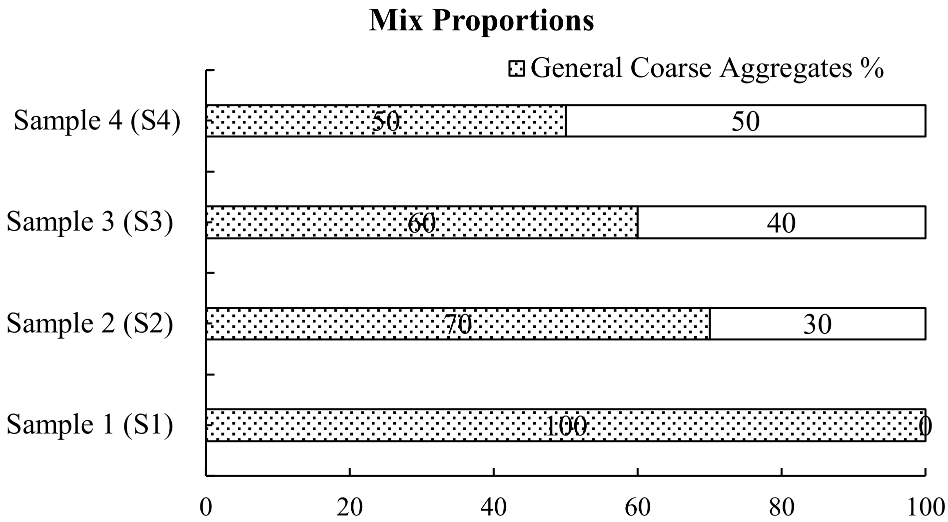

Fig. 2. Mix Proportions of Coarse Aggregates

2.3 Bitumen

Bitumen is a hydrocarbon composed mainly of hydrogen and carbon, plus, to a lesser extent, calcium, iron, sulphur and oxygen, among other elements. The type and source of the raw petroleum used to make a material determines its nature and the ease with which it was created. The substance is frequently used to clear streets. Because of its waterproofing qualities, makers use it in the creation of material goods [56-58]. Depending on the composition of the black-top combination, the ambient temperature, and the amount of pressure applied to the material, bitumen can permanently deform under heavy loads. Blacktop may become brittle and crumble as a result of bitumen oxidizing. According to IS-73-1992, the qualities for bitumen 80/100 are confirmed to be S90 grade. This level was the gentlest and was used on low traffic roads. Bitumen 60/70 was used in the construction of National and State Highways because it had a harder level than 80/100 and was certified to the S65 level of IS-73-1992. It could also withstand larger traffic loads. The hardest bitumen, 30/40, was confirmed to meet S35 level of IS-73-1992 and could handle heavy traffic loads; as a result, it was used in specialized applications, such as airport runways and high traffic volume streets in waterfront urban neighbourhoods. The bitumen 60/70 is taken into consideration for this study and is analysed further. A road contractor was hired to provide the 10 kg of 60/70 bitumen that was determined to be necessary for the entire project and is shown in Figure 3.

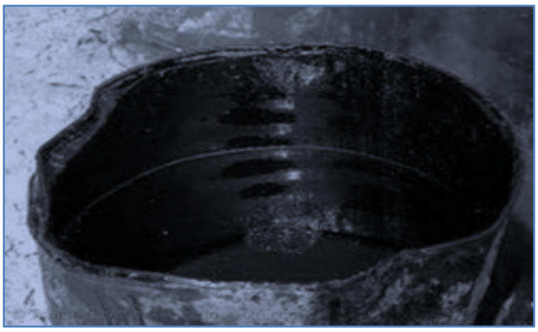

Fig. 3. Bitumen

2.4 Concrete Dust

The Asphalt Institute recommends using black-top cement with 4 to 8 percent filler. Common filler substances include concrete, limestone, rock powder, and other. Therefore, since they also produce amazing results, scrap concrete powder or brick dust can occasionally be used as filler materials. The significant residue used in the bituminous mixture improves the strength characteristics and reduces scraped area and grinding concerns in coarse totals of porous asphalts. Pavement construction can employ ceramic waste as a 20% substitute with sufficient quality control. When compared to typical concrete, it was found that the flexural strength and split-tensile strength had not significantly changed. The adjoining site is where the building waste is collected. They are crushed and then sieved which is presented in Figure 4. The sieve that was utilized was designed for sieving flour. For this experiment, particles with a size of less than 15 microns that are passing through the sieve are used. Concrete dust is employed as a filler material in the building of permeable pavement in this work to the extent of 25%.

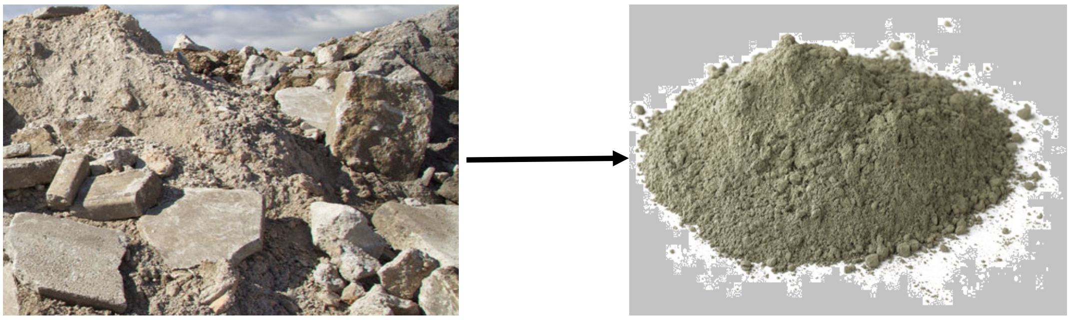

Fig. 4. Concrete Dust

2.5 Geo-Textiles

Polyester or polypropylene are frequently used in the production of geo-materials. Numerous structural design applications, such as streets, landing strips, railways, dikes, holding structures, supplies, canals, dams, bank insurance, beach front planning, and building site sediment walls, are supported by geo-materials today. Geo-materials are typically applied to the strain surface to strengthen the soil. To address moving water in the two directions, filtering geotextile properties are used. These geotextiles, which can be woven or nonwoven, are used to stop tiny particles from transferring between soil layers. Geotextiles can also facilitate the parallel progression of waste water, spreading the dynamic energy of the gradual ascent of groundwater, depending on the porosity and porousness of the material. For this experimental effort, 0.93 square meter of geotextile fabric are bought from the market and is given in Figure 5. Geo-textile is utilized to address seepage problems in this work.

Fig. 5. Geotextile Fabric

2.6 Composite Sample

The ability of the cast sample mixture to withstand the traffic volume and asphalt mileage will be tested through experimental analysis. IRC & MORTH advise Marshall Stability analysis as the optimum technique for determining the mix strength. Thus, bituminous sample moulds are formed in order to evaluate the stability of the suggested composite combination. Concrete dust is utilised during casting as a filler ingredient instead of fine particles. In order for the composite mixture to keep the shape of the cast sample, it is thought that 4 to 8% of the filler materials will be necessary. The fixed composite mix proportions for experimental analysis are shown in Table 1.

Table 1
Composite Mix Proportions

Sample No	20 mm Aggregate (40%)	12.5 mm Aggregate (35%)	Filler Dust (25%)
S1	40% of General aggregates + 0% of Ceramic aggregates	35% of General aggregates + 0% of Ceramic aggregates	25% of concrete dust
S2	28% of general aggregates + 12% of Ceramic aggregates	28% of general aggregates + 12% of Ceramic aggregates	25% of concrete dust
S3	24% of general aggregates + 16% of Ceramic aggregates	24% of general aggregates + 16% of Ceramic aggregates	25% of concrete dust
S4	20% of general aggregates + 20% of Ceramic aggregates	20% of general aggregates + 20% of Ceramic aggregates	25% of concrete dust

S1, S2, S3, and S4 are the nomenclature used for 0, 30, and 40% of ceramic wastes as an alternative material for coarse aggregates, respectively. The design characteristics taken into account by IS requirements are listed in Table 2. The bituminous mix's stability, flow value, air voids, bitumen-filled voids, and ideal binder content values can all be calculated using the experimental data.

Table 2
Marshall Design Mix Desirable Values for Reference

Test Property	Specified Value
Marshall stability, kg	900 kg
Flow value, mm	2 - 4 mm
Percent air voids in the mix %	3 - 6 %
Voids filled with bitumen (V.F.B) %	65 - 75 %

3. Results and Discussion

3.1 Aggregate Test Results

The effects of the relative abundance of four different examples of totals are contrasted, and Table 3 and Figure 6 present the Indian Standard Code Specifications and a similar classification of the experimental results. The experimental findings for samples S1, S2, and S3 all match the requirements set forth by the IS code for all carried out experimental analysis. Since the sample S4's crushing and impact values are beyond the permitted limit, it may not perform as predicted in further analysis.

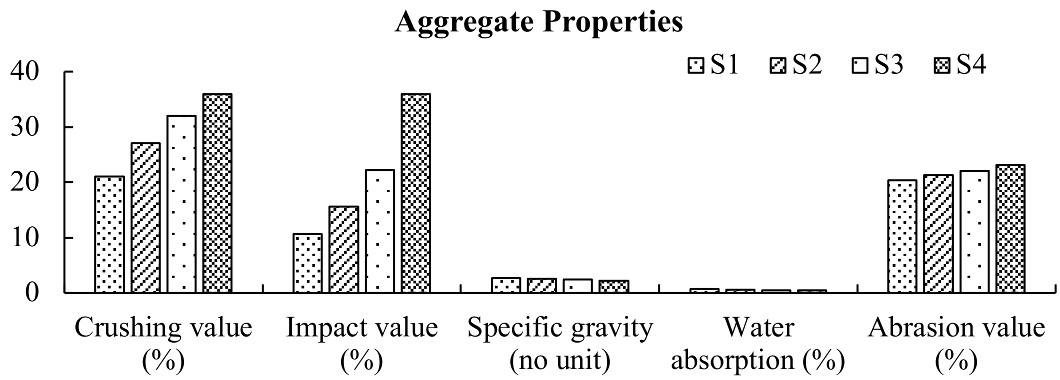

Fig. 6. Aggregate Properties for the Developed Composite Material

However, the sample's specific gravity and water absorption capacity are within the permissible range. S4's impact test result is just barely within allowable limits. It is chosen to continue in order to bring its performance to a close. The test findings indicate that, with the exception of S4, every other sample’s quality conforms with the requirements outlined in the IS Code.

Table 3
Aggregate Test Results

Tests	Is Code Standards	S1	S2	S3	S4
Crushing Value (%)	0 – 40	21	27	32	36
Impact Value (%)	0 – 30	10.7	15.6	22.2	36
Specific Gravity (No Unit)	2.5 - 3.0	2.74	2.58	2.43	2.19
Water Absorption (%)	0 - 3.0	0.73	0.61	0.53	0.48
Abrasion Value (%)	0 – 40	20.4	21.3	22.1	23.1

To evaluate the samples qualities, the manufactured samples are subjected to experimental analysis. Crushing value, impact value, abrasion resistance, water absorption capacity, and specific gravity are a few of the qualities evaluated which are presented in Figure 7.

Fig. 7. (a) Aggregate Impact Value Test Conducted (b) Aggregate Crushing Strength Test Conducted (c) Aggregate Water Absorption Test Conducted

3.2 Bitumen Test Results

The collected results are shown in Table 4 along with a comparison to the IS specifications. The bitumen that was gathered for the fabrication of the composite sample clearly complies with the standards according to the experimental results.

Table 4
Bitumen Test Results

Tests Performed	Is Code Standards	Sample Results
Penetration value (tenths of mm)	60 - 70	63.8
Softening point value (°C)	30 - 157	81.5
Ductility value (cm)	50 - 100	60.3

The experimental results are all displayed in Figure 8 and all fall within the IS Specifications' range. Therefore, it is advised to cast composite samples using the bitumen sample that was taken.

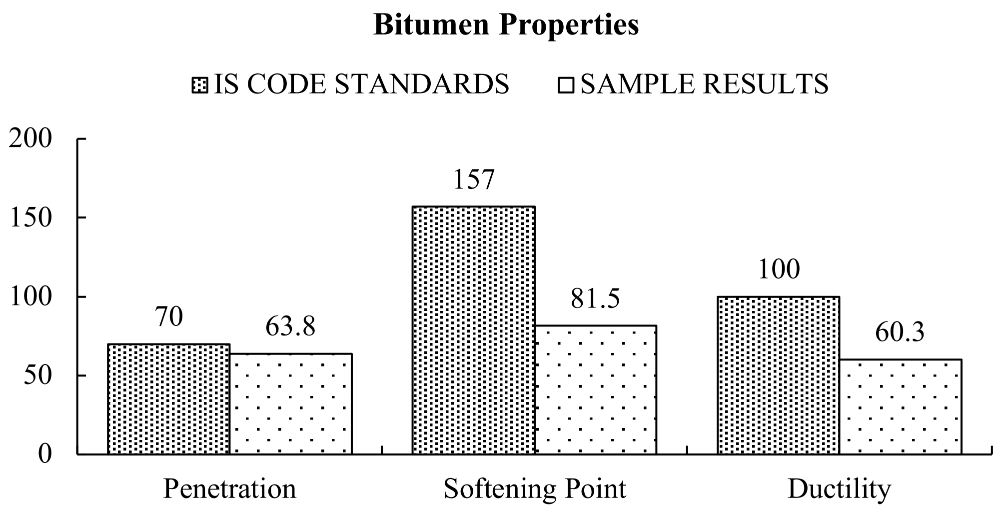

Fig. 8. Analysis of Bitumen Properties for Construction of Permeable Pavement Model

Grade 60/70 bitumen is taken into consideration while casting the composite sample mix. The experimental analysis of the gathered sample focuses primarily on its penetration, softening point, and ductility value which are presented in Figure 9.

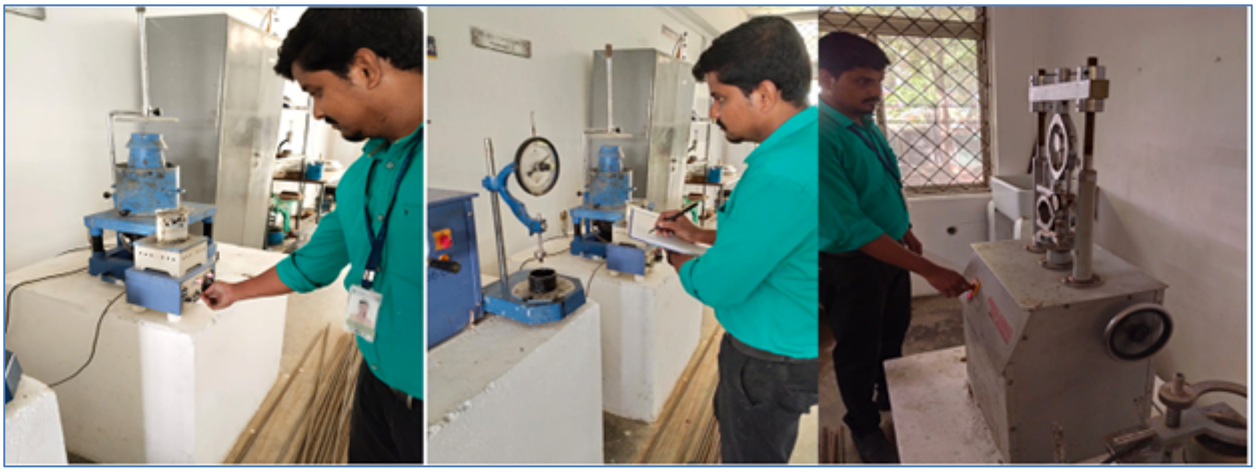

Fig. 9. (a) Bitumen Softening Point Value (b) Bitumen Penetration Value (c) Marshal Stability Test Conducted on Bitumen

3.3 Analysis of Sample 1 (S1)

One hundred percent of the generic aggregates make up sample 1. Because this sample is typically used for bituminous asphalts, it produces an excellent result because all of the attributes meet IS standards as listed in Table 5. When examined with various examples, aggregate, bitumen, and composite combinations yield excellent results. The results of the experiment in comparison with other samples are shown in Figure 10.

Table 5
Composite Mix Proportion Analysis

Sample No	Properties					
	Density (g/cc)	Marshall stability (KN)	Binder Content (%)	Flow value (mm)	Air Voids (%)	Voids filled with bitumen (%)
S1 (100% of general aggregates)	2.459	16.385	4.1	2.365	3.5	68
S2 (70% of general aggregates + 30% of ceramic aggregates)	2.491	14.419	4.3	2.418	4.7	66
S3 (60% of general aggregates + 40% of ceramic aggregates)	2.464	14.004	4.4	2.698	5.2	73
S4 (50% of general aggregates + 50% of ceramic aggregates)	2.493	10.205	4.5	3.327	6.1	77

3.4 Analysis of Sample 2 (S2)

Sample 2 consists of a blend of ceramic waste and coarse aggregate at a level of 70:30. The use of waste clay materials as aggregates in this mixture of ceramic waste reduces the double-dealing of ordinary assets and advances the practice of reusing waste materials. S2 combined produces fantastic results in terms of pounding, effect, scraped area, and water consumption. The experimental results are presented in Table 5. Although the specific gravity is a little lower than the suggested estimates, the blend can nevertheless work well in asphalt constructions. Both high temperatures and traffic stacks can be tolerated by them. The geotextile layer is used at the base over the dirt layer to frame a flat base and with the objective of filtration. This example can be connected to permeable asphalts. With 20 to 30 percent voids, example 2 can be used in various locations and save a lot of water. It is therefore advised to use this sample as a replacement material for all asphalt constructions, to construct parking lots, and to build pathways. It frequently serves as a replacement for rigid designs. It can also be used in areas with extreme temperatures and water scarcity. From Figure 10, it is evident that sample 2 results are on par with sample 1, which is a conventional pavement sample.

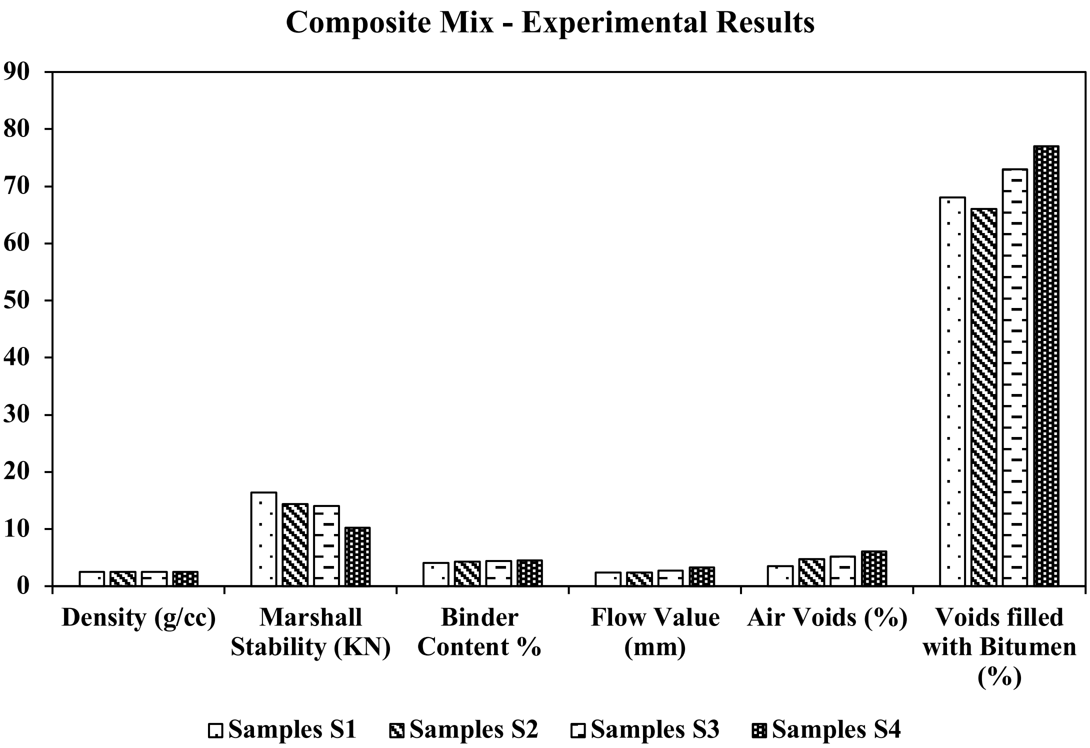

Fig. 10. Analysis of the Permeable Pavement Model Formed with Developed Composite Mix

3.5 Analysis of Sample 3 (S3)

A combination of 60% general totals and 40% burned garbage totals makes up sample 3. Additionally, this example provides excellent results in relation to IS coding principles and is presented in Table 5. Compared to S1 and S2, the example is thinner and lighter in weight. Compared to S1 and S2, this sample had a higher penetration rate and more voids can be visually seen from Figure 10. The mixture is suitable for locations with low to direct traffic loads. It can support a typical amount of weight with almost no asphalt structure deformation. It is therefore advised to apply this example while creating parking lots and walkways. It frequently serves as a trade for rigid buildings. It can also be used in areas with extreme temperatures and water scarcity.

3.6 Analysis of Sample 4 (S4)

The thinnest sample, S4, has a high-water intake and invasion limit, but it is unable to bear heavy loads since it fails the effect test and the explicit gravity test is presented in Table 5. As a result, although this sample can be used in gardens and walks, it cannot be used as a replacement for asphalt structures.

4. Conclusion

A penetrable asphalt material constructed of construction waste was examined for its various mechanical and practical qualities. The cost of development is reduced when such waste materials are used for worthwhile projects, and it also prevents the depreciation of conventional assets. The characteristics were compared to those of typical bitumen-bound permeable pavement. In comparison to a typical permeable pavement; the natural display of permeable asphalt with recycled ceramic aggregate is evaluated experimentally. Significant improvements in mechanical and practical aspects as well as in natural execution were seen. The materials used are raw and safe for the environment, and the presenting process as a whole is "cleaner" than with traditional black-top combinations.

i. The findings indicated that 60:40 and 70:30 blend proportions are more suitable for asphalt constructions than 50:50 mix experiments.
ii. Three of the four samples prepared were successful, and applying them to make penetrable asphalt will both advance the recycling process and be financially beneficial.
iii. The morphological characteristics of ceramic achieved a high void substance and worked on void availability due to the firm durability and cement bonds provided by clay waste material and considerable residue.
iv. As a result, it makes sense to use the mixture to build porous asphalt frameworks for improving storm water seepage.

Further investigations are anticipated to learn more about the material's exhaustion behaviour and progress the material plan with possible natural and financial benefits. The strength of the surface and an appropriate foundation determine how reasonable a geotextile can be. Geotextiles are a cost-effective way to guarantee improved drainage and subgrade changes. As a result, it will be expected that geotextiles are useful in improving roads if the proper foundation, management, and support are carried out.

Acknowledgement
This research was not funded by any grant.

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