A Review of the Mechanical Properties of Pervious Concrete and its Limitation

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Abstract - As we can see, due to the impermeable surfaces built over time with the increase in urbanization, the groundwater table is currently evaporating at a faster rate. To address this issue, a special type of concrete that can be used in the construction industry has been introduced and is not brand-new to the world. Pervious concrete is a type of concrete that is permeable because the fine aggregate is either absent or present in very small quantities. Any sort of concrete must first be applied after studying the qualities and ideal dose of all the ingredients and admixtures for the structure's longevity. This review intends to investigate the effects of silica fume and copper slag, two additional cementitious materials studied in earlier studies, on the characteristics of pervious concrete. According to the findings of the research paper linked below, pervious concrete's mechanical qualities (compressive and flexural strength) are significantly impacted by the use of copper slag and silica fume in a set proportion.

Key Words: Pervious Concrete, Mechanical Properties, Porosity & Void ratio, Permeability, Density, Aggregate, Silica Fume, GGBFS.

I. INTRODUCTION

Urbanization has increased during the previous few decades. it has been noted that the development of infrastructure, such as high-rise buildings, transportation infrastructure, dams, tunnels, etc., has significantly depleted natural resources and continues to do so. Groundwater table reduction is mostly due to the construction of impermeable surfaces everywhere caused by all of these large structures, which have prevented precipitation from rainfall from percolating through the ground. Concrete is, as we all know, currently used more than water anywhere in the globe. It is created by combining Portland cement, water, coarse aggregate, sand, and perhaps additional cementation ingredients or admixtures. This mixture needs to be workable, frost and chemical resistant, have low permeability, be durable, and be cost-effective. In concrete construction, dead load (self-weight) makes up a significant portion of the overall load on the structure, increasing the size of the foundations. In addition, concrete-made roadway walkways provide an impervious surface that significantly increases runoff in urban areas. If possible, permeable surfaces could be used to combat this serious issue (Figure -1 below shows how a pervious concrete looks like). Therefore, in order to be durable and energy-efficient, it is imperative to start exploring for lighter and permeable construction materials. Many efforts have been made to address this issue, and one potential option is pervious concrete, a porous composite material. Concrete that is porous can absorb surface runoff and provide a suitable solution to the issue of ground water depletion.

Pervious concrete is a porous composite media with a void ratio ranging from 15% to 35%. Water containing dirt is more prone to become blocked in concrete with low void levels. Pervious concrete differs from conventional concrete in that the use of fine aggregate is restricted to a particular proportion or not at all, despite the fact i.e. both are not new to the world and are similar in many aspects. Pervious Concrete is a mixture of cement, water, coarse aggregate, and little to no sand; when these ingredients are combined; they form a solid substance with interconnected pores that is highly permeable to water. The use of gap-graded aggregates, or stones that are all the same size between 4.75mm and 20mm and sometimes graded between the given permissible limits, is one of the key differences between conventional and pervious concrete. The density of the mixture and aggregate size will affect the drainage of pervious concrete pavement. To raise the compressive strength to the appropriate working strength, a modest quantity or fraction of sand might be utilized. Pervious concrete pavement's primary goal is to drain off storm water and lessen the chance of urban flooding. Pavements are the main application for pervious concrete. Given its large void content, pervious concrete has a low compressive strength. But for many applications, compressive strengths between 5MPa and 25MPa are usual and adequate [1].

Fig-1: PERVIOUS CONCRETE

Additionally, it goes by the names enhanced-porosity concrete, no-fines concrete, gap-graded concrete, and porous concrete.

The size of the gap-graded aggregates, the void ratio, the admixtures used to make pervious concrete, and the water cement ratio are a few other factors that affect the strength of pervious concrete. A high water cement ratio decreases the adhesion of the paste to the aggregate and causes the paste to flow and fill the voids, making it low permeable and increasing mechanical strength even when compacted low.

Table 1:- Properties of pervious concrete[1][2]

Property	Range
Density	1600 to 2200 kg/m^3
Compressive Strength	5MPa to 30MPa
Flexural Strength	1MPa to 5MPa
Void Ratio	15% to 35%
Porosity	14.8% to 32.52%
Permeability	0.135 cm/s to 1.61 cm/s

1.1 Materials

GGBFS: (As per IS; 10875) Blast furnace slag is a nonmetallic product composed primarily of glass-containing silicates and alumina silicates of lime and other bases produced concurrently with iron in a blast furnace or electric pig. Iron furnace granulated slag is produced by rapidly chilling or quenching molten slag with water or steam, and air blast furnace granulated slag is used in the production of hydraulic cement. It can be with cement replaced up to 50% by weight on site as a binder material [16].

Fig 2- GGBFS

Silica Fume: (As per IS: 15388 and IS: 456) Silicon and ferrosilicon alloys are used to make micro silica. Micro silica (Silica Fume) is a type of supplementary cementitious material used in limited quantities as a binder substitute to improve the strength properties of concrete. Silica Fume (SF) has a SiO2 content of more than 89% and a particle size of 0.1 to 0.3 µm on average. It is usually used in proportion of 5% to 10%of the cementitious material content of the mix [2].

Fig 3- SILICA FUME

Copper slag: Copper slag is a byproduct of the smelting of copper. Impurities in the molten metal become slag during the smelting process. Slag quenched in water produces angular granules, which are either discarded or used as Copper slag has a high Fe content and has been used as an iron adjustment material in the production of cement clinker. Because copper slag is primarily composed of vitreous FeSiO3, it has a low melting point and may reduce the calcination temperature of cement clinker [3].

Fig 4- COPPER SLAG

II. LITERATURE REVIEW

A. Review Based on use of Silica Fume

Amand Arun et al. (2022) In his paper, Strength improvement techniques on pervious concrete, he discovered that coarse aggregate of 6.3mm to 10mm increases the compressive and flexural strength of pervious concrete by 74.39% and 45.59%, respectively, with the use of micro silica replacing cement by 10% in weight and adding fine aggregate for about 7.5% with coarse aggregate, the best results for compressive strength and flexural strength came out to be 32.2MPa and 3.80MPa, the calculation is done using IS 516 at 28°C [2].

Chaitanya and Ramakrishna (2020) The research focuses on employing silica fumes to improve the mechanical characteristics of pervious recycled aggregate concrete. India's building sector has grown significantly over the last few years. This leads to a huge global demand for construction materials, which negatively affects the environment by causing a shortage of aggregate and a lack of ground water recharge due to impermeable paved surfaces, noise pollution, and dust pollution. Some of the consequences can be mitigated by using recycled concrete aggregate in the construction industry, and developing permeable surfaces encourages ground water recharging. In this work, the effect of recycled concrete aggregate on the mechanical properties of pervious concrete is investigated. Furthermore, silica fumes added in 8% to 16% increments improve the strength of pervious concrete built from recycled concrete aggregate. An accurate power distribution was discovered when compressive strength and permeability were tested for additions of various amounts of silica fumes [4].

Adil et, al. (2020) Using paste formulations with proportions and additive doses representative of field-placed pervious concrete, the research described here investigated the performance of paste and two types of pervious concrete to discover how silica fume effects pervious concrete qualities and durability. In the test, silica fume was substituted in the mixture by amounts of 20%, 10%, and 5%, and it was discovered that the 5% silica fume performed best in terms of improved workability, strength, and durability. For samples containing unwashed coarse aggregate, silica fume improved paste-to-aggregate bonding. The aforementioned experiment demonstrated that ravelling was not improved by silica fume [5].

B. Review based on Type & Size of Aggregate

Fan Yu et al. (2019) Influence of aggregate size on compressive strength of pervious concrete Compressive strength increases with increase in aggregate size but beyond 7mm aggregate size it show no obvious result even that the increase of pores content will decrease the compressive strength [6].

L. G. Li et al. (2022) Study the effect of aggregate bulking and film thicknesses on water permeability and strength of pervious concrete the test was carried in three phase where properties of paste, bulking of aggregate and hardness of concrete was studied as per the paper aggregate bulking decreases the compressive strength of pervious concrete whereas paste film thickness shows a positive effect on both strength and permeability [7].

Sourabh Rahang dale et al. (2017) The compressive strength of pervious concrete was determined by Sourabh Rahang Dale et al. (2017) because it is a highly unique type of concrete that may be utilized for low traffic areas, park walks, footpaths, etc., while also being environmentally friendly. They employed a mix design with a cement to aggregate ratio of 1:4 and a water content of 0.36 for this project task. The samples are made for various aggregate ranges (10mm-12.5mm, 12.5mm-16mm, and 16mm-20mm) and examined after 7, 14, and 28 days of curing. In comparison to other methods, the results for Pervious Concrete cast with aggregates measuring 12.5" to 16" were more encouraging [8].

C. Review Based on Other Materials used in Pervious Concrete

Jiwei Cai et al.(2022) Studied a new method to assess pervious concrete's clogging resistance. The compressive strength after 28 days is increased by 10Mpa by increasing the filling ratio or mortar ratio from 0.68 to 0.74. The proposed method could evaluate the clogging risk with clogging cycles for pervious concrete with different pore structures. The clogging resistance will rise with increased porosity. Saturated slurry with plasticizer added reduces the water content by roughly 18%, which helps with clogging resistance [9].

Kanghao Tan et al. (2022) According to the results of the evaluation of the properties and carbon sequestration potential of bio-char modified pervious concrete, adding bio-char to cementitious material to replace partial cement leads to an increase in compressive and flexural strength of pervious concrete, a bio-char content of 1-3% by weight provides the best results, a 10% reduction in temperature, and a 15% reduction in CO2 emissions [10].

Peiliang Shen et al. (2021) The use of municipal solid waste incineration bottom ash (IBA) aggregates in high strength pervious concrete is demonstrated in this study. Incineration bottom ash (IBA) with different percentages (25%, 50%, 75% and 100%) by volume of natural aggregate replacement improved the mechanical properties of pervious concrete. However, the high IBA content in the pervious concrete reduced water permeability. Pervious concrete containing IBA-metallic aluminum ash has a low thermal conductivity and density [11].

Haibing Zheng et al. (2020) In his paper, investigated, pervious concrete produced with using 80-81% waste glass of total mass and results showed excellent compressive strength, adequate permeability and good stability. In order to achieve the maximum reuse of waste glass (WG) in concrete, outstanding compressive strength, appropriate permeability, and good volume stability were still demonstrated for the pervious concrete made with 80.95% WG of the total mass. It was possible to create pervious concrete with thermal conductivity 0.34 W/mK which was less than that of regular light weight concrete with the use of waste glass. [12].

Salaheddin Arafa et. al.(2021) Investigation of the permeability and strength of pervious geo-polymer concrete including coated biomass aggregate material in light of the recent increase in urbanization. PGC, or pervious geo-polymer concrete, is a porous non-slip surface. In this instance, waste palm oil products will be used as biomass aggregate to replace natural material. According to the findings of the present investigation, coated biomass aggregate in pervious geo-polymer concrete had a compressive strength that was 51% greater than that of conventional Portland cement pervious concrete including natural aggregate. During all storms with total rainfall intensities between 0.3 and 0.37 cm/s, storm water discharge rose by 28.3% for permeable concrete decades [13].

Huang et, al. (2020) Researchers concentrated on the standards for pavement concrete. Pervious concrete needs to balance compressive strength and permeability. The type, size, and mineral admixtures have a big impact on the permeability and compressive strength of pervious concrete. 56 percent of earlier concrete samples were created using different mineral admixtures, aggregate kinds, and size ranges. Compared to pervious concrete with granite aggregate, pervious concrete with dolerite aggregate has higher compressive strength and permeability, according to test results. The optimal porosity and water content for pervious concrete made with dolerite and granite in the studied ranges are 18% and 0.25, respectively. The permeability of granite aggregate decreases as the particle size grows in the case of a single size and the lowest permeability [14].

Hla Hla Htay et al. (2018) According to experts, porous concrete was investigated for its mechanical and hydraulic properties in order to determine the balance between those properties and durability in pervious concrete. The study looked at the effects of replacing cement with natural pozzolan (Popa Volcanic) as a supplementary cementitious material to partially replace Portland cement in amounts of 10%, 20%, and 30% with or without pozzolonic material replacement. According to ACI specifications, the mix design includes 19mm crushed aggregate (American Concrete Institute) [15].

Abel Shiferaw et al. (2021) In his case study of Practical considerations of porosity, strength, and acoustic absorption of structural pervious concrete studied the practical problems of structural pervious concrete such as paste sagging, porosity, strength etc. for this they designed mixes with different synthetic fiber content for target void ratio of 10-15% which gave them better results and improved compressive strength exceeding the structural compressive strength of 20MPa [16].

Mr. K. Appala Naidu et.al.(2020) Studied to suggest the solution for storm water logging on the pavement in urban area. The storm water gets run off in to the water stream directly without percolating into the ground due to presence of the impermeable surface of concrete. Hence one of the most effective way to counter the problem is to use of Pervious Concrete. The Pervious Concrete pavement provides the improvement in ground water quality, reduction in storm water runoff and water stagnation on the pavement that can be used in low volume drive ways, parking, walkway, paved way in parks etc [17].

Elango, K. S., and Revathi, V. (2020) The aggregate to binder and water to binder weight ratios were maintained at 3.3 and 0.35, respectively, according to many experimental mixes. To make the FaL-G binder, fly ash, lime, and gypsum were mixed 50:40:10 respectively. Notably, pervious concrete constructed with PPC binder outperformed conventional control mix OPC binder and FaL-G binder in terms of resistance to chemical attack. The test results show that pervious concrete made with OPC, PPC, and FaL-G binders has better durability resistance with the right strength parameters as required by legal requirements. Construction projects for pedestrian walkways, sidewalks, parking lots, and locations with modest traffic volumes can employ pervious concrete [18].

Baskar et al. (2019) Tested the pervious concrete for mechanical properties, the aggregates are joined at the site of contact by cement paste because there are no tiny particles in the mix, which causes a large percentage of voids in the finished product after casting. Various percentages of polypropylene monofilament fiber are used as raw materials in this project work, and a new measurement technique is used to determine the permeability of pervious concrete, which offers a superior design methodology. The specified size aggregate of 10mm and 4.75mm with water cement ratio of 0.30 is used to lower the void content. The addition of the polypropylene fiber shows the enhancement in mechanical properties of the pervious concrete as expected and the mix was tested for properties such as void ratio, density, compressive strength & permeability [19].

D. Review Based on use of Copper Slag and Steel Slag in Pervious Concrete

M. V. Patil (2015) The impact of replacing some of the sand with copper slag was examined. The findings demonstrate that copper slag's high toughness boosts compressive and flexural strength. Making cement and concrete is one of the most promising uses for recycling copper slag. When compared to natural sand, copper slag is discovered to have a very low water absorption rate, which has an impact on the workability of concrete. The free water content in concrete mixtures is anticipated to rise as the amount of copper slag does, though, due to its poor water absorption. This will increase the workability of concrete mixtures containing a significant amount of copper slag. The maximum compressive strength of concrete improved by 34% at a replacement of fine aggregate of 20%.When copper slag is used up to 30% of the time in place of natural sand, concrete gains 14% more flexural strength. Additionally, the price of making concrete is reduced when copper slag is used in place of fine aggregate [3].

Lori et, al (2018) The mechanical and hydraulic characteristics of pervious concrete with coarse aggregate produced of copper slag were investigated in this study. Seven primary mixtures were examined in this study, with copper slag replacement rates of 0%, 20%, 40%, 50%, 60%, 80%, and 100%. Mechanical strength tests revealed that 60% replacement, when compared to the control mix, had the largest improvement in strength, with increases in compressive strength, flexural strength, and splitting tensile strength of 31%, 19%, and 18%, respectively. According to tests on permeability and porosity, pervious concrete's permeability and porosity were boosted with the addition of more copper slag [20].

Nainwal et, al. (2020) The study demonstrates the impact of metakaolin on concrete with copper slag in place and Beas River fine aggregate. For these, researchers have looked at the characteristics of copper slag and how its performance is affected by mixing. The mixture's ratios are utilised in grades 43 and 44 for varying degrees of copper slag substitution in concrete admixture as fine aggregate. When used as a replacement for Beas river fine aggregates, metakaolin improves the mechanical and durability properties of Copper Slag (CS) concrete. On the workability of concrete, the performance of Metakaolin and Fly Ash as cementitious material substitutes was also investigated [21].

Zhang et, al (2020) The major subject of this study is how the binder-to-aggregate ratio and different binders affect the properties and microstructure of pervious concrete made with steel slag as aggregates. The results show that increasing the binder-to-aggregate ratio improves the mechanical properties, even if it is connected to porosity and the water permeability coefficient. When compared to the reference pervious concrete, which uses only Portland cement as the binder, the compressive strengths of pervious concretes incorporating different binders with ground blast furnace slag, fly ash, and/or silica fume to partially replace Portland cement are lower and the connected porosities are significantly higher. Different binders may enhance the interface transition zone of pervious concrete, but they are believed to have little impact on hydration. These pervious concretes' compressive strengths are really lower because their linked porosities are substantially higher than those of the reference pervious concrete, which utilizes only Portland cement as a binder [22].

Table 2- On the basis of above lit., below table shows the result for different additives for Pervious Concrete.

Material	Range	Results
Silica Fume	at 10%	Enhanced the compressive and flexural strength by 74% and 45%.
Copper Slag	use of copper slag up to 20%	Results in increased mechanical properties i.e. compressive strength by 34% and flexural strength by 14%.
Waste glass	80-81%	Increase the permeability and thermal conductivity but reduced the mechanical properties(compressive and flexural strength)
Bio-char	1-3% by weight	Reduce the CO_2 by 15%

III. CONCLUSION

In the investigation, cement is used as a binding substance, and coarse aggregates (CA) with sizes ranging from 6.3 mm to 10 mm are utilized. The ratio of aggregate to binder was fixed at 3, while the ratio of water to binder was set at 0.4 Micro Silica was utilized as a binder in place of cement, and Silica Sand was substituted for aggregates in specific quantities, improving the strength properties. The impact on the parameters of dry density, permeability, porosity, and void ratio as well as compression, split-tensile, and flexural strength was investigated.

The pore structure's irregularity has the greatest impact on compressive strength. The compressive strength improves as cementitious paste thickness increases. The compressive strength is largely steady till the cementitious paste thickness reaches 1.15mm.

Strong connections between the compressive strength and permeability coefficient and the filling ratio demonstrate the importance of this factor in the mix design of pervious concrete. Based on compressive strength and permeability, concrete with a W/C ratio of 0.23 to 0.4 performs well, capable of exceeding 20MPa in compressive strength and having a sizable permeability coefficient. On the other hand, to build an unclogged pervious concrete, the pore size distribution should be appropriately taken into account.

The strength of pervious concrete is greatly increased by adding 1.0-3.0 wt% bio-char to the mixture. According to strength tests, pervious concrete's compressive strength falls as BC content rises above 5% by weight. Similar to the compressive strength, the flexural strength of pervious concrete also peaks at the same cement replacement level.

According to the experimental findings, adding bio-char greatly improves pervious concrete's ability to absorb and hold water using pulverized Bio-Char as an additive in pervious concrete helps to reduce net CO_2 emissions and protecting the environment.

When coarse aggregate voids are partially filled with paste, the bulking (reduction in packing density and increase in voids ratio) varies with the paste's W/C ratio and paste ratio. Pervious concrete mix design should account for the potential 22% increase in void ratio caused by such bulking effect.

When the proper amount of IBA (Incineration bottom ash-lower than 50%) was used to replace the Natural Aggregate in the pervious concrete, the compressive strength was improved. The IBA can serve as an internal curing agent and encouraged the hydration of paste, increasing its micro hardness and hydration level.

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