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Influence of GGBFS and Polypropylene Fibers on Strength and Compressibility of PPC Pervious Concrete

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Abstract—*Pervious Concrete is no fines discontinuous concrete with interconnected void system, which captures surface infiltration in a network of voids and allows it to percolate into the underlying soil. Hailed as "the holy grail of environmental site design", the pervious concrete application is limited mainly, due to strength considerations. This work aims to design high performance pervious concrete by studying the impact of Ground Granulated Blast Furnace Slag based product Alccofine and polypropylene based Recron fibers on strength and compressibility of pervious concrete. Alccofine increase strength while fibers increase the impact strength. 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.*

Index Terms*: Pervious Concrete; GGBFS; Alccofine; Compressibility; Recron Fibers; High performance concrete; Impact strength*

1. INTRODUCTION

Portland cement pervious concrete is a discontinuous mixture of coarse aggregate, hydraulic cement and other cementitious materials, admixtures and water. By creating a permeable surface, storm water is given access to filter through the pavement and underlying soil, provided that the underlying soil is suitable for drainage. This allows for potential filtration of pollutants. To achieve this permeability, PCPC is typically designed with high void content (15-25%).[1]

The permeability and compressive strength of pervious concrete depend upon aggregate skeleton. Fine aggregates are either used sparingly or removed altogether from the mix design. It has been shown that using smaller aggregates increases the compressive strength of pervious concrete by providing a tighter bond between coarse aggregate and cement. Using fine aggregates in the mix design of pervious concrete will also decrease the void space.[2] Increasing the percent amount of larger aggregates will increase the void ratio in pervious concrete, but will decrease the compressive strength.[3]

Typical water cement ratio is 0.27-0.40. Excessive water in mix can cause collapse of pervious concrete, leading to destruction of void structure. Void content is preferably greater than the paste content by the volume. Interconnected voids allow water to pass through pervious concrete layer, providing an effective solution for storm water management. With the draining rates of 81-730liters/min/m^2, pervious concrete can capture and eliminate harmful contaminants of storm water runoff, as well as lead to aerobic degradation of pollutants. It can also trap trace elements like copper and chloride, thus preventing groundwater contamination.[4] However, proper maintenance is necessary to prevent clogging and reduction of pore size. Other benefits of pervious concrete pavements are reduction in heat island effect, noise absorption, reduced risk of accidents etc.

Despite all these environmental advantages, there are some limitations, which confine the use of pervious concrete to light vehicular loading traffic areas. Due to its pervious structure, compressive, tensile and impact strengths are low. However, with the aid of new chemical admixtures and different types of fibers, compressive strengths up to 40MPa have been achieved. No standard methods and specialized construction methods, lead to varied levels of performance of pervious concrete pavements. Extended curing time coupled with its sensitivity to expansive soils and freeze-thaw cycles, makes the design and placement of pervious concrete, a highly meticulous task. [5]

Nonetheless, new materials are being studied to work upon these limitations and increase the durability and service life of pervious concrete. Mineral and chemical admixtures are being used to increase paste strength. Varied fibers both artificial and natural, are being used to increase the tensile strength and impact strength of pervious concrete. By bridging the gap between coarse aggregates, they bound pervious concrete with an interwoven matrix of fibers. Biological and chemical agents can be used to detoxify the water passing through the pervious concrete, as well as to induce self-healing capacity in cementitious content. Piezoelectric minerals can also be embodied in pervious concrete pavements, producing electricity in response to vehicular moving loads over pavement. Titanium dioxide is also being added to concrete pavements, for photo catalytic decomposition of air pollutants. Vast research potential lies in field of pervious concrete and pavements, which can enable the pervious concrete to work in wide range of environments and traffic conditions.

2. OBJECTIVE

The primary aim of this research is to examine the effect of various constituents on the strength and durability characteristics of pervious concrete. Properties like impact strength and tensile strength are roughly indicated by compressibility and compressive strength of pervious concrete. These properties stipulate the behavior of pervious pavement under vehicular loading conditions.

Main objectives of this study are

1. To develop mix design for pervious concrete with strength above 20MPa.
2. To study the effect of mineral admixture and polypropylene fibers on fresh and hardened properties of pervious concrete.
3. To relate the proportions of mineral and fiber additives, with compressive strength of specimen.

3. EXPERIMENTAL SETUP

The experimental program for this study consists of following stages:

1. Mix design for Pervious concrete of strength 20MPa.
2. Sample preparation.
3. Study of fresh and hardened properties of pervious concrete.
4. Mix design with Alccofine.
5. Mix design with Alccofine and Recron fibers.
6. Sample Preparation.
7. Study of fresh and hardened properties of pervious concrete.

4. MATERIALS

4.1. Cement

Pozzolana based PPC cement with specific gravity of 2.88 and Blaine value of 380, is used.

4.2. Coarse Aggregates

Both 10mm and 20mm aggregates are used for uniform pore size distribution. With 15% aggregate impact value and dry loose bulk density of 1350-1400kg/m^3, they form aggregate skeleton, which provide interconnected voids as well as strength.

Their origin lies in sedimentary dolomites of Himalayas, transported by highly erosive actions of rivers Beas and Satluj. Chemically, these aggregates are pink quartzite, cemented with iron oxide.

4.3 Fine Aggregates

Although pervious concrete can also be no fines concrete, but a little amount of sand increase the viscosity of paste.

Here, river sand with specific gravity of 2.5 and dry loose bulk density of 1680kg/m^3, is used.

4.4 Chemical Admixture

Polycarboxylate based High Range Water Reducer, is used to produce workable mix at low water cement ratio.

Master Matrix is super plasticizer used, with relative density 1.1.

4.5 Mineral Admixture

Alccofine 1203 is a Ground Granulated Blast Furnace Slag based product of high glass content with high reactivity obtained through the process of controlled granulation. With controlled Particle Size Distribution (PSD) and 12000cm^2/g Blaine value, they provide effective particle packing between cement and fine aggregates. Alccofine reacts with by-product $Ca(OH)_2$, to produce more CSH gel, leading to denser and strong cementitious matrix as well as aggregate –paste bond.

4.6 Fibers

Recron 3s fibers are used in this study. Polypropylene based fibers have high tensile strength (4000-6000kg/cm^2) and are required in very low dosages of less than 2%. They impart tensile strength and prevent micro-shrinkage. Upon vehicular loading, fibers are responsible for uniform distribution of stress, which lead to small crack dimensions. It is also responsible for strain hardening behavior and self healing capacity, which is pronounced at hairline cracks.

5. PERVIOUS CONCRETE MIX DESIGN

5.1 Benchmark Mix Design – M1

For benchmark pervious concrete mix design, designed strength is taken as 20MPa. A little amount of sand is used. Void content is 15%. Mix design is based on dry loose bulk densities of coarse and fine aggregates, so that pervious concrete resembles the natural void structure of bulk aggregate. Theoretical pervious concrete density was 1950kg/m^3.

Fig. 1: Pervious Concrete Sample.

Table 1: Pervious Concrete Mix Design – M1

Raw Materials	Bulk Mix Proportion
Cement	400kg/m3
CA - 10mm	600kg/m3
CA - 20mm	850kg/m3
FA	150kg/m3
w/c	0.36
SP dosage	0.5%

Fifteen cubes of size 15mm*15mm*15mm were prepared and cured in water till 3, 7 and 28 days.

5.2 Benchmark Mix Design – M2

In this mix, some cement is replaced by Alccofine 1203.W/c ratio and S.P. dosage is reduced, as Alccofine increase slump at constant w/c ratio. It is no fines concrete, with no sand in the mix.

Table 2: Pervious Concrete Mix Design – M2

Raw Materials	Bulk Mix Proportion
Cement	350kg/m3
CA - 10mm	550kg/m3
CA - 20mm	850kg/m3
Alccofine	50kg/m3
w/c	0.33
SP dosage	0.4%

Fifteen cubes of size 15mm*15mm*15mm were prepared and cured in water till 3, 7 and 28 days.

5.3 Benchmark Mix Design – M3

In final mix, Recron 3s fibers are added. Cementitious content is increased so that paste to fiber ratio remains high.

Table 3: Pervious Concrete Mix Design – M3

Raw Materials	Bulk Mix Proportion
Cement	380kg/m3
CA - 10mm	550kg/m3
CA - 20mm	850kg/m3
Alccofine	70kg/m3
w/c	0.6
SP dosage	0.5%
Fiber dosage	800g/m3

Fifteen cubes of size 15mm*15mm*15mm were prepared and cured in water till 3,7 and 28 days.

6. RESULTS AND ANALYSIS

Bulk Density of wet mixes was in range of 1800-2000kg/m^3.

6.1 Fresh and Hardened Properties – M1

Mix was uniform and permeability was fair. Compaction energy required was high.

Table 4: Hardened Properties – M1

No. of Days	Compressive Strength
3	3.1MPa
7	10MPa
28	21.8MPa

6.2 Fresh and Hardened Properties – M2

Mix was more workable, due to Alccofine. However paste was thicker at bottom and pore size was reduced, as Alccofine settles at bottom. Strength was greatly enhanced and color of concrete was whitish.

Table 5: Hardened Properties – M2

No. of Days	Compressive Strength
3	4MPa
7	12MPa
28	25.3MPa

6.3 Fresh and Hardened Properties – M3

Fibers hold the whole aggregate skeleton and paste matrix. Ultimate failure was delayed, however a few sample also showed elastic behavior and compressibility at small loads.

Table 6: Hardened Properties – M3

No. of Days	Compressive Strength
3	5.5MPa
7	13MPa
28	26.9MPa

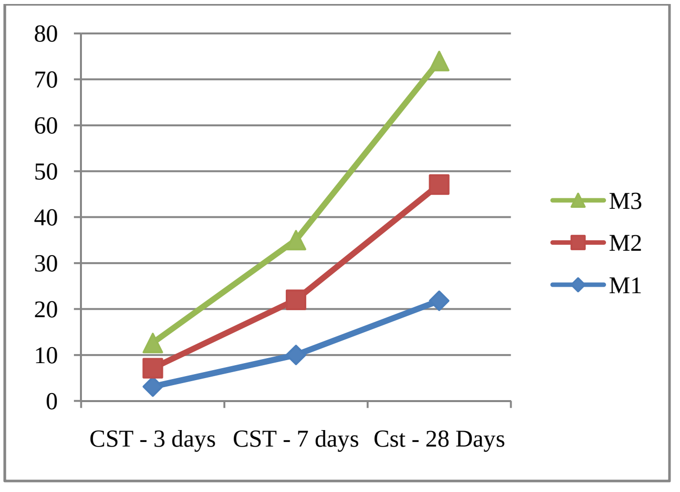

Fig. 2: Compressive Strength Results

7. CONCLUSIONS

Based on presented results and their analysis, following conclusion can be made:

1. High strengths can be achieved in laboratory conditions using mineral admixtures, high cementitious content, and low water/cement ratios.
2. A large sample size is needed to compare the results, as variation within specimens is very high.
3. High content of mineral and chemical admixtures, can lead to settling of paste at bottom, which can cause reduced pore size at bottom.
4. In mixes with Alccofine, excessive fluidity resulted in non homogenous pervious concrete. However strength was greatly enhanced due to replacement of sand by A lccofine. Master Matrix admixture lead to excellent surface finish.
5. In mixes with fibers, excess fibers can lead to low strength , as skeleton is made up of fibers, not the coarse aggregates.
6. Compressibility could be controlled to achieve shock absorbing properties, working on different proportions of fibers.
7. 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.

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