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Exploring the Effectiveness of Various Waste Materials in Enhancing Pervious Concrete Performance: A Comprehensive Review

Anjali Gupta[1*], Sandeep Singla[2], Lakshay Mongia [1], Shagufta Jabin [1], Abrar Hussain Gatoo[3], Asif Altaf[2]

[1]*Manav Rachna International Institute of Research and Studies Faridabad, Haryana*
[2]*RIMT University, Mandi Gobindgarh, Punjab, India*
[3]*Thapar Institute of Engineering & Technology, Punjab, India*
**Corresponding Author: anjaligupta.fet@mriu.edu.in*

Abstract: Pervious concrete is a special concrete and has gained popularity due to its pioneering method to control, manage, and handle storm water runoff is widely used in many applications such as parking lots, pavements, and green roofs, due to its ability to mitigate the urban heat island effect and reduce stormwater runoff. It is a family of different materials such as cement, coarse & fine aggregate and admixtures. Since use of cement and natural aggregates for production of concrete are considered having negative environmental and cost effects, hence to control these different researchers are working on the utilization of waste materials as their replacement. This paper gives a detailed review about the previous finding of use of wastes such as flyash, ground granulated blast steel slag (GGBSS), rice husk, bottom ash, red mud, recycled aggregates, crump rubber etc. as a replacement in production and change in the properties of pervious concrete. It also leads towards use of pervious concrete in construction industry for building environment friendly, cost effective, self- cleansing and durable structures.

Keywords: *Pervious concrete, Waste material, Properties, GGBSS, Flyash*

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I. INTRODUCTION

Concrete being an important building material that is essential to the construction industry all over the world. It is considered to be the most commonly utilized material in the field of construction because of its reasonably low price, high durability, availability of the incorporated materials and ability to be formed into any shape or size. Due to urbanization, the production and consumption of concrete materials has been considerably increased mainly in developing countries like India. Concrete is meant to be impervious in nature and many urban areas across the globe has been being paved with impervious surfaces causing floods and soil erosion. To mitigate this impact of urbanization, many research contemplates are going and use of pervious concrete is gaining traction due to its innovative approach to managing, controlling, and treating storm water runoff.

Pervious concrete is a non-traditional concrete prepared using ordinary Portland binder, coarse aggregate, minimum fines or no fine aggregate, admixture and water with void space of 15 to 30% (Ong et al., 2016). These ingredients on mixing bind each other and form a matrix of highly permeable interconnected voids due to absence of fines which is a sustainable solution for rapid drainage of stormwater runoff in urban areas (ACI Committee 522, 2010). Nevertheless, cement and natural aggregates have their own limitations such as high CO_2 emissions, high cost, consumption of non-renewable resource etc. Hence, in order to conserve these materials, minimizing the environmental effects and increasing sustainability of the concrete now a days incorporation of waste materials has become a contemporary trend(Faraj et al., 2020; Gupta et al., 2019; Haque et al., 2002; Terzić et al., 2013; Zaetang et al., 2013). Such incorporations not only help conserve natural resources, reduction of CO_2 emissions but also helps to resolve an evolving waste disposal problem. This paper gives a detailed review about the previous finding of use of wastes as a replacement in production and change in the properties of pervious concrete after the replacement and future scope of work.

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II. BENEFITS, KEY PARAMETERS, AND CO-BENEFITS APPROACH

Pervious pavement is an innovative stormwater management practice that has been gaining attention due to its potential to mitigate the negative impacts of urbanization on the hydrological cycle and urban heat island (UHI) effects. This technology is designed to allow rainfall and stormwater runoff to infiltrate into the underlying soil, reducing the volume and velocity of surface runoff while also providing an opportunity for groundwater recharge.

Benefits of Pervious Pavement:

Stormwater management: Pervious pavement helps to manage stormwater by minimizing the volume of runoff and the peak discharge rates (Agouridis et al., 2018; Seifeddine et al., 2023). This technology promotes infiltration of rainfall into the soil, which reduces the amount of water that runs off the surface and enters stormwater systems.

Water quality improvement: Pervious pavement helps to improve water quality by filtering pollutants and sedimentation through the permeable surface, which reduces the amount of pollutants that enter streams, lakes, and other water bodies.(Pilon et al., 2019; Tota-Maharaj & Scholz, 2010)

Reduced UHI effects: Pervious pavement can help to mitigate UHI effects by reducing the amount of heat that is absorbed and retained by the pavement surface. This helps to reduce surface temperatures, air temperatures, and overall heat retention in urban areas. (Marolf et al., 2004; Neithalath et al., 2005, 2006)

Key Parameters for Pervious Pavement:

Strength: The compressive strength of pervious concrete varies depending on several factors, including the mix design, porosity, and density of the concrete (Amminudin Ab Latif et al., 2023). Generally, pervious concrete has lower compressive strength in comparison to traditional concrete because the mix contains voids, which are necessary to allow water to pass through the surface. The American Concrete Institute (ACI) provides guidelines for the minimum compressive strength of pervious concrete ranging from 20.7 to 27.6 MPa, depending on the specific application and exposure conditions.

Permeability: The permeability of the pavement surface is one of the key parameters for effective stormwater management and UHI mitigation, (Seifeddine et al., 2023). The pavement surface must be permeable enough to allow rainfall and stormwater runoff to infiltrate into the underlying soil.

Porosity: The porosity of the pavement surface is also important for effective infiltration of rainfall and stormwater runoff. The pavement surface must be designed to have enough void space to allow for infiltration while also maintaining structural integrity.

Maintenance: Regular maintenance of pervious pavement is critical to preserving its efficacy in managing stormwater and UHI mitigation. Maintenance includes regular cleaning, removal of debris, and repair of damaged areas.

Co-benefits Approach:

A co-benefits approach involves considering the multiple benefits of pervious pavement on stormwater management and UHI mitigation. This approach recognizes that the benefits of pervious pavement extend beyond just stormwater management and UHI mitigation (Wang et al., 2022). Other co-benefits of pervious pavement include:

Increased aesthetic value: Pervious pavement can enhance the aesthetic value of urban areas by providing a green space that is visually appealing.

Improved air quality: Pervious pavement can help to improve air quality by reducing the amount of pollutants that are generated from stormwater runoff.

Reduced noise pollution: Pervious pavement can help to reduce noise pollution by absorbing sound and reducing the amount of noise that is generated by traffic. (Chagas Rodrigues et al., 2022; Tian et al., 2014)

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Overall, pervious pavement is a promising technology for stormwater management and UHI mitigation in urban areas. The benefits of this technology can be maximized by considering the key parameters for effective design and maintenance, as well as taking a co-benefits approach to recognize the additional benefits of this technology.

Previous Studies on pervious concrete

Since pervious concrete is a family of different materials such as cement, coarse & fine aggregate and admixtures, this paper provides insight into some of the findings of the inclusion of waste material as cement (partial or full), aggregates or admixture replacement. Figure 1 shows percentage studies based upon various waste materials used for PC published in last two decades. Fly ash has been the most widely studied waste material in pervious concrete, followed by GGBFS, rice husk ash, silica fume, quarry dust, waste glass, and other waste materials. Although several research studies have been conducted using various waste materials enhance properties of PC but still performance characteristics of PC are not entirely understood in various aspects.

A. Flyash

(Ravindrarajah & Yukari, 2010) investigated by replacing 20% and 50% of the binder with fly ash, the compressive strength and permeability of porous concrete. According to the findings, the addition of fly ash led to a decrease in the compressive strength of the mix. The highest compressive strength was recorded to be 10 MPa for the control pervious concrete and the lowest resistance to compression was about 6 MPa for mix prepared by replacing 50% fly ash with cement. On substitution of 20% of cement with fly ash, the penetrable property of pervious concrete reduced. Whereas on 50% substitution it increased and achieved value nearly same to concrete mix with no fly ash.

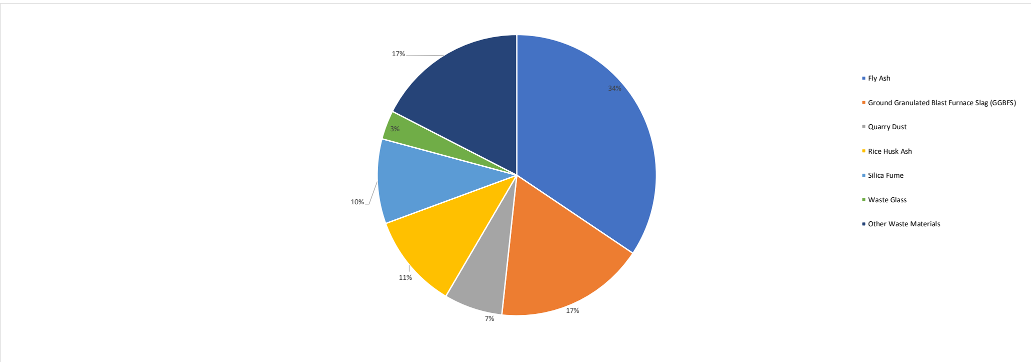

Figure 1. Percentage studies based upon various waste materials used for PC published in last two decades.

.(Aoki et al., 2012) conducted experimental study of porous concrete by supplanting cement with low calcium fly ash. Seven different trial mixes of porous concrete were produced with varying levels of fly ash substitution (0%, 20%, and 50%) and fine aggregate addition (0%, 7.5%, and 10%). It was noted that on substitution of cement with 50% fly ash, compressive strength of mix decreased by 40% compared to no fly ash mix. Additionally, the permeability of pervious concrete improved when 20% fly ash was included, with values increasing from 10.2 mm/s (without fines) and 7.5% fines to 13.6 mm/s for 10% fines. However, no significant change in the permeability coefficient was observed when the binder was substituted with 50% fly ash content.

(J. X. Lu et al., 2019)attempted to cast pervious concrete samples by using alternate of cement i.e. geopolymer. Geopolymer was prepared by mixing high calcium fly ash, sodium silicate, sodium hydroxide solution and coarse aggregates. The ratio of various ingredients was taken as 1.0-8.0 for fly ash to coarse aggregate, 0.50 for sodium silicate to sodium hydroxide and 0.35, 0.40, and 0.45 for alkaline liquid to fly ash. The results indicated that the compressive strength of all the mixes ranged from 5.4-11.4 MPa and the split tensile strength was approximately 0.7 MPa. Moreover, there was an increase of 10.4-16.3% observed in the ratio of compressive strength to split tension strength when compared to conventional concrete.

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(Opiso et al., 2019) studied the effect of substitution of OPC with coal fly ash (CFA) act as a replacement for binder and fine sawdust (FSD) as filler material on compressive strength, flexural strength and permeability of pervious concrete. They also examined the field performance of pervious concrete by placing the concrete at the parking lot. In this study, two mix proportions were prepared i.e. control mix (comprises of no CFA and FSD) and treated mix (composed of 2%, 4%, 6%, 8%, 10%, and 12% FSD by weight of cement and 10% CFA as replacement of OPC). Test results showed that the highest average compressive strength (29.13 MPa) was observed on addition of 8% FSD to concrete mix which was 15.9% higher than the control mix. The flexural strength was found to be 4.167 MPa which surpass the domestic and international standard requirement for flexural strength of concrete parking lots of 3.4-4.5 MPa. Furthermore, the statistic of infiltration rate showed improvement in permeability in all the 3 sites accordingly Site 1 (pressure washing) attained the maximum infiltration rate of 21.7%, Site 2 (blowing) gained 0.5% increment and Site 3 (vacuuming) gave 17.9% increment in the infiltration rate.

(Liu et al., 2019) conducted a study to investigate the impact of different levels of FA (3%, 6%, 9%, and 12%) on the properties of PC. Results indicated that the addition of FA resulted in a decline in both flexural and compressive strength during the early stages of the curing period (28 days), with compressive strength decreasing by 34% with 12% FA. However, over a longer curing period of 150 days, the strength of the FA-modified PC increased due to a faster hydration rate, leading to stronger bonding between the coarse aggregates. The authors concluded that although the addition of FA to PC may not have a positive effect on its characteristics, FA can still be used as a substitute for cement in PC. Moreover, an increase in the curing time was found to enhance the rate of strength gain.

(Carmichael et al., 2020) discovered that the optimal mixture of materials for concrete involved a W/B ratio of 0.34 and the addition of 40% nano FA particles. This particular blend yielded the highest tensile strength of 3.89 MPa and compressive strength of 20.93 MPa after 28 days. The concrete's strength increased proportionally to the amount of nano FA added, but beyond 40%, the strength slightly decreased. This could be attributed to the excessive amount of pozzolanic and filler materials present in the mixture.

(Al-sallami et al., 2020) examined how substituting different levels of Class F FA for cement affected the behavior and performance of PC. The study investigated cement substitutions ranging from 30% to 50%. The findings showed that substituting 30% of cement with FA by weight led to a considerable improvement in flexural strength and compressive strength by 38.34% and 40%, respectively, after 90 days of curing. This improvement was due to the pozzolanic properties of FA, which acted as a micro-filler and produced secondary C-S-H gels, resulting in cohesive activity, decreased voids, and improved modulus of elasticity and strength. However, substituting 50% of cement with FA resulted in a decrease in PC strength. This decrease could be attributed to the inactivity of some FA particles in the hydration process. These inactive particles acted as fillers, increasing density and decreasing void content, but did not contribute to strength enhancement.

B. Ground Granulated Blast Furnace Slag (GGBFS)

(Yang & Jiang, 2003) inspected the effect on compressive strength and permeability of the pervious concrete by partially substituting with GGBFS. Samples were prepared by supplanting binder with 35% and 75% GGBFS by weight and recycle coarse aggregate of sizes 13 mm were used. The test result showed that with increase of GGBFS proportion from 35% to 70%, the 28th day compressive strength increased from 6.19 MPa to 10.6 MPa. However, the porosity percentage decreased from 25.5% to 16.7%.

(Ramkrishnan et al., 2018) evaluated the percentage of GGBFS which was used to produce an eco-friendly pervious geo-polymer concrete. In the production of this type of concrete sodium silicate, sodium hydroxide solution, coarse aggregate, and different compositions of fly ash and GGBFS were utilized. After several tests, the investigation shows that the presence of 80% GGBFS and 20% fly ash in the trial mix gave higher strength when compared with the other trial mixes i.e. 60/40% and 50/50% of the use of GGBFS and Fly ash respectively.

(El-Hassan et al., 2019)examined the impact of replacing cement with ultrafine ground granulated blast furnace slag (UFGGBFS) and metakaolin on durability, compressive strength, and infiltration rate of pervious concrete. It was observed

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experimentally that after replacement of the binder with 10% and 15% of metakaolin showed better results against sulfate attack and surface wearing but a substantial decrement in the compressive strength was also noted as compared to the standard mix, further the reduction in compressive strength, better results against sulfate attack and reduction of weight by 30% in abrasion test was noted when fly ash was used as a replacement. A decrease in strength was noted when cement was replaced by 10% of UFGGBS, but better results against sulfate attack and surface wearing was observed. Therefore, UFGGBS performed better as compared to Metakaolin when both strength and durability are concerned.

(Hamid et al., 2013)examined the properties of porous concrete by using slag and recycle aggregate. 0%, 10%, 20%, 40%, 70%, and 100% recycle aggregate were added to the mixture by replacing natural aggregate, 0% and 50% proportions of slag were also incorporated, and 0.4 W/C ratio was considered. They concluded that slag provided better workability due to its smooth texture. On increasing the RCA proportion, it decreased the workability but increased the porosity of the mix. Increment in the rate of clogging percentage was noted within 5 years which decreased the infiltration rate of the concrete. Up to 20% of RCA replacement showed no significant effect on the abrasion resistance. 100% RCA porous concrete was proposed for low abrasion structures such as sidewalk, low traffic road, low-grade road, and parking area, etc.

C. Rice Husk

(Kartini, 2011)investigated the workability and compressive resistance of porous concrete by replacing the binder, three types of RHA mixtures named RHA1, RHA2, and RHA3 were prepared by grinding for 30, 60, 90 minutes, respectively. Samples were made by partially replacing cement with 5% of each and results were compared with samples having no cement as a replacement. After several tests, it was concluded that on increasing RHA grinding time (means increasing the surface area of RHA, making it finer and increase in water demand), the workability of concrete decreases. Out of all the samples, RHA3 showed highest compressive strength (40.6 N/mm2 on 28th day), which showed that the improvement of compressive resistance of porous concrete is governed by increasing the grinding time of RHA. The increment in compressive strength possibly due to fineness of RHA particles as finer the RHA particle, more would be the water demand which further lead to increase the formation of calcium silicate gel in the lattice.

(Hesami et al., 2014) conducted a study to investigate the impact of partially replacing cement with rice husk ash (RHA) on concrete properties. The findings revealed that a 20% increase in RHA did not have a substantial effect on the concrete's compressive strength; however, beyond that, the strength decreased. Furthermore, the study found that substituting RHA did not enhance the flexural and tensile strengths of the concrete.

(Hesami et al., 2014) investigated the impact of using Rice Husk Ash (RHA) and a mixture of different fibres on the mechanical properties of pervious concrete. The study found that incorporating RHA as a partial replacement for cement up to 8-10% did not significantly affect the optimal amount. However, using a mix of glass, steel, and PPS fibres increased the compressive strength of pervious concrete containing RHA by 34%, 37%, and 36% respectively. The study also discovered the highest mechanical properties, such as compressive, tensile, and flexural strength, were achieved with a water-cement (w/c) ratio of 0.33. Additionally, concrete with 10% RHA exhibited better compressive, tensile, and flexural strength compared to concrete with 12% RHA, although its permeability was significantly lower. The study also found a similar trend in the compressive, tensile, and flexural strength of concrete with both RHA and fiber, but the optimal percentage of RHA varied for different w/c ratios of 0.27, 0.33, and 0.4. In all cases, the mechanical strength increased rapidly before reaching the optimum percentage and then gradually decreased.

D. Bottom ash

(Zaetang et al., 2015)used the coal ash as a geopolymer binder and used bottom ash as coarse aggregate in their investigation and analyzed the compressive strength and other properties of porous concrete. Results revealed that 10-15 M of NH concentration and 0-15% replacement of FA with OPC enhanced the strength of the porous concrete. The 15 M and 15% replacement of binder with FA gave decent compressive strength to the porous concrete. The compressive resistance of different mixes was observed between the range of 5.7-8.6 MPa, thermal conductivity between the range of 0.33-0.35 W/mK was noted and recommended curing at 90 degrees Celsius.

(Jang et al., 2015)carefully examined the properties of pervious concrete samples prepared by incorporating coal bottom ash as a substitute for coarse aggregate and geopolymeric binder. In their study, mechanical properties and heavy metal leaching behavior of the concrete were evaluated. Further investigation shows that the concentration of heavy metal leached from the

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bottom ash is below the chosen criteria, it is stated that the pervious concrete created in this research effectively arrest the movement of heavy metals as solidified/stabilized concrete.

(Kuo et al., 2013) substituted natural aggregate with municipal solid waste incinerator bottom ash (MSWIBA) in pervious concrete. They determined the concrete's mix proportions using a vertical flow test and conducted several tests to evaluate its properties, including permeability, compressive strength, bending strength, and split tensile strength. The study found that the unit weight of fresh pervious concrete made with MSWIBA ranged from 1653 to 2080 kg/m3 and increased as the cement paste filling ratio increased. Increasing the filling paste ratio resulted in improved compressive, bending, and split tensile strengths for specimens with the same water-cement ratio. The split tensile and bending strengths were approximately 1/9 and 1/4 of the compressive strength, respectively. Moreover, there was a linear correlation between the connected porosity and permeability coefficients, which decreased as the filling ratio increased.

In 2022, (Park et al., 2022) conducted a study to examine the properties of pervious concrete containing coal bottom ash (CBA) aggregates, with a focus on strength and permeability. Two pervious concrete mixtures were created using CBA aggregates of different size distributions: one with a single-type distribution and the other with a hybrid-type distribution. The study investigated the effects of water/cement (W/C) ratio and compaction level on the CBA pervious concrete under varying conditions. Pervious specimens were fabricated with W/C ratios of 0.25, 0.30, and 0.35, and compaction levels of 0.5, 1.5, and 3.0 MPa. The results showed that increasing the W/C ratio reduced strength by about 20% to 30%, while increasing the compaction level reduced permeability by about four to five times but significantly increased strength. The use of single-type or hybrid CBA aggregates of different size distributions had an impact on the properties of the pervious concrete. Specimens containing hybrid CBA aggregates had 30% to 45% greater strength compared to those containing single-type CBA aggregates, but the use of hybrid CBA aggregates reduced permeability by approximately 20% to 35%. Based on the results, the study proposes relationships between the strength properties, permeability characteristics, and total void ratios of the CBA pervious concrete specimens.

E. Red mud

(Chen et al., 2019) in their study of Red Mud (RM) which is an industrial solid waste was utilized as a basic material to produce a geopolymer type porous concrete with granulated blast furnace slag. They stated that RM contains alkali content and has a tendency to adsorb some heavy metal ions. Due to the adsorption characteristic of RM, it could be used to produce a geopolymer type porous concrete incorporated with GBFS having rainwater filtering characteristic. Results reveled that the compressive strength of the geopolymer based porous concrete decreased with the increment of RM content at 0-50% concentration but adsorption of heavy metal ion characteristics improved considerably.

F. Recycle aggregates

(Sata et al., 2013) closely inspected different properties of sustainable pervious concrete by using the geopolymer concrete and recycled aggregate. Two types of aggregate were used in this study first is crushed structure concrete member and second one is crushed clay brick. Further in their research, they used high calcium fly ash with Sodium silicate and sodium hydroxide. Results revealed that by the utilization of recycling concrete members and recycle clay brick the compressive strength get reduce and was found in the range of 2.9-10.3 MPa. Their findings suggest that utilizing RCA (recycled coarse aggregate) and RBA (recycled brick aggregate) as substitutes can be a viable option for creating pervious geopolymer concrete.

(Zaetang et al., 2013) attempted to utilize lightweight aggregate in the porous concrete. Pumice (PA) and Diatomite (DA) were used as the natural lightweight aggregate and recycle aggregate was also used in the production of porous concrete (Recycled aggregate based concrete). In their research, they used three types of binder mix comprised of 15%, 20%, and 25% by volume. They further analyzed that by the incorporation of Diatomite, Pumice, and Recycle aggregate as coarse aggregate in porous concrete the thermal conductivity and solidity of the material get reduced to three to four times when compared with natural aggregate type porous concrete. The results also confirmed that the compressive strength of lightweight porous concrete is in the range of 2.47-5.99 MPa. Use of DA reduces the thermal conductivity but increases the mechanical properties. However, PA increased the water permeability. The thermal conductivity coefficient of Lightweight porous concrete was 0.16-0.25 W/m-K noted which is marginally greater than the autoclaved aerated concrete.

(Ibrahim et al., 2017) analyzed the properties of permeable concrete by the inclusion of palm oil clinker as a substitute for coarse aggregate. Different mixes were prepared by using type 1 Portland cement and replacing coarse aggregate of size 10

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mm with 0 to 100% palm oil clinker, with W/B ratio of 0.3. Further it was concluded with the inclusion of palm oil clinker the strength of the material gets reduced but helped in increasing the permeability and porosity. The compressive strength was in the range of 3.43-9.52 MPa. 65% strength loss was observed on 100% replacement with palm oil clinker. However, when substituted at a rate of 25%, palm oil clinker exhibited showed better result.

(Zaetang et al., 2016) in their research replaced the natural aggregate by using the recycle concrete aggregate (RCA) and recycle concrete block aggregate (RBA). Samples were prepared by replacing natural aggregate with 0%, 20%, 40%, 60%, 80%, and 100% by weight of RCA and RBA. The incorporation of 40% RBA in the concrete gave compressive strength up to 17.0 MPa when analyzed with pervious concrete of compressive strength 13.4 MPa comprised of natural aggregate. Surface wearing resistance improved by 20% when RBA was used but reduced when composition of RCA becomes greater in the mix. Incorporation of 60% RCA in the mix optimized the compressive strength at 15.0 MPa. By the use of RCA and RBA, there was a very small influence on split tensile strength and flexure strength. Slight reduction in thermal conductivity was also observed in the range of 0.78-0.99 W/m-K.

(Aliabdo et al., 2018) have inspected the penetrability and strength indices by using recycle aggregate. In their investigation the natural aggregate was replaced up to 100% with Recycle aggregate and polypropylene fiber was also used in 0.1% and 0.2% by volume fraction, rubber fiber in proportion of 1.5% and 3% was included as a replacement of coarse aggregate by weight, crumb rubber in 5% and 10% of fine aggregate, cement binder was replaced with 5% to 10% of silica fume, and styrene butadiene latex was applied in proportions of 10% and 20% by cement weight. The results of the tests validated that incorporating polypropylene fiber into concrete had a positive impact on its flexural strength, splitting tensile strength, and disintegration, but it adversely affected the compressive strength. The use of rubber and crumble fiber caused a reduction in both compressive and tensile strength; however, it enhanced the concrete's resistance to degradation. Furthermore, adding silica fume to the concrete mix was found to enhance its strength parameters, and it was recommended to use 10% silica fume with recycled aggregate. Additionally, the application of styrene-butadiene latex to the concrete mix was observed to improve its tensile strength.

(Debnath & Sarkar, 2019) investigated the prediction of permeability and the feature of the pore structure of the pervious concrete by using brick as aggregate. They used the over burnt brick in the range of 2.36-19 mm. The main objective of this investigation was to co-relate the pore structure and hydraulic conductivity. This paper was also modified by the Kozney-Carman model for permeability. Twelve samples were created out of these 4 types of mixes based on different W/C ratio, three types were based on the different ratio of fine aggregate and the remaining 5 were based on the different gradation of aggregate. They concluded that the W/B ratio influenced the workability of pervious concrete so the best W/B ratio was in the range between 0.30-0.32. By intensifying the amount of fine aggregate negatively affected the permeability of the porous concrete, and gradation has also affected the porosity and penetrability of the pervious concrete. The modified Konzney-Carman model gives a better descriptive understanding of the pores structure of pervious concrete.

(J. Lu et al., 2019) evaluated the sustainable design of pervious concrete with the utilization of Recycled aggregate (RA), Waste glass cullet (WGC) and used the silica fume with the cement paste. The study was divided into two series, in the first series fine aggregate in the range of 2.36 -5 mm used and the same size of WGC availed to replace the Natural aggregate by 25%, 50%,75%, and 100% replacement by wt. The second series composed of the use of coarse aggregate within 5-10 mm range, RCA introduced in similar size range and same percentage as of WGC which was used in the first series. Further the investigation concluded that using similar size of coarse aggregate exhibited higher permeability and 10% silica fume helped in improving the compressive strength but reduced the infiltration rate. Due to the utilization of WGC or RCA, there is a diminution in compressive strength because of reduction in density and bonding, also there is a reduction in thermal conductivity of the concrete. The use of 50% WGC and 50% RCA is best suited to permeable pedestrian paving block.

(Nguyen et al., 2017) in their research replaced the aggregate by the sea shell and studied the durability of pervious concrete. In this investigation, the freeze-thaw, clogging test, and leaching test with or without seashell was conducted. 60% sea shell by mass replaced with the natural aggregate and W/C ratio was constantly maintained. Blended materials like silt clay and sand affect the clogging rate. Later it was observed that the pervious concrete with the Crushed seashell decreased the mechanical strength when compared with natural aggregate based concrete, silt clay and sand reduce the permeability whereas Freeze-thaw performance of the concrete reduced by the use of sea-shell. Pervious concrete has lower compressive strength which restrict its use in many applications such as highway projects, airport pavements etc., numerous efforts have been made to improve the

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strength and enhance its properties.

(Rubber et al., 2020) studied pervious concrete mixes, having different quantities of Styrene-Butadiene Rubber (SBR) of (0, 5%, 8% wt. of cement), two W/B ratios i.e. (0.30 and 0.35). The results indicated that due to the amplification of polymer content in the mix it gradually increased the compressive strength and also enhance the density of the concrete at different w/c ratio, moreover use of SBR content in the concrete mix improved its thermal stability and resistance to high temperature.

(Grubeša et al., 2018) took six samples of single size aggregate. They use three different kinds of aggregate which are dolomite, diabase, and steel slag procured from the near town of Sisak. Each of the pervious concrete samples considered 10% sand from Darva. The drainage capacity was determined by using three methods which are constant head, falling head, and standard method in ASTMC 1701-09. Further investigation showed that the diabase-based aggregate gave better result for preparing the pervious concrete due to the sharp grain edge and smooth surface. They further noticed that the coarser aggregate gives the better mechanical and hydraulic property to porous concrete.

G. Silica Fumes

(Sartipi & Sartipi, 2019) made a case study to check feasibility of pervious concrete using silica fume. In their investigation, study area of 754 km2 of the western suburbs of Sydney was chosen. They consider the precipitation data which was acquired from the Australian Bureau of the metrology department. Different experiments such as compressive strength and infiltration test to match the rainfall demand was concluded. This study state that storm water retention increases 0.0824 l/s for the average thickness of 15 cm pavement. If the sample contains silica fume, then permeability got better but compressive strength gets decreased.

In 2022, Geannina (Lima et al., 2022) T d S L conducted a study to investigate a novel combination of superplasticizer (SP) and Hydroxypropyl methylcellulose (HPMC) admixtures that aimed to enhance the adhesion between paste and aggregate in pervious concrete utilizing recycled coarse aggregate (RCA). Pervious concrete samples were produced with different paste contents (15.2%, 18.3%, and 22.5%) and varying substitution levels of natural aggregate (NA) with RCA (0%, 50%, and 100%). The study analyzed several physical, hydraulic, and mechanical properties of the pervious concrete, including density, voids, water permeability coefficient, interconnected pores, pore structure, compressive strength, flexural strength, and splitting-tensile strength.

The study's results showed that utilizing 50% RCA in paste contents of 15.2% and 18.3% led to enhanced mechanical performance without sacrificing permeability. Furthermore, the inclusion of RCA augmented the pervious concrete's pore structure by enlarging pore size and increasing connectivity. Consequently, the research recommends utilizing SP and HPMC admixtures to upgrade the interfacial transition zone between pervious concrete and RCA, resulting in hydraulic-mechanical properties comparable to those of NA concrete.

H. Crump Rubber

(Qi et al., 2023) examined the properties of rubber aggregate-combined permeable concrete mixture (RAPCM) by conducting a series of laboratory experiments. They investigated that for pervious concrete consisting of 15% rubber of size 16 mesh the compressive strength of specimen reached 28 MPa and permeability coefficient exceeds 9mm/s., The results showed that the (RAPCM) had good permeability and water retention capacity, which are essential properties for sponge city construction. Moreover, the researchers conducted a field experiment in a real-life application to evaluate the performance of the rubber aggregate-combined permeable concrete mixture in sponge city construction. They constructed a permeable pavement with the mixture and monitored the water infiltration rate and retention capacity. The results indicated that the permeable pavement constructed with the rubber aggregate-combined permeable concrete mixture had good water permeability and retention capacity, which is crucial for sponge city construction.

According to (Gesoğlu et al., 2014), incorporating waste tire rubber in place of some of the fine aggregate in pervious concrete mixtures has a notable impact on both physical and mechanical properties. The resulting pervious concrete mixtures with waste tire rubber exhibited lower densities and higher porosities, leading to increased permeability values. However, as the proportion of waste tire rubber increased, the pervious concrete mixtures showed a decrease in compressive and flexural

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strength. Therefore, the authors suggested that the use of waste tire rubber in pervious concrete mixtures could be limited to a certain percentage to maintain an acceptable level of compressive and flexural strength.

III. CONCLUSION

Sustainable development, waste utilization and conservation of natural resources has become the need of the hour. Different studies made by numerous research experts on replacing cement or aggregates with various wastes, it has been concluded:

1. Flyash, GGBFS, rice husk, bottom ash, red mud and crump rubber have potential to substitute cement while recycled aggregates have capability to substitute natural aggregates, partially or fully.
2. Although utilization of these industrial wastes reduced cost of production of pervious concrete. However, in terms of strength, there is improvement in some cases whereas reduction in others.
3. As mentioned above, almost same results were observed for permeability, infiltration rate, sulfate attack and abrasion.
4. Pervious concrete with waste as substitute of cement or aggregate has potential to be used as construction material for parking lot, low volume roads, sidewalks etc. Singular heading even if you have many acknowledgments.
5. After evaluation of surface permeability rates, it was concluded that pressure washing is the most successful and efficient method for maintenance of pervious pavement among vacuum and blower maintenance methods as the avg percentage increment in infiltration rate after maintenance was noted to be 21.7% when pressure washer was used.
6. The Incorporation of Coal FlyAsh and Fine Saw Dust as a filler considerably the performance of pervious concrete and the pavement produced could be used for various field applications such as parking areas, residential roads, college campus roads etc.
7. Incorporating waste materials into the production of pervious concrete presents an appealing alternative, as it offers both an environmentally-friendly and economically viable solution for disposing of industrial by-products.

IV. FUTURE VISION OF PERVIOUS CONCRETE USING WASTE MATERIAL

The review article outlines the properties of pervious concrete (PC) that contains various waste materials. While there is growing acknowledgment of the potential of waste materials as a sustainable alternative to cement, researchers have already demonstrated the successful utilization of waste materials in PC production. Nevertheless, there is still a lack of adequate data on the durability characteristics of PC that incorporates waste materials, and there are limited studies that examine the combined impact of waste materials and other additives on PC production. To address this knowledge gap, the authors propose the following recommendations for future research:

- Conduct long-term behavior and property assessments of pervious concrete that incorporates waste materials to evaluate the sustainability benefits over the service life of the material.
- Assess the leaching performance of PC containing waste materials to determine its suitability as a construction material.
- Study the effect of waste materials on the thermal and sound insulation of PC to enhance the knowledge of utilizing pervious concrete for pavement applications.
- Apply durability tests against harsh environments to explore the behavior of PC containing waste materials, with the aim of evaluating its long-term performance in diverse conditions.

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