Utilization of Waste Materials in the Production of Pervious Concrete – A Review

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Abstract— Pervious concrete is an ideal sustainable solution continuing to gain popularity as a viable paving material and a tool of sustainable development because of its environmental benefits. It has been considered as an environmental friendly building material which is quickly gaining recognition as a green building component. Many researches has been conducted to investigate the possibility of replacing the environmentally unfriendly Portland cement by supplementary cementitious materials, such as fly ash, silica fume, cement kiln dust (CKD) and ground granulated blast-furnace slag (GGBFS), and coarse aggregate by recycled concrete aggregate to enhance the environmental benefits of pervious concrete.

The main aim of this study is to review the performance of pervious concrete with these sustainable materials replacing or partially replacing cement and aggregate. It was found that substituting the natural aggregate with recycled aggregate resulted in a considerable increase of permeability coefficient whereas the mechanical properties of such concretes were adversely affected up to a certain degree. It is also observed that partially replacement of cement with cementitious materials fly ash, silica fume, rice husk ash, cement kiln dust and furnace slag can lead to enhancing the compressive strength of pervious concrete and permeability of pervious concrete. It is concluded that waste materials significantly contribute to improving of the environmental friendliness of pervious concrete.

Key words: Pervious concrete, recycled aggregate, fly ash, silica fume, rice husk ash, cement kiln dust, blast furnace

I. INTRODUCTION

Due to the increased urbanization most of the places are covered with impervious surfaces such as parking lots, driveways, sideways, and street, which block the percolation of water from rainfall and snow down through the ground [1]. This creates an imbalance in the natural ecosystem and causes many problems including erosion, floods, ground water depletion and pollution of rivers, lakes, and coastal waters as rainwater rushing across pavement surfaces picks up everything from oil and grease spills to de-icing Salts and chemical fertilizers [2,3].

According to ACI522R-10, "pervious concrete" is defined as a near-zero slump, open-graded material consisting of Portland cement, course aggregate, little or no fine aggregate, admixtures, and water [4]. Pervious concrete is a special type of concrete having a high void content potentially used to reduce the rain water runoff. Pervious concrete is also known as porous, permeable and No- fines concrete. Air void content, water permeability rate, and unit weight are the measures of pervious concrete quality. These properties are essential for the proper functionality of this material. Higher compressive strength is a plus measure but not a determining factor for quality.

Pervious Concrete has been around for hundreds of years. The initial use of porous concrete was in the United Kingdom in 1852 with the construction of two residential houses and a sea groaned. This time it was limited to the construction of 2-story homes in areas such as Scotland, Liverpool, London and Manchester. Use of porous concrete in Europe increased steadily, especially in the World War II era. Pervious concrete was brought to the United States after World War II. It first showed up in Florida and other southern coastal states. Slowly it has migrated to the other states where it has met different successes. Porous concrete continued to gain popularity and its use spread to areas such as Venezuela, West Africa, Australia, Russia and the Middle East. [5].

II. COMPONENTS OF PERVIOUS CONCRETE

The main components of pervious concrete are coarse aggregate, little or no fine aggregate, cement, and water. Sometimes different types of admixtures used. In some cases, cementitious materials are used as a substitute for Portland cement to enhance the environmental friendliness of pervious concrete.

A. Course Aggregate

Course aggregate is important constituents in pervious concrete. The course aggregate gradation, shape, size and type have been found to affect the properties of pervious concrete. Aggregates can have a direct influence in the permeability, surface texture and the appearance of the pervious slab. Coarse aggregate is kept to a narrow gradation, with the most common gradings of coarse aggregate used in pervious concrete meeting the requirements of ASTM C33/ C33M—aggregate sizes of 7, 8, 67, and 89 [6]. Aggregate gradings used in pervious concrete are typically either single-sized coarse aggregate or grading between ¾ and 3/8 in. (19 and 9.5 mm) [7, 8]. Both rounded aggregates like river gravel and angular aggregates like granite, quartzite and limestone have been used in making of pervious concrete.

B. Cementitious Materials

Similar to conventional concrete mixtures, ordinary Portland cements (OPC) Type I/II or blended cements are used as the primary binder materials in pervious concrete [9, 10, 11, 12]. In addition, supplementary cementitious materials (SCMs), such as fly ash and natural pozzolans (ASTM C 618), ground-granulated blast furnace slag (ASTM C 989), and silica fume (ASTM C 1240) may be used. The content of cement is dependent on the amount and size of coarse aggregate and the water content.

C. Water

Water meeting standard requirements for conventional concrete can be used for the production of pervious concrete. No special requirements in terms of water quality are necessary. The water content of pervious concrete is determined in the same way as conventional concrete. Testing has indicated that a water/cement ratio in the ranges of 0.27– 0.35 and 0.28-0.40 allows for best dispersion of cement paste/mortar and best coating of aggregate particles and w/cm ratios as high as 0.40 have been used successfully. The control of water is important in the development of pervious concrete mixtures, and the selection of an appropriate w/cm value is important for obtaining desired strength and void structure in the concrete. A high w/cm can result in the cement paste flowing off of aggregate and filling the void structure, whereas a low w/cm can result in mixing and placement difficulties and reduced durability [1, 13].

D. Admixtures

Chemical admixtures are used in pervious concrete to obtain special properties and to enhance paste/mortar quality, which ultimately determines the quality of pervious concrete as in conventional concrete. Types of chemical admixtures and their functions are shown below:

- Water reducing: Used for lowering W/C ratio and increasing the strength of paste/mortar
- Retarding / Accelerating: Used to adjust the setting properties of concrete in relation to ambient conditions.
- Air Entraining: Used to improve the freeze/thaw durability of the paste/mortar.
- Special products such as Viscosity Modifying Admixtures (VMA), latex-based admixtures, or water repellents: To ease placement, compaction and improve placement speed. Water repellents have a positive impact on overall durability.
- Colour/pigment additives in powdered or liquid form: Used for the production of colouring pervious concrete.

III. PREVIOUS STUDIES

A. Aggregate Replacement By Recycled Aggregate

The use of waste aggregate such as recycled aggregate (RA) in pervious concrete is advantageous for the environment. Substitution of natural aggregate (NA) by recycled aggregate can reduce wastes to landfill and resuce the consumption of natural material resources. The studies with respect to the usage of RA in pervious concrete have been conducted worldwide.

T. Hossain et al. (2012) carried out an experimental investigation on pervious concrete made of brick chips and also highlighted the engineering properties of this new product. The authors found that strength of brick aggregate pervious concrete is less than that of stone aggregate concrete for same aggregate size. However, permeability of brick aggregate pervious concrete is higher than stone aggregate pervious concrete. Thus it was concluded that brick aggregate can be used in pervious concrete in places where load is comparatively less and more permeability is required. [14].

V. Sata et al. (2013) studied the properties of pervious geopolymer concrete (PGC) using recycled aggregates (RAs). PGCs were prepared using two different types of RA viz., crushed structural concrete member (RC) and crushed clay brick (RB).. The overall results indicated that it is feasible to use RC and RB as recycled coarse aggregates with high-calcium fly ash geopolymer binder for making pervious concrete with acceptable properties. However, the using RC and RB resulted in significant losses in strength as compared to a NA pervious concrete. It was concluded that both RC and RB can be used as recycled coarse aggregates for making PGC with acceptable properties [15].

Y. Zaetang et al. (2013) investigated the use of lightweight aggregate (LWA) for making lightweight pervious concrete (LWPC). Diatomite (DA) and pumice (PA) were used as natural LWAs in pervious concretes. The results were compared to those of LWPC containing recycled LWA from autoclaved aerated concrete (RA). The results indicated that the use of DA, PA, and RA as coarse aggregates in pervious concrete could reduce the density and thermal conductivity about 3–4 times compared with the pervious concrete containing natural aggregate. LWPC containing DA showed higher mechanical properties and a lower thermal conductivity than those of RA and PA. However PA exhibited higher water permeability [16].

E. Guneyisi et al. (2014) investigated the incorporation recycled aggregate into pervious concrete to create a very sustainable concrete product for many applications. The natural aggregate was replaced with recycled aggregate at 4 different replacement levels of 25, 50, 75 and 100 %. The experimental results showed that the properties of pervious concrete were significantly affected by using recycled aggregate. Substituting the natural aggregate with recycled aggregate resulted in a considerable increment in permeability coefficient. However, it was observed that the mechanical properties of such concretes were adversely influenced up to a certain degree [17].

Patrick W. et al. (2016) carried out an investigation to characterize the mechanical, physical, and hydraulic conductivity properties of macro porous (>30% voids) pervious concrete (MPC) containing recycled aggregates and two binder additives, namely sand and titanium dioxide (TiO_2). It was concluded that while MPC exhibited lower compressive strength and higher permeability than normal pervious concrete, the experimental data suggest that the high absorption and low specific gravity of recycled aggregates did not compromise the mechanical properties or permeability of MPC. A modification to the well-known Carman–Kozeny hydraulic conductivity model is proposed to more accurately predict the permeability of both normal and macro porous pervious concrete [18].

B. Cement Replacement by Fly Ash

Fly ash is a finely divided residue resulting from the combustion of ground or powdered bituminous coal or sub-bituminous coal (lignite) and transported by the flue gases of boilers fired by pulverized coal or lignite. Fly ash can be used as a pozzolana in the manufacture of cement and for part replacement of cement, as an admixture in cement mortar and concrete and in lime pozzolana mixture. Recent investigations on fly ashes have indicated greater scope for their utilization as a construction material [19]. Physical and chemical properties of fly ash are shown in Table 2 and Table 3 respectively.

Ravindrarajah et al. (2010) carried out an experimental investigation into the physical and engineering properties of pervious concrete having varying amounts of low calcium fly ash as cement replacement material. The cement was replaced by fly ash in three substitutions 0, 20% and 50%. The results showed that the water permeability of pervious concrete was not significantly affected when 50% of the cement was replaced by fly ash. However, the dimensional stability due to drying shrinkage was increased significantly with fly ash use. It can be concluded that environmentally friendly sustainable pervious concrete could be produced with significantly reduced amount of Portland cement with fly ash [20].

Na Jin (2010) investigated the applicability of fly ash in pervious concrete. Unconfined compressive strength tests were carried out on pervious concrete specimens with fly ash contents of 0%, 2%, 9%, 30%, and 32% by weight of the total cementitious materials. Falling head permeability tests were carried out on specimens having 2% and 32% fly ash. The results indicated the pervious concrete containing 2% fly ash can achieve higher compressive strength at low void content. The pervious concrete with 32% fly ash had a lower at high void content. It was observed that the permeability of pervious concrete increased with the increase of fly ash content. It was expected for pervious concrete with 32% fly ash to reach a higher compressive strength at lower void content, the failure mode indicated that it may not reach the value as high as that of pervious concrete with 2% fly ash at the same void content [21].

Tawatchai et al. (2012) investigated the use of lignite high-calcium fly ash binder in pervious geopolymer concrete. It was found that compressive strengths and splitting tensile strengths are within acceptable limits. The ratios of splitting tensile to compressive strength were slightly higher than conventional concrete. Because of the high void content, the densities of PGC were low approximately 30% lower than that of the conventional concrete. Higher void content also resulted in higher permeability of pervious geopolymer concrete. It has therefore been concluded that lignite high-calcium fly ash geopolymer binder could be used for fabricating pervious concrete with acceptable strength [22].

Sr. No	Characteristic	Requirement (Grade of Fly Ash) I	II
1	Fineness - Specific surface in m^3/kg by Blaine's permeability method, Min	320	250
2	Lime reactivity – Average compressive strength in N/mm^3, Min	4	3
3	Compressive strength at 28 days in N/mm^3, Min	Not less than 80 percent of the strength of corresponding plain cement mortar cubes	
4	Drying shrinkage, percent, Max	0.15	0.1

Table 2: Physical Properties Of Fly Ash [19]

Sr. No	Particulars	Value (%)
1	$SiO_2 + Al_2O_3 + Fe_2O_3$ percent by mass, Min	70
2	SiO_2 percent by mass, Min	35
3	MgO percent by mass, Max	5
4	SO_3 percent by mass, Max	2.75
5	Na_2O percent by mass, Max	1.5
6	Loss on ignition, percent by mass, Max	12

Table 3: Chemical Properties Of Fly Ash [19]

Praveenkumar P. et al. (2014) conducted a study on the properties of pervious concrete containing replacement of cement with fly ash. The percentages of cement replaced with fly ash were 20%, 40 %, 60%, 80% and 100%. It was found that the optimum replacement of cement by fly ash is found to be 20 % in the present study. It is concluded that cement can be effectively replaced by fly ash which reduces the cost of pervious concrete [23].

Ravindrarajah et al. (2014) investigated the effect of supplementary cementitious materials on the properties of pervious concrete with fixed porosity. The investigation considered four mixes with the following combinations of cement and supplementary cementitious materials, by weight proportion: (a) 100% cement; (b) 75% cement and 25% fly ash; (c) 92.6% cement and 7.4% silica fume; and (d) 84.2% cement, 8.2% fly ash and 7.6% silica fume. It was concluded that the cement replacements with supplementary cementitious materials had improved the compressive strength, reduced modulus of elasticity and decreased the water permeability of pervious concrete with fixed porosity [24].

T. Manju et al (2014) studied the influence of recycled aggregate based pervious concrete with fly ash. PC was prepared by partial replacement of cement with class F fly ash (FA). The overall results indicate that use of recycled concrete aggregate as coarse aggregates with fly ash binder for making pervious concrete was found to be feasible with acceptable properties. It was concluded that the replacement of fly ash can be up to 20%. [25].

C. Cement Replacement by Silica Fume

Silica fume is a by-product resulting from the reduction of high-purity quartz with coal or coke and wood chips in an electric arc furnace during the production of silicon metal or ferrosilicon alloys. By-products of the production of silicon metal and the ferrosilicon alloys having silicon contents of 75% or more contain 85–95% non-crystalline silica [26]. The physical and chemical properties of silica fume are shown in Table 4 and Table 5 respectively.

A. S. Agar Ozbek (2010) et al. carried out an investigation of porous concrete through macro and meso-scale testing. Cement was replaced by silica fume. It was found that replacing cement by silica fume even slightly lowered the strength values of the porous concretes which were explained by the presence of agglomerates. Meso-scale tension tests were also conducted to determine the tensile strength of the ITZ. The tests at the two different scales revealed that, even though the ITZ phase did not become weaker with the presence of silica fume with the inclusion of agglomerates, the strengths of macro-size samples were lowered due to the bulk cement paste phase being degraded [28].

Daniel A. M. (2012) studied the effects of utilizing silica fume in Portland cement pervious concrete. It was found that silica fume has negligible effects on the viscosity of cement paste until a dosage rate of 5%, at which point the viscosity increases rapidly. Workability tests showed that mixtures containing a silica fume dosage rate of 5% or less had comparable or slightly improved workability when compared to control groups. Workability was found to decrease at a 7% dosage rate. It was found that strength increased with dosage rates of 3% to 5% but often decreased when the dosage reached 7% [29].

Sr. No	Characteristic	Value
1	Particle size (typical)	< 1 µm
2	Bulk density	
	As – produced	130 to 430 Kg/m^3
	Densified	480 to 720 Kg/m^3
	Slurry	1320 to 1440 Kg/m^3
3	Specific gravity	2.2
4	Specific surface	15000 to 30000 m^2/Kg

Table 4: Physical Properties Of Silica Fume [26]

Sr. No	Particulars (%)	Value
1	SiO_2	96
2	Al_2O_3	0.1
3	Fe_2O_3	0.6
4	CaO	0.1
5	MgO	0.2
6	SO_3	-
7	Na_2O	0.1
8	K_2O	0.4
9	Loss on ignition	1.7

Table 5: Chemical Properties of Silica Fume [27]

Y. Chen et al. investigated the strength, fracture toughness and fatigue life of two types of pervious concrete, supplementary cementitious material (SCM)-modified pervious concrete (SPC) with silica fume (SF) and superplasticizer (SP) and polymer-modified pervious concrete (PPC). It was found that for both SPC and PPC, porosity significantly affects compressive strength, but it has little effect on the rate of strength development. Flexural strength of pervious concrete is more sensitive to porosity than compressive strength. PPC demonstrates much higher fracture toughness and far longer fatigue life than SPC at any stress level. It was concluded that high strength pervious concrete can be achieved through both SCM-modification, and polymer-modification, using polymer SJ-601. [30].

Vikram et al. (2015) investigated the behaviour of pervious concrete containing silica fume as replacement of cement by weight experimentally. Various mix proportions were prepared by replacing cement with silica fume (6% by the weight of cement), by adding super plasticizers (0.13% & 0.25%) and varying size of aggregates. Experimental results showed that strength of pervious concrete decreased with the addition of silica fume (6%) and super plasticizers (0.13% & 0.25%). Compaction Factor of previous concrete mix proportions was increased with the addition of silica fume. Flowability of previous concrete mix proportions increased with the addition of silica flume. It was concluded that the addition of silica fume can enhance the strength, compaction factor, and flowability of pervious concrete. [31].

D. Cement Replacement By Rice Husk Ash

Rice Husk Ash (RHA) is an agricultural waste product which is produced in large quantities globally every year and due to the difficulty involved in its disposal, RHA becoming an environmental hazard in rice producing countries. Production of rice paddy is associated with the production of essentially two by products, rice husk and rice bran. Husk, also called hulls, consists of the outer shell covering the rice kernel [33]. The physical and chemical properties of RHA are shown in Table 6 and Table 7 respectively.

Akeke et al. (2013) investigated the properties of concrete by replacing cement with 10%, 20% and 25% RHA. According to him flexural strength and split tensile strength are decreasing gradually with increase of RHA content from 10 to 25 %. However, there was not any significant effect on compressive strength with the increment in RHA content [32].

S. Hesami et al. (2014) investigated the effects of rice husk ash and fiber on mechanical properties of pervious concrete pavement. 0%, 2%, 4%, 6%, 8%, 10% and 10% Rice husk ash (RHA) weight percentages were used as a cement replacement in concrete. It was concluded that the optimum percentage of RHA without fibres is 8% while it is between 8 to 10% with fibres, it was noted that the permeability of pervious concrete by adding 12% RHA content is significantly higher than adding 10% of RHA content. But addition of 10% RHA content gives higher compressive, tensile and flexural strength than 12% RHA content [33].

S. Talsania et al. (2015) studied the effect of rise husk ash on properties of pervious concrete. The (OPC) cement has been replaced by RHA accordingly in the range of 10% and 20% by weight of cement. Based on experimental investigations, it was noticed that the compressive strength of concrete is increases up to 10% of Cement with RHA beyond than it is starting to decrease and the Flexural Strength of Pervious Concrete is increases up to 10% replacement of Cement with RHA beyond than it is starting to decrease. It was concluded that utilizing RHA in pervious concrete is the possible alternative solution of safe disposal of RHA [34].

Sr. No	Characteristic	Property
1	Colour	Grey
2	Shape	Irregular
3	Particle size	<45 micron
4	Specific gravity	2.3
5	Appearance	Very fine

Table 6: Physical Properties Of Rice Husk Ash [34]=

Sr. No	Particulars (%)	Value
1	SiO_2	85.5 – 95.5
2	Al_2O_3	0 – 2.5
3	Fe_2O_3	0 – 1.5
4	CaO	0 – 1
5	C	2 – 4
6	Na_2O	0 – 1
7	K_2O	0 – 3

Table 7: Chemical Properties Of Rice Husk Ash [34]

Afolayan et al. (2015) investigated the further enhancement of concrete properties using the combined cement kiln dust (CKD) and Rice husk ash (RHA). The percentage level of cement replacement adopted were 0%, 10%, 20%, 30%, 40% and 50%. The replacement percentage by weight was divided equally between the RHA and CKD for each concrete mix. Based on the experimental results, it was found that workability still reduced with increase in percentage of replacement. It was also noticed that compressive strengths is increased with the increase in the percentage of replacement. The highest compressive strength was obtained at 10% replacement. The strengths values obtained for 10% and 20% cement replacement also satisfied the provisions for minimum structural grade concrete. This leads to economy of material and enhances the alternative usage of agricultural and industrial wastes [35].

E. Cement Replacement By Cement Kiln Dust

CKDS are a fine by-product of the Portland cement rotary kiln production operation that is captured in the air control dust collection systems. It is a grained solid material generated as the primary by product of the production of cement [36]. The physical and chemical properties of CKD are shown in Table 8 and Table 9 respectively.

M. Maslehuddin et al. (2009) conducted a study to assess the properties of cement kiln dust (CKD) blended cement concretes. ASTM C 150 Type I and Type V cement were replaced by 0%, 5%, 10%, and 15% of CKD. The results showed that the compressive strength of concrete specimens decreased with the quantity of CKD. However, there was no significant difference in the compressive strength of 0% and 5% CKD cement concretes. A similar trend was noted in the drying shrinkage strain. The chloride permeability increased and the electrical resistivity decreased due to the incorporation of CKD. The performance of concrete with 5% CKD was almost similar to that of concrete without CKD. Therefore, it is suggested to limit the amount of CKD in concrete to 5% since the chloride permeability and electrical resistivity data indicated that the chances of reinforcement corrosion would increase with 10% and 15% CKD [39].

A. M. Mohammad (2010) investigated the effect of addition admixture (cement kiln dust) to concrete as a partial replacement of cement weight. Cement kiln dust was added by (10, 30, and 50) % of cement weight. Results of investigation showed that the compressive strength, flexural strength and splitting tensile strength decrease with the increasing of CKD. It was also observed that the UPV and MOE decrease with the increasing of CKD. The slump decreases with the increasing of CKD. It was concluded that CKD can be used as partial replacement of cement to produce a concrete with acceptable properties [40].

D. E. Ewa et al. (2013) conducted an investigation into the effect of partial replacement of cement with cement kiln dust (CKD) on the compressive strength of laterized hollow block. The cement was replaced by CKD in the range from 10-50%. The results showed that the compressive strength for all mix decreases with age at curing as the cement kiln dust content increased. Cement kiln dust can be used as a partial replacement of Portland cement in the production of hollow laterized blocks and 10% replacement of OPC by CKD was observed to yield maximum compressive strength for them to be used as walling based on NIS and British Standard, beyond this there was a drastic dropped in the compressive strength of the hollow blocks. The optimum replacement level of OPC with CKD for hollow laterized block is 10%. It was concluded that Cement kiln dust and laterite are suitable for hollow blocks making [41].

TABLE 8
PHYSICAL PROPERTIES OF CKD [37]

Sr. No	Characteristic	Value
1	Gradation (75% passing)	0.030 mm (no. 450 sieve)
2	Maximum Particle size	0.300 mm (no.50 sieve)
3	Specific surface (cm2/g)	4600-14000
4	Specific gravity	2.6-2.8

Sr. No	Particulars	Value (%)
1	SiO_2	13.37
2	Al_2O_3	3.36
3	Fe_2O_3	2.29
4	CaO	42.99
5	MgO	1.9
6	SO_3	5.1
7	Na_2O	3.32
8	K_2O	3.32
9	$Cl-$	7.5
10	FL	2.59
11	L.O.I	15.96
12	Surface, Area g/cm^2	3180

Table 9: Chemical Properties Of Ckd [38]

Z. H. Abdulabbas (2013) carried out a study to assess the properties of concrete containing cement kiln dust (CKD). Concrete specimens were prepared with 0% CKD, (10% and 20% CKD) as a replacement of cement weight, (10% and 20% CKD) as an addition of cement weight and 20% CKD as an addition of cement weight. It was shown that the using of CKD in concrete mixtures increases the water demand for a constant consistency. The compressive strength increased in the concrete mixtures including 10% and 20% CKD (as an addition of cement weight). A decrease in the compressive strength was noted in the concrete mixtures including 10% and 20% CKD (as a replacement of cement weight). A similar trend was noted in the splitting tensile strength. It was also observed that the absorption percentage increased when CKD was used in concrete mixtures. It was concluded that the ordinary Portland cement concrete mixtures and the sulphate resisting Portland cement concrete mixtures including CKD had almost the same behaviours [42].

Khalid B. et al. (2014) carried out an investigation to explore the possibility of using CKD material as a cement replacement in concrete mortar production. In addition to reference mix, three different CKD replacements (10%, 20% and 30% wt. of cement) were used. The results showed that there is a systematic increase in mortar porosity with CKD replacement and this increase was in parallel to decrease in mortar strength. Image processing was utilized to study the mortars in terms of 2-D porosity and cement paste colour values. It was found that the calculated porosity using image J software also increased with CKD replacement and the pore-size distribution can be counted as fractal object, where the fractal dimension of these pores was calculated.

Additionally, a good correlation between grey colour value and compressive strength was also concluded [43].

F. Cement Replacement by Furnace Slag

Slag is a non-metallic product consisting essentially of glass containing silicates and aluminates of lime and other bases, as in the case of blast furnace slag, which is developed simultaneously with iron in blast furnace or electric pig iron furnace. Granulated slag is obtained by further processing the molten slag by rapidly chilling or quenching it with water or steam and air. The physical and chemical properties of furnace slag are shown in Table 10 and Table 11 respectively.

M.A. Khafaga et al. (2014) investigated the properties of electric arc furnace slag as aggregate. According to experimental values, using 66.67% of electric arc furnace slag as a replacement of natural coarse aggregate gives maximum utility of compressive strength, flexural strength, tensile strength and modulus of elasticity. It also increases water permeability which is suitable for pervious concrete [45].

R. Bhardwaj (2015) studied the impact of Ground Granulated Blast Furnace Slag based product Alccofine and polypropylene based Recron fibers on strength and compressibility of pervious concrete. Results were compared with ordinary pervious concrete, which showed induction of compressibility in concrete. With optimum dosage and design, it is possible to not only increase the compressive and tensile strength, but also to enhance impact strength of pavements subjected to vehicular loading. It was seen that in mixes with Alccofine, excessive fluidity resulted in non-homogenous pervious concrete. However strength was greatly enhanced due to replacement of sand by Alccofine. Master Matrix admixture lead to excellent surface finish. It was concluded that concrete is basically brittle and adding fibers to pervious concrete increase the tensile strength. By increasing both compressive and tensile strength, durability of concrete pavement is enhanced [46].

Sr. No	Characteristic	Value
1	SSD Specific Gravity	2 – 2.5
2	Bulk Density(in kg/m^3)	1120 – 1360
3	Water Absorption (in %)	1 – 6
4	Los Angeles Abrasion Value (in %)	35 – 45
5	Soundness (Sodium Sulfate) (in %)	12
6	Mohs Scale	5 – 6

Table 10: Physical Properties Of Ggbfs [47]

Sr. No	Particulars	Value (%)
1	SiO_2	33.1
2	Al_2O_3	13.9
3	Fe_2O_3	0.29
4	CaO	42.4
5	MgO	6.1
6	MnO	0.4
7	TiO	0.96
8	S	0.66

Table 11: Chemical Properties Of Ggbfs [47]

H. H. Kim et al. (2016) conducted a study to investigate the physical, strength, and freeze/thaw resistances of porous concrete for plant growth, prepared by replacing cement with blast furnace slag powder at 60% by weight, and replacing natural stone aggregates with coarse blast furnace slag aggregates at rates of 0%, 20%, 40%, 60% and 100% by weight. In addition, natural jute fiber and styrene butadiene (SB) latex were added to these concrete mixtures to evaluate their effects. It was observed that with increasing replacement rate of blast furnace aggregates, addition of latex, and mixing of natural jute fiber the void ratio of the concrete was increased. Compressive strength decreased as the replacement rate of blast-furnace slag aggregates increased. Blast furnace aggregates can also be used to replace the natural aggregates and it was seen that with increasing replacement rate of blast furnace aggregates, addition of latex, and mixing of natural jute fiber the void ratio of the concrete was increased. Compressive strength decreased as the replacement rate of blast-furnace slag aggregates increased. [47].

IV. CONCLUSION

Based on previous studies carried out by many researchers, it was found that substituting the natural aggregate with recycled aggregate resulted in a considerable increment in permeability coefficient. However, it was observed that the mechanical properties of such concretes were adversely influenced up to a certain degree. Diatomite (DA) and pumice (PA) can used as natural light weight aggregates (LWAs) in pervious concretes resulting in higher mechanical properties and a lower thermal conductivity than those of RA and PA. However PA exhibited higher water permeability. It is observed that partially replacement of cement with cementitious materials fly ash, silica fume, rice husk ash, cement kiln dust and furnace slag can lead to enhancing the compressive strength of pervious concrete. Permeability of concrete is increasing with furnace slag and rice husk ash whereas it is decreasing with the use of silica fume and cement kiln dust. Utilization of fly ash in pervious concrete was not affecting the permeability. All the above mentioned materials are environment friendly but fly ash, furnace slag and silica fume has the highest contribution to the strength and permeability of pervious concrete.

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