Project Report On

Effect of Aggregate size in Pervious Concrete Pavement

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REPORT APPROVAL SHEET

This project report entitled "Effect of aggregate size in Pervious Concrete Pavement" by Priyanshu Kumar, Pranjal Khandelwal and Pawan Shrivastava is approved for the degree of their Bachelor's Degree in Civil Engineering.

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DECLARATION

We hereby declare that this project entitled “Effect of aggregate size in Pervious Concrete Pavement” represents my ideas in my own words and where others' ideas or words have been included. This is a record of original work done by us under the guidance of Dr. Partha Pratim Sarkar Sir (Professor, Department of Civil Engineering, NIT Agartala). I have adequately cited and referenced the sources. We also declare that we have adhered to all principles of academic honesty and integrity and have not misrepresented or fabricated or falsified any idea/data/fact/source in my submission. We understand that any violation of the above will be cause for disciplinary action by the Institute and can also evoke penal action from the sources which have thus not been properly cited or from whom proper permission has not been taken when needed.

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CERTIFICATE

It is certified that the work contained in the project report titled "Effect of aggregate size in Pervious Concrete Pavement" submitted by Priyanshu Kumar, Pranjal Khandelwal and Pawan Shrivastava has been carried out under my supervision and that work has not been submitted elsewhere.

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Deepest gratitude to my parents and family members for their unwavering support, constant encouragement, and unwavering love. Their belief in my abilities has been a constant motivator throughout this academic pursuit.

Lastly, we humbly acknowledge that despite putting best efforts, there might be shortcomings or errors in this report. I apologize in advance for any such oversight.

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Thanking you,

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List of Figure

Figure. No.	Description	Page No.
1.1	Typical pervious concrete pavement cross section (adapted from EPA 2010)	14
1.2	Permeable Concrete and Permeable Asphalt	16
1.3	Traditional and Permeable pavement	17
4.1	Different size of Aggregates	35
4.2	Samples of pervious concrete with different water contents, formed into a ball	38
4.3	Silica Fumes	40
4.4	Apparatus for fineness Test	41
4.5	Aggregate Crushing Test	44
4.6	Aggregate Impact Test	45
4.7	Aggregate Abrasion Test	46
4.8	Methodology of making Pervious Concrete	48
4.9	Compression Testing Machine	55
4.10	Permeability test setup by Falling Head Method	60
5.1	Sieving	62
5.2	Mixing and placing	65
5.3	Curing	65
5.4	Casting and Compressive Strength Test of Sample 1	67
5.5	Casting and Compressive Strength Test of Sample 2	69

5.6	Casting and Compressive Strength Test of Sample 3	71
5.7	Modulus of elasticity Test Apparatus and failure of specimen	72
5.8	Stress Strain Curve of Sample – 1	73
5.9	Stress Strain Curve of Sample – 2	74
5.10	Stress Strain Curve of Sample – 3	75
6.1	Change in Compressive Strength at both 7 days and 28 days for samples without silica fumes.	77
6.2	Change in Compressive Strength at both 7 days and 28 days for samples with silica fumes.	77
6.3	Variation in permeability of pervious concrete	78
6.4	Variation in porosity of pervious concrete	78
6.5	Variation in Young's Modulus of pervious concrete	79
6.6	Comparision of 7 day strength of pervious concrete with and without silica fumes	79
6.7	Comparision of 28 day strength of pervious concrete with and without silica fumes	80

List of Table

Table. No.	Description	Page No.
1.1	Typical Pervious Concrete Properties	15
4.1	Typical Ranges of Materials Proportions in Pervious Concrete	34
4.2	Calculation of cement's degree of fineness	42
4.3	Assumed Standard Deviation Values for mix designs based on compressive strength	50
4.4	Estimation of Approximate Void Content for Different Rates of Percolation	51
4.5	Estimation of Approximate Void Content for Different Strength of Pervious Concrete	51
4.6	Estimation of Paste Content Using Void Content Value for MSA 9.5 mm aggregate	52
5.1	Compressive Strength variation of Sample-1 (with Silica Fumes)	66
5.2	Compressive Strength variation of Sample-1 (without Silica Fumes)	66
5.3	Compressive Strength variation of Sample-2 (with Silica Fumes)	68
5.4	Compressive Strength variation of Sample-2 (without Silica Fumes)	68
5.5	Compressive Strength variation of Sample-3 (with Silica Fumes)	70
5.6	Compressive Strength variation of Sample-3 (without Silica Fumes)	70
5.7	Modulus of Elasticity of Sample-1	73
5.8	Modulus of Elasticity of Sample-2	74
5.9	Modulus of Elasticity of Sample-3	75
6.1	Variation of different parameters with Aggregate Size	76

ABSTRACT

Pervious concrete pavement has emerged as a sustainable solution in modern civil engineering due to its ability to mitigate storm water runoff and reduce environmental impacts. This project investigates the pivotal role of aggregate size in the design and performance of pervious concrete pavements. The study focuses on evaluating the influence of varying aggregate sizes on the structural integrity, permeability, and overall effectiveness of pervious concrete.

Through a series of experimental tests and comprehensive assessments, this research aims to identify the impact of different aggregate sizes on the compressive strength and permeability of pervious concrete. The study delves into the optimization of aggregate sizes to enhance water infiltration, strength, and durability, considering various practical applications and environmental implications.

Experimental procedures involve the fabrication of pervious concrete specimens using different gradation of aggregate and subsequent testing to assess the compressive strength, permeability, and overall structural performance. The results obtained will provide insights into the ideal aggregate size that maximizes both permeability and structural stability, thereby contributing to the advancement of efficient and durable pervious concrete pavements.

The porosity in pervious concrete is created by the reduction or elimination of fine aggregate from the concrete mix design. Standard pervious concrete in India is a mixture of a single-size coarse aggregate and cement combined at low water to cement ratios. Strength is often the primary concern for concrete pavement designs. Since pervious concrete has a high void ratio (15%-35%), often without fine aggregate the compressive, tensile, and flexural strengths tend to be lower than that of conventional concrete.

This investigation underscores the significance of aggregate size as a fundamental factor in the design and functionality of pervious concrete, shedding light on the key parameters essential for developing sustainable and high-performing pavement systems. The findings of this study aim to offer valuable guidance for engineers and practitioners involved in the construction and implementation of environmentally conscious infrastructure.

TABLE OF CONTENTS

		Page No.
Title Page		1
Report Approval Sheet		2
Declaration		3
Certificate		4
Acknowledgement		5
List of Figures		6-7
List of Tables		8
Abstract		9
Contents		10-12
Chapter 1	**Introduction**	**13-20**
1.1	General	13
1.2	Typical Properties and Characteristics	15
1.3	Porous Concrete and Porous Asphalt	15
1.4	How is pervious concrete made	17
1.5	Benefits of Pervious Concrete Pavements	18
1.6	Disadvantages of Pervious Concrete	19
1.7	Why Pervious concrete?	19
1.8	Summary and Future needs	20
1.9	References	20
Chapter 2	**Objectives of Project**	**21**
Chapter 3	**Literature Review**	**22-32**
3.1	General	22
3.2	Aggregate Size's Impact: A Literature Review on Pervious Concrete's Strength, Permeability and Porosity	22
3.2.1	Strength	22
3.2.2	Permeability	26
3.2.3	Porosity	28
3.3	Summary	30
3.4	References	30

Chapter 4	**Materials and Methodology**	**33-61**
4.1	General	33
4.2	Materials	34
4.2.1	Aggregates	34
4.2.2	Cement	35
4.2.3	Cementitious materials	36
4.2.4	Water/Cement Ratio	37
4.2.5	Admixtures	38
4.2.6	Silica Fumes	38
4.3	Tests	40
4.3.1	Tests on Cement	40
4.3.1.1	Fineness Test of Cement	40
4.3.2	Tests on Aggregate	43
4.3.2.1	Water absorption test:	43
4.3.2.2	Aggregate Crushing Test	43
4.3.2.3	Aggregate Impact Test	44
4.3.2.4	Aggregate Abrasion Test	45
4.4	Methodology	47
4.4.1	Introduction	47
4.4.2	Materials	47
4.4.3	Flow chart showing methodology of making Pervious concrete	48
4.4.4	Mix Proportioning	49
4.4.5	Overview of the Tests Conducted on Pervious concrete	54
4.4.6	Compressive strength test	55
4.4.7	Modulus of elasticity Modulus Test	57
4.4.8	Porosity Test	59
4.4.9	Determination of Permeability	59
4.5	References	61

Chapter 5	**Experimental Investigation**	**62-75**
5.1	Sieving of Aggregate	62
5.2	Calculation of mix design	63
5.3	Casting Procedure	64
5.4	Curing	65
5.5	Compressive strength test of cast specimen	66
5.6	Modulus of elasticity	72
Chapter 6	**Results**	**76-80**
Chapter 7	**Conclusion**	**81-82**
Chapter 8	**Future Scope**	**83-84**

Chapter 1

INTRODUCTION

1.1 General

The evolution of modern construction practices has increasingly gravitated towards sustainable and eco-conscious solutions. It offers an innovative approach to infrastructure development by addressing the challenges of stormwater management and environmental degradation. Unlike traditional concrete, pervious concrete is engineered with a porosity that allows water to percolate through its structure, thereby mitigating stormwater runoff. This unique characteristic makes it a compelling choice for various applications in pavement construction, green infrastructure, and sustainable urban development.

Pervious concrete system has advantages over impervious concrete in that it is effective in managing run-off from paved surfaces, prevent contamination in run-off water, and recharge aquifer, repelling salt water intrusion, control pollution in water seepage to ground water recharge thus, preventing subterranean storm water sewer drains, absorbs less heat than regular concrete and asphalt, reduces the need for air conditioning. Pervious concrete allows for increased site optimization because in most cases, its use should totally limit the need for detention and retention ponds, swales and other more traditional storm water management devices that are otherwise required for compliances with the Federal storm water regulations on commercial sites of one acre or more.

Pervious concrete's ability to act as a natural filtration system, allowing rainwater to infiltrate the ground, reduces the strain on conventional stormwater systems. Consequently, it helps in recharging groundwater, controlling erosion, and diminishing the adverse impact of pollutants on natural water bodies. Its permeability facilitates water conservation, limits flooding, and contributes to the preservation of the natural hydrological cycle. The implementation of pervious concrete presents a multifaceted solution, not just in stormwater management but also in promoting environmental sustainability. Its porous nature aids in reducing the urban heat island effect by minimizing surface runoff, allowing water to evaporate and cool the surrounding environment.

Pervious concrete contains little or no fine aggregate (sand) and carefully controlled amounts of water and cementitious materials. The paste coats and binds the aggregate particles together to create a system of highly permeable, interconnected voids that promote the rapid drainage of water (Tennis et al. 2004; ACI 2010). Typically, between 15 and 25 percent voids are achieved in the hardened concrete, and flow rates for water through the pervious concrete are generally in the range of 2 to 18 gal/min/ft2 (81 to 730 L/min/m2), or 192 to 1,724 inch/hr (488 to 4,379 cm/hr) (ACI 2010). Figure 1 shows a typical cross section of a pervious concrete pavement.

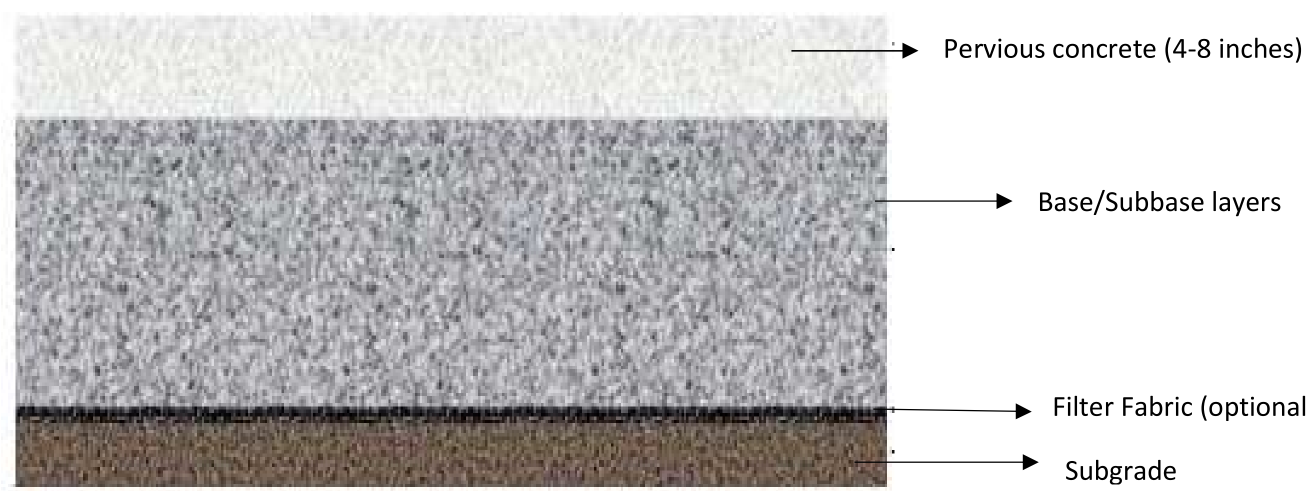

Figure 1.1: Typical pervious concrete pavement cross section (adapted from EPA 2010).

Pervious concrete can be used in a wide range of applications, although its primary use in pavements which are in: residual roads, alleys and driveways, low volume pavements, low water crossings, sidewalks and pathways, parking areas, tennis courts, slope stabilization, sub-base for conventional concrete pavements etc.

1.2 Typical Properties and Characteristics

Many of the properties of pervious concrete are different from those of conventional concrete. These properties are primarily a function of the porosity (air void content) of the pervious concrete, which in turn depends on the cementitious content, the water-to cementitious materials (w/cm) content, the compaction level, and the aggregate gradation and quality (ACI 2010). Table 1 summarizes some of the typical material properties associated with pervious concrete. These properties and characteristics must be considered during the structural design and pavement construction. The cost of pervious concrete may be 15 to 25 percent higher than conventional concrete, but cost can vary significantly depending on the region, the type of application, the size of the project, and the inclusion of admixtures.

Table 1.1: Typical Pervious Concrete Properties
(Tennis et al. 2004; obla 2007)

Property	**Common value/Range**
Plastic concrete	
Slump	N/A
Unit weight	70% of conventional concrete
Working time	1 hour
Hardened concrete	
In-place density	1600 to 2000 kg/m^3
Compressive strength	5 to 30 N/mm^2
Flexural strength	1 to 4 N/mm^2
Permeability	0.135 to 1.22 cm/s

1.3 Porous concrete and Porous asphalt

Porous concrete and porous asphalt are two distinct types of pervious materials used in construction, primarily to manage stormwater runoff and prevent issues associated with urban development such as flooding and soil erosion. Both materials offer permeability, allowing water to infiltrate through the surface and into the ground below. However, they differ in composition, application, and performance.

Porous concrete, also known as pervious or permeable concrete, is a blend of Portland cement, water, and coarse aggregate. What distinguishes it from traditional concrete is the absence of fine aggregates (such as sand), resulting in voids that enable water to pass through. This material is often used in applications like parking lots, sidewalks, and low-traffic pavements. Its various types include traditional pervious concrete, fiber-reinforced pervious concrete, admixture-modified pervious concrete, colored pervious concrete, polymer-modified pervious concrete, and rapid-set pervious concrete.

Porous asphalt, on the other hand, is a blend of bitumen, aggregates, and filler. It's designed to have interconnected voids that allow water to flow through the surface and into a stone reservoir and soil beneath. Typically used for road surfaces, driveways, and parking lots, porous asphalt is adept at managing stormwater and preventing surface water accumulation. While it shares the same function of promoting water infiltration, it differs from porous concrete in its composition, relying on asphalt materials rather than cement-based mixtures.

Figure 1.2: Permeable Concrete and Permeable Asphalt

Both porous concrete and porous asphalt offer benefits such as reduced stormwater runoff, minimized erosion, and enhanced groundwater recharge. They contribute to sustainability efforts by reducing the burden on conventional drainage systems and mitigating the heat island effect in urban areas. However, their application and performance characteristics may vary based on the specific needs of a project, such as traffic load, local climate conditions, and maintenance requirements. Selecting the appropriate type of pervious material depends on factors like intended use, durability, and the desired aesthetic or structural attributes.

1.4 How is Pervious concrete made?

Pervious concrete, distinct from traditional concrete, is formulated with a deliberate emphasis on porosity to facilitate water permeability. The process of making pervious concrete involves carefully controlled proportions of water and cementitious materials, creating a paste that envelops aggregate particles. Unlike standard concrete mixes, the pervious variety includes minimal or no fine aggregates, resulting in a notable void content, typically ranging between 15 to 25 percent.

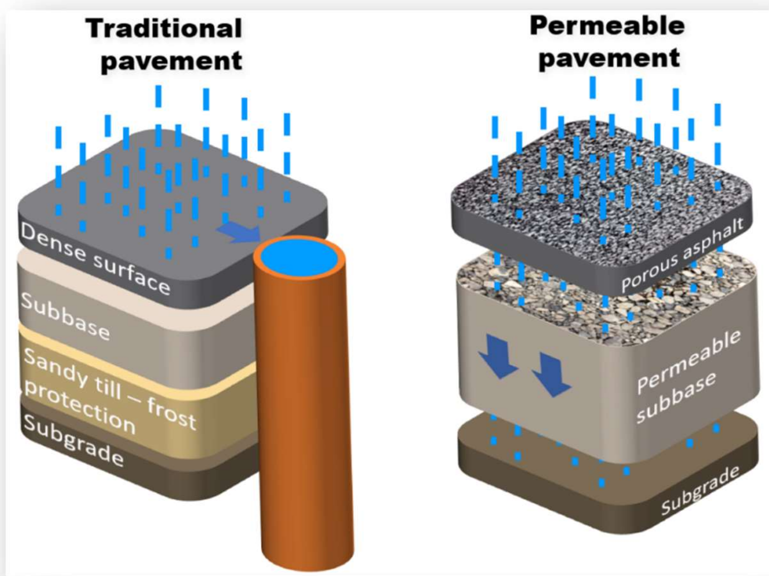

Figure 1.3: Traditional and Permeable pavement

This intentional omission of fine aggregates allows for a significant number of interconnected voids within the concrete structure. The resulting system of voids provides high permeability, enabling rapid water drainage. Although the lower mortar content and higher porosity reduce the material's strength compared to conventional concrete, pervious concrete maintains sufficient strength for various applications.

Pervious concrete exhibits an impressive water drainage capacity, allowing an estimated 3 to 8 gallons of water per minute to pass through each square foot of the material. By permitting rainwater to infiltrate the ground, this specialized concrete plays a crucial role in recharging groundwater and mitigating stormwater runoff. Consequently, the utilization of pervious concrete can potentially diminish the necessity for retention ponds, swales, and other stormwater management infrastructures.

Pervious pavement, integrating hardscape surfaces with stormwater management, offers a sustainable solution to water management issues, effectively balancing urban development with environmental considerations. Its ability to support natural groundwater recharge while reducing surface runoff makes it a significant asset in sustainable construction practices and green infrastructure development.

1.5 Benefits of Pervious Concrete Pavements

Benefits of pervious pavements include:

1. Reducing the rate of runoff
2. Filtering pollutants out of runoff
3. Infiltrating runoff into the ground, and
4. Maintaining the natural hydrologic function of the site

Pervious pavement is designed primarily to promote stormwater infiltration and improve the quality of stormwater runoff. It is typically designed to capture rainfall on the pavement surface area, but may also accept run-on from adjacent impervious areas and other hardscapes (sidewalks), rooftops, or gutters. Another benefit of pervious pavement is the reduction of pollutants that enter stormwater runoff by reducing the amount of splash and spray that wash pollutants from the underside of vehicles. This would be considered a form of source control and a useful component of stormwater compliance. Pervious pavements infiltrate the water below the pavement surface and eliminate standing water issues. This will help to eliminate concerns of mosquito breeding. Some recent studies have also found that pervious pavement can help reduce temperatures on and around pavements which helps reduce urban heat island effect.

1.6 Disadvantages of Pervious Concrete

1. Can not be used on pavements with heavy traffic flow.

2. Requires longer curing time.

3. Difficult to find out water content in fresh concrete.

4. Conventional concrete tests like slump test and compaction factor test are not applicable.

5. Requires specialized construction practice.

6. Special design considerations need to be implemented.

7. Requires regular cleaning to maintain its permeability.

1.7 Why Pervious concrete?

The escalating urban development and increased impervious surfaces have intensified stormwater runoff, leading to reduced groundwater recharge, elevated pollution, and amplified urban flooding risks. Addressing these environmental challenges demands an innovative solution for effective stormwater management. Pervious concrete, renowned for its high porosity and water infiltration capacity, emerges as a promising option. However, the successful implementation faces hurdles concerning clogging, structural integrity, and adaptability to diverse environmental conditions.

The need to refine and optimize pervious concrete technology is crucial. This study focuses on evaluating novel pervious concrete mixes using sand as fine aggregates and silica fume as a supplementary cementitious material. It aims to fill the knowledge gap by comprehensively examining the performance of these modified mixes through rigorous laboratory tests. The ultimate goal is to overcome existing limitations, enhancing formulations and installation methods, and establishing effective maintenance strategies. These advancements are vital for pervious concrete to emerge as a sustainable solution for stormwater management in urban environments.

1.8 Summary and Future needs

The use of pervious concrete has increased significantly in the last several years, perhaps largely because it is considered an environmentally friendly, sustainable product. The use of pervious concrete provides a number of benefits, most notably in the effective management of stormwater runoff. Other significant benefits include reducing contaminants in waterways, recharging groundwater supplies, reducing heat island effects, and reducing pavement–tire noise emissions. Still, there are several areas that need additional developmental work to improve or enhance the capabilities of pervious concrete pavements. One area is the continued monitoring of the performance of pervious concrete so that long-term performance trends can be documented; this will also help in evaluating the suitability of pervious concrete for other applications, such as overlays. Tied in with this is the assessment of the suitability of current structural design approaches to provide competent designs, particularly regarding the fatigue behavior of pervious concrete. Finally, a third area is in the testing and evaluation of pervious concrete, as current test methods for conventional concrete are not generally applicable to pervious concrete.

1.9 References:

- IRC:44. (2017). Code of guideline for cement concrete mix design for pavements
- Wikipedia
- https://www.fhwa.dot.gov/pavement/concrete/pubs/hif13006/hif13006
- https://www.concretenetwork.com/pervious/how_it_works.html

Chapter 2

Objectives of the Project

1. To evaluate the performance of pervious concrete pavements in terms of their strength, permeability, and porosity.

2. To see the improvement in strength by using Silica Fumes as additives

3. To find the material property of pervious concrete in terms of Young's modulus

Chapter 3

Literature Review

3.1 General

This literature review delves into the impact of aggregate size on key properties of pervious concrete: permeability, porosity, and strength. Larger aggregates typically increase permeability and porosity by creating more void spaces within the concrete matrix, facilitating efficient water drainage and storage. However, they often compromise compressive strength due to reduced interlocking between particles. Conversely, smaller aggregates enhance compressive strength by promoting denser packing but may decrease permeability and porosity. Striking the right balance between these factors is essential for optimizing pervious concrete mixes to meet specific application requirements. Understanding these dynamics not only aids in improving stormwater management capabilities but also ensures structural integrity. This review seeks to synthesize existing research findings while identifying areas for further investigation, aiming to advance the development of pervious concrete with enhanced performance characteristics. Finding this balance is critical for achieving sustainable and resilient infrastructure solutions, addressing both environmental and structural needs effectively.

3.2 Aggregate Size's Impact: A Literature Review on Pervious Concrete's Strength, Permeability and Porosity

3.2.1 Strength: The strength of pervious concrete has been extensively explored in the following literature reviews:

Pradhan and Behera (2022) investigated the performance properties of pervious concrete with or without silica fume as an additive at the different percentages by controlling the fine content and developing a relationship between the strength, permeability, and percentage of fine aggregate. To minimize environmental pollution they used silica fumes as a partial replacement for cement. In this research, it was studied the effect of fine aggregate on pervious concrete. The trial mix was carried out by using 5%, 7%, and 9% fine aggregates and from the various laboratory experiments, 9% fine aggregate gives maximum strength and satisfy all parameter. Then replacement was done with silica fume at different percentages like 0%, 4%, 8%, 12%, and 16% of cement. Five concrete mixes were prepared, including one control mix with M35 grade and four mixes with partial replacement of fine aggregate by coarse aggregate. Results indicate that increasing fine aggregates led to improved mechanical properties but decreased permeability. Experimental tests demonstrated that partial replacement of silica fume with cement resulted in superior performance compared to the control mix, highlighting the potential for optimizing pervious concrete for various applications.

Shen et al. (2021) proposed a novel design concept of high strength pervious concrete, aiming at improving its compressive strength with adequate permeability. An ultra-high performance paste was developed and used as the binder of the high strength pervious concrete. The effects of aggregate characteristics and membrane-forming ability of the paste on the performance were investigated and their compatibility was evaluated. The experimental results showed that the use of ultra-high performance paste, improvement of homogeneity and compatibility between the paste and the aggregates by elimination of coarse aggregates could improve the mechanical properties. The combined use of aggregates with two-size ranges also resulted in an increase of compressive strength due to the increase of homogeneity and interlocking effect between the aggregates. The enhancement of the membrane-forming ability could optimize the bonding area and thickness of the cement paste between the aggregates. Therefore, the application of the proposed design concepts was able to produce a high strength pervious concrete with a compressive strength of 60.93 MPa and a water permeability of 0.37 mm/s, which would potentially broaden the scope of application of pervious concrete.

Yu et al. (2019) analyzed eight sets of pervious concrete samples, maintaining consistent porosity while varying aggregate size. Using CT imaging and a novel semi-manual method, they examined the pore structure and cementitious paste thickness, aiming to understand the impact of aggregate size on compressive strength.

The findings suggest that increasing aggregate size initially boosts compressive strength, but beyond a certain threshold (identified as 7 mm), further changes have minimal effect. Cracks predominantly occur at the cement slurry-aggregate interface, highlighting its critical role in structural integrity. Additionally, compressive strength is most sensitive to pore structure irregularities and the ratio of total void volume to surface area (Vt/St), while being less influenced by average pore size (Aav). Furthermore, increasing cementitious paste thickness initially enhances strength, but this effect plateaus, leading to stable strength values. These insights offer practical guidance for optimizing pervious concrete's mechanical properties for diverse construction needs.

Shukla and Gupta (2019) selected the specific gravity of cement, coarse aggregate and fine aggregate as 3.15, 2.68, 2.65 respectively. Cement used in this project was OPC-43. Coarse aggregate were used at different proportions. With interconnected void content, we can achieve high porosity. Water-to-cementitious material ratio is 0.40–0.50. Designs were made at different water–cement ratios, and these ratios show the different exposure conditions. In this undertaking, the mechanical properties of pervious concrete have been used to plan road pavements. The properties of PCC blend to be examined are compressive strength and flexural strength. An optimum percentage has been determined which shows the concrete is permeable and having good compressive and flexural strength. In this research paper, the mechanical properties of pervious concrete have been used to design road pavements. Main focus of the research is to determine and improve compressive strength, and flexural strength.

Tripathi et al. (2017) represented the experimental methodology and experimental results related to strength, Mix ratio and water absorption. Cubes of size 150 mm*150mm*150 mm height are prepared to investigate both these properties. This investigation is carried out at the end of 1day,3day.7day and 28 days for Strength of pervious concrete and for water absorption. Different concrete mix proportion such as 1:4, 1:5, 1:6, and 1:7 with different size of gravel such as 20 mm,12.5mm and 9.6 mm should be used to check both these properties of pervious concrete. Test results concluded that pervious concrete made by 1:4 concrete mix proportion has more strength full and less water absorption and pervious concrete made by 1:7 mix proportion has more water absorption and less strength, that’s why strength and water absorption are inversely proportional to each other. Using selected aggregates, fine mineral, admixtures, organic intensifiers and by adjusting the concrete mix proportion, strength and abrasion resistance can improve the pervious concrete greatly. The Primary object of this investigation is to get a maximum compressive Strength without any change in permeability characteristic of the pervious concrete.

Rajasekhar and Spandana (2016) reported the results of an experimental investigation in the development of pervious concrete with reduced cement content and coarse aggregate for sustainable permeable pavement construction. In this research, they used a super plasticizer conplast SP430 to reduce the amount of water content. The compressive strength properties of pervious concrete were determined by the age of 3, 7 and 28days. This research gives the results about the properties like void ratio and compressive strength of concrete. The experimental investigation in this thesis draws several conclusions regarding pervious concrete compared to conventional concrete. Firstly, there is a substantial reduction in compressive strength, ranging from 50% to 75%, and split tensile strength, ranging from 45% to 50%, in pervious concrete. This decrease in strength is accompanied by a significant increase in void ratio, reaching up to 4%, resulting in higher permeability. Additionally, pervious concrete exhibits a notable decrease in density, around 30%, compared to conventional concrete. These findings underscore significant differences between pervious and conventional concrete across various parameters, highlighting the distinct characteristics of pervious concrete in terms of strength, permeability, and density.

Mulligan (2005) investigated prior studies on the compressive strength on pervious concrete as it relates to water-cement ratio, aggregate-cement ratio, aggregate size, and compaction and compare those results with results obtained in laboratory experiments conducted on samples of pervious concrete cylinders created for this purpose. The loadings and types of vehicles these systems can withstand will also be examined as well as the design of appropriate thickness levels for the pavement. Since voids are supposed to reduce the strength of concrete 1% for every 5% voids (Klieger, 2003), the goal is to find a balance between water, aggregate, and cement in order to increase strength and permeability, two characteristics which tend to counteract one another. In this study, also determined are appropriate traffic loads and volumes so that the pervious concrete is able to maintain its structural integrity. Ann Marie Mulligan concluded that the end result of this research will be a recommendation as to the water-cement ratio, the aggregate-cement ratio, aggregate size, and compaction necessary to maximize compressive strength without having detrimental effects on the permeability of the pervious concrete system. This research confirms that pervious concrete does in fact provide a lower compressive strength than that of conventional concrete; compressive strengths in acceptable mixtures only reached 1700 psi.

3.2.2 Permeability: The Permeability of pervious concrete has been extensively explored in the following literature reviews:

Eliabdo et al. (2018) investigated the properties of pervious concrete with varying levels of concrete aggregate (CA) and additional materials such as rubber fiber, crumb rubber, polypropylene fiber, silica fume, and styrene butadiene latex. Two replacement percentages of CA (50% and 100%) and two aggregate sizes (9.5 mm and 19 mm) were considered. Permeability and strength indices were examined, including water permeability, density, voids ratio. Results indicate that the use of aggregate, rubber fiber, and crumb rubber slightly affected permeability but negatively impacted strength indices, particularly splitting tensile strength. However, the addition of polypropylene fibers enhanced tensile strength and degradation resistance without significant effects on permeability or compressive strength. Furthermore, the inclusion of silica fume and styrene butadiene latex increased density and improved strength indices. Overall, this study establishes important relationships between the investigated variables mainly permeability, providing insights for optimizing the properties of pervious concrete for various applications.

Liu et al. (2018) investigated the permeability of pervious concrete composed of Portland cement, silica fume (SF), polycarboxylate superplasticizer (SP), and limestone aggregates. Laboratory tests examined porosity, pore distribution, and permeability coefficients using various methods, including water displacement and image processing technology. Results indicate that paste segregation and flow values increase with SP and water-cement ratio (W/C) increments. Aggregate size significantly influences pore distribution, with single-size aggregate concrete closely matching design porosity. The permeability coefficient, determined using Darcy's law and a sealed sidewall permeameter, correlates with porosity and aggregate size, increasing with larger aggregates and higher design porosity. These findings provide optimized parameters for practical engineering applications, including specific W/C ratios, SP and SF contents, and recommended aggregate sizes.

Cui et al. (2016) conducted a series of tests to demonstrate the effects of water-cement ratio, aggregate-cement ratio and porosity on the properties of pervious concrete including strength and permeability. and found that for pervious concrete, there is an optimum water content unlike the conventional concrete, and in the test, when water content equals to 0.36, the pervious concrete is the strongest. The strength-permeability empirical model of pervious concrete was established.

The strength of pervious concrete decreases when the permeability increases, but the rate of reduction decreases gradually. Based on the strength-permeability empirical model, the optimum mix proportion can be determined according to the engineering requirements. Strength and permeability are two important design factors for pervious concrete, but limited research is conducted on their interactional relationship. This study focuses on the balance between permeability and strength properties of pervious concrete.

Joshi and Dave (2016) investigated the impact of aggregate size and water-cement ratio variations on the permeability of pervious concrete. Three aggregate sizes (6-10mm, 10-20mm, and a 50% mix of both) were examined alongside water-cement ratios of 0.30, 0.35, and 0.40. Results reveal that smaller aggregate sizes lead to decreased permeability, while higher water-cement ratios generally result in lower permeability. Optimal permeability is achieved with a water-cement ratio of 0.30 and a 50% mix of aggregates. These findings highlight the crucial role of aggregate size and water-cement ratio in determining the permeability characteristics of pervious concrete, providing valuable insights for its optimization in various applications.

Qin et al. (2015) used the Falling head method (FHM) and constant head method (CHM) to test the water permeability of permeable concrete, using different water heads on the testing samples.Two Portland concrete mixtures are prepared and cored for the water permeability test.The fundamental difference between the CHM and FHM is examined from the theory of fluid flowing through porous media. The permeability measured by the CHM is lower than that by the FHM. The selection of the starting and finishing water heads from the FHM strongly affects the calculated permeability. The difference decreases as the water head approaches zero. Due to this correlation, the water permeability of permeable concrete should be reported with the applied pressure and the associated testing method.

Sriravindrarajah et al. (2010) discussed the results of an experimental investigation into the effect of pore structure clogging and compaction on the water permeability of pervious concrete. The water permeability of pervious concrete was studied under falling head. Compaction during the placement of pervious concrete pavements should be avoided to prevent damage to water permeability. Uncompacted pervious concrete, with 50% cement replaced by fly ash, achieved a 7-day compressive strength of 6.9 MPa and a water permeability of 12.5 mm/s. However, pore clogging poses a significant challenge to maintaining water permeability over time. High-pressure water cleaning emerges as a viable maintenance approach to restore water permeability in pervious concrete.The results showed that the clayey materials presence in the percolating water had seriously reduced the water permeability of pervious concrete. High-pressure water cleaning was found to partially recover the water permeability of pervious concrete. Since compaction causes pore structure modification, it should not be used with pervious concrete to ensure high water permeability of pervious concrete.

3.2.3 Porosity: The Porosity of pervious concrete has been extensively explored in the following literature reviews:

Anburuvel and Subhramaniam (2023) dictated the vertical porosity profile of pervious concrete by various mix design parameters, including aggregate/cement (a/c) ratio, compaction type and effort. The presented work is an attempt was made to reveal the profound impacts of these parameters on porosity and strength. Vertical profile analysis using image processing techniques revealed that a zone approximately 10–15 mm thick with high porosity was observed at the top and bottom ends of a cylindrical PC core (13–20% of total PC thickness in total). Total porosities in that zone were 20–42% and 35–60% for lower and higher a/c ratios, respectively. The middle span of 120–130 mm of the vertical profile showed porosity variations of 5–15% and 30–45% for low and high a/c ratios, respectively. Overall, the a/c ratio and compaction effort manifested a profound impact on the vertical porosity profile. Compaction types showed trivial impact on porosity and compressive strength properties of PC for a/c ratios from 3.0 to 5.0. The authors recommend that the findings of this study would help to obtain the required porosity profile in PC without compromising strength characteristics.

Ibrahim et al. (2014) prepared twenty-four Portland Cement Pervious Concrete mixtures prepared and tested them to address the effect of different size fractions of coarse aggregate, water-to-cement ratio, cement content, and coarse aggregate volume on the relationships between compressive strength, tensile strength, porosity, and permeability. The mixtures used in this study consisted of either one or two aggregate sizes. Linear regression relationships were developed to establish relationships between density and porosity, compressive strength and permeability, tensile strength and permeability, and compressive strength and porosity. The results showed that properties such as permeability, porosity, are significantly affected by using either one or two coarse aggregate sizes in all concrete mixtures. Furthermore, density can be an effective factor for predicting compressive strength, and porosity. In this study, the maximum compressive strength was 6.95 MPa, which obtained by using one aggregate size of 9.5 mm with 250 kg/m3 cement content. The obtained results showed that Portland Cement Pervious Concrete could be produced using one or two aggregate sizes at most.

Emiko et al. (2013) carried out a study to achieve high-strength, high porosity and permeability pervious concrete pavement. First, the mix proportion in terms of cement content and coarse aggregate-cement ratio (CA/C) and water-cement (W/C) ratio were varied. Next, a mix proportion providing the optimal combination of strength and porosity was chosen, and polymer superplasticizers and short discrete fibers were added to examine their effect on the strength and porosity. Results showed that a water-cement ratio of 0.2 resulted in a dry and brittle mix that led to compressive strength less than 15 MPa but a high permeability rate of approximately 20mm/s. A mix with CA/C ratio of 4.25 resulted in compressive strength of 13.9 MPa, flexural strength of 3MPa and high porosity of more than 20%. Using comb polymer superplasticier and 2% steel fibers resulted in compressive strength of 25.1 MPa and flexural strength of 3.6 MPa at 28 days without compromising on the porosity.

3.3 Summary

The literature on pervious concrete elucidates the intricate balance between compressive strength, permeability, and porosity, crucial for optimizing its performance across diverse applications. Researchers have explored various factors impacting these properties, including the addition of additives like silica fume and polymer superplasticizers, fine aggregate content, and aggregate size distribution. Studies reveal that while increasing fine aggregate content can enhance mechanical properties, it often leads to reduced permeability. Similarly, optimizing mix design parameters such as water-cement ratios and aggregate proportions is essential for achieving the desired balance between strength and permeability, particularly in applications like road pavements where both properties are critical.

Furthermore, investigations into aggregate size highlight its significant influence on both compressive strength and permeability, with larger aggregates initially boosting strength but beyond certain thresholds exhibiting diminishing returns. Additionally, studies emphasize the importance of maintaining adequate porosity for pervious concrete's permeability while ensuring sufficient strength for structural integrity. Overall, the literature underscores the intricate interplay between material composition, mix design, and mechanical properties, offering valuable insights for optimizing pervious concrete's performance across various engineering applications while addressing environmental concerns such as stormwater management and sustainability.

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Chapter 4

Materials and Methodology

4.1 General

Pervious concrete uses the same materials as conventional concrete, with the exceptions that the fine aggregate typically is eliminated entirely, and the size distribution (grading) of the coarse aggregate is kept narrow, allowing for relatively little particle packing. This provides the useful hardened properties, but also results in a mix that requires different considerations in mixing, placing, compaction, and curing. Proportioning pervious concrete mixtures is different compared to procedures used for conventional concrete and the mixture proportions are somewhat less forgiving than conventional concrete mixtures—tight controls on batching of all of the ingredients are necessary to provide the desired results.

When developing pervious concrete mixtures, the goal is to obtain a target or design void content that will allow for the percolation of water. The void content of a pervious concrete mixture will depend on the characteristics of the ingredients, how they are proportioned and how the mixture is consolidated. Pervious concrete is typically designed for a void content in the range of 15% to 30%. Generally, as the void content decreases, the strength increases and permeability decreases. For pervious concrete mixtures it is even more important to verify through trial batches that the mixture achieves the characteristics assumed or targeted when developing mixture proportions. Frequently one finds that even though the design void content is 20%, when the pervious concrete mixture is proportioned, the experimentally measured void content is considerably different. This depends on the workability of the mixture and amount of consolidation.

4.2 Materials

In general, concrete consists of cement as binding material, with coarse aggregate as main constituent responsible for the strength and volume of the concrete and fine aggregate acting as a filler material of occupy the spaces between the aggregate to render it dense. Admixtures are also used in concrete production to increase is workability as well as other hydraulic and mechanical properties. Pervious Concrete differs from conventional concrete as the use of fine aggregate is limited creating a continuous interconnected void in concrete responsible for better hydraulic conductivity. Natural stone aggregates are mainly used in this study as a coarse aggregate in the pervious concrete mix. Sand is used as fine aggregate of grading zone I. Ordinary Portland Cement (OPC) of 43 grade is used as a binding material. The details of all the materials are described in the following sub- section.

Table 4.1 provides typical ranges of materials proportions in pervious concrete

Table-4.1: Typical Ranges of Materials Proportions in Pervious Concrete

Materials	Proportions(kg/m^3)
Cementitious Materials	270-415
Aggregate	1190-1480
Water-Cement Ratio (by mass)	0.27-0.34
Aggregate-Cement Ratio (by mass)	4 to 4.5:1
Fine-Coarse Aggregate Ratio (by mass)	0 to 1:1

4.2.1 Aggregates

Fine aggregate content is limited in pervious concrete and coarse aggregate is kept to a narrow gradation. The required physical properties of the coarse aggregate used in porous (pervious) concrete are that it should be clean, hard and durable. There are four different grades for coarse aggregate; passing through the 19 mm sieve and retained on the 12.5 mm sieve, passing through 12.5 mm sieve and retained on the 9.5 mm sieve, and passing through the 9.5 mm sieve and retained on the 4.75 mm sieve and passing through the 4.75 mm sieve and retained on the 2.37 mm. 10% of coarse aggregate should be retained and 90% should be passed

Figure 4.1: Different size of Aggregates

4.2.2 Cement

The role of cement as the primary binding agent is instrumental in creating the distinctive porous structure of the material. Primarily composed of Portland cement, the matrix formed around the aggregate particles through the hydration process is central to generating a network of interconnected voids. This unique structure allows for the passage of water, aligning with the intended purpose of pervious concrete in managing stormwater.

The proportion of cement within the mix profoundly influences various properties of the pervious concrete, particularly its porosity, permeability, and strength. Compared to traditional concrete, the lower cement content in pervious concrete formulations is crucial for creating increased void space. This elevated porosity is essential for facilitating water infiltration, ensuring efficient water passage through the material to the ground below. However, it's vital to strike a precise balance between the cement content and the size of aggregates to optimize the porosity without compromising the structural integrity of the pavement.

This equilibrium, delicately balancing cement content, aggregate sizes, and the resultant void structure, plays a pivotal role in determining the material's ability to manage stormwater runoff effectively while maintaining requisite structural strength. In this project, exploring the adjustment of the cement-to-aggregate ratio in pervious concrete pavements is a critical aspect influencing the material's permeability and overall performance. Understanding how variations in aggregate sizes impact the ideal cement content and subsequent void structure is paramount in refining mix designs for optimized pervious concrete, particularly in the management of stormwater in urban environments.

4.2.3 Cementitious materials

Cementitious materials encompass a variety of substances crucial in the formulation of concrete. These materials predominantly consist of Portland cement, a finely ground powder mainly comprising calcium silicates, often considered the backbone of concrete mixtures. Supplementary Cementitious Materials (SCMs) play a vital role, including fly ash, a by-product of coal combustion; slag cement, a by-product of iron production; and silica fume, collected from the production of silicon metals. These materials are used as partial replacements for Portland cement to enhance specific properties of the concrete. Additionally, hydraulic binders, such as blended cements and masonry cement, offer diverse chemical compositions and unique characteristics. Moreover, chemical admixtures, though not cementitious in essence, play a significant role in altering properties like setting time, workability, and strength development of concrete mixtures. The careful selection and appropriate utilization of these materials, in accordance with standards and guidelines, significantly impact the overall quality, durability, and performance of concrete in diverse construction applications.

4.2.4 Water/Cement Ratio

The water/cement (w/c) ratio in pervious concrete stands as a pivotal determinant governing its overall quality and performance. This ratio holds immense importance across multiple facets of concrete construction. It significantly influences the strength and durability of the concrete, with a lower w/c ratio generally correlating to higher strength and increased long-term durability. In the context of pervious concrete, this ratio plays a crucial role in determining the material's permeability and porosity. A well-controlled w/c ratio ensures the desired balance between strength and the concrete's ability to allow water to pass through. Moreover, the workability and placement of pervious concrete are directly affected by the water content. Excess water might lead to segregation, impacting the concrete's placement and compaction, while a lower content might reduce workability. Striking an optimal w/c ratio also aligns with environmental considerations by reducing excess water usage, promoting sustainability, and ensuring compliance with regulations. The structural integrity of the concrete structure is also at stake, with an imbalanced ratio potentially leading to issues like cracking, reduced strength, and compromised long-term durability. Therefore, managing and controlling the water/cement ratio in pervious concrete is vital to achieve a well-balanced mix that ensures strength, durability, permeability, and workability for diverse construction applications.

Considering the intricate relationship between water content and the resulting properties of pervious concrete, this study on the effect of aggregate size in pervious concrete pavement aims to delve deeper into understanding how variations in water-to-cementitious materials ratios might influence the material's porosity, permeability, and strength. This investigation will contribute to a clearer comprehension of the ideal mix designs essential for optimizing the performance of pervious concrete in stormwater management applications.

Figure 4.2: Samples of pervious concrete with different water contents, formed into a ball: (a) too little water, (b) proper amount of water, and (c) too much water.

4.2.5 Admixtures

Chemical admixtures are used in pervious concrete to give it special properties, such as controlling setting time and increasing workability. The type and amount of admixture used can significantly affect the workability of the concrete. Some common admixtures used in pervious concrete include such as Superplasticizers (SPs).

4.2.6 Silica Fumes

Silica fume is a fine, amorphous powder that is a by-product of the production of silicon and ferrosilicon alloys in electric arc furnaces. It's made up of spherical particles that are 100 to 150 times smaller than a grain of cement, with an average diameter of 150 nanometers. Silica fume is also known as microsilica.

The advantages of silica fume include significantly increasing concrete strength, a reduction in concrete bleeding and segregation (although this increases the need for proper curing), improved resistance to chemically-aggressive environments, and inhibition of alkali-silica reactions, which can severely damage concrete structures.

Silica fume is used in concrete to improve its durability and damage resistance. It has several properties that can benefit concrete, including:

- Compressive strength: Silica fume increases concrete's compressive strength.
- Durability: Silica fume provides corrosion resistance against iron attacks and chemical salts.
- Abrasion resistance: Silica fume increases concrete's abrasion resistance, except when exposed to organic acids.
- Permeability: Silica fume concrete has lower permeability than conventional concrete because its fine particles fill voids and capillary pores.
- Early strength: Silica fume increases concrete's early strength by consuming calcium hydroxide produced during cement hydration.

  However, concrete containing silica fume has some disadvantages, including:

- Plastic shrinkage: Concrete with silica fume is more likely to experience plastic shrinkage because of its low bleeding rate.
- Workability: Concrete with silica fume is difficult to plaster and vibrate into a close-grained texture, which can make the concrete surface less smooth and uniform.

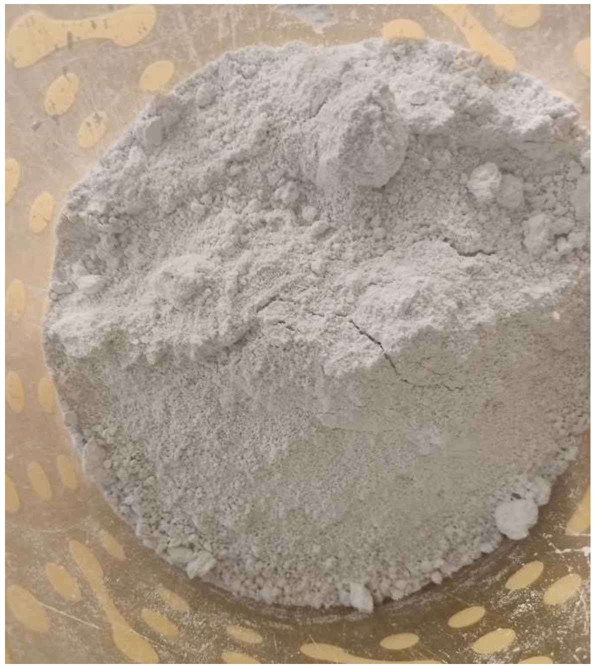

Figure 4.3: Silica Fumes

4.3 Tests

4.3.1 Tests on cement

Laboratory tests on cement for pervious concrete are crucial to assess its quality, performance, and suitability for creating the desired porous structure. These tests determine the cement's hydration characteristics, setting time, and strength development, ensuring it effectively binds the aggregates to form the porous matrix. Evaluating the cement properties through lab tests aids in fine-tuning mix designs, determining the optimal water-to-cement ratio, and validating the material's ability to facilitate water permeability. This meticulous analysis guarantees the cement's compatibility with the specific requirements of pervious concrete, contributing to durable pavements that effectively manage stormwater while upholding structural integrity.

4.3.1.1 Fineness test of cement

The fineness test for cement holds significant importance in pervious concrete. It determines the particle size distribution in cement, impacting the concrete's permeability and strength. In pervious concrete, fine particles affect the pore structure, potentially influencing porosity and permeability. Finer cement particles facilitate improved paste coating around aggregates, enhancing overall strength and durability. Optimal fineness aids in achieving a balanced permeability without compromising structural integrity, crucial for pervious concrete's functionality in allowing water passage while maintaining necessary strength for load-bearing applications. Therefore, ensuring the right fineness of cement is pivotal for achieving the desired properties in pervious concrete.

Aim: To evaluate the fineness of cement utilising an IS sieve with a 90 m opening in accordance with the requirements of IS: 4031 (Part 1) – 1996.

Apparatus:

- 90µm IS Sieve,
- Weight Balance has a capacity of 10 mg to 100 g,
- Nylon or pure bristle brush

Figure 4.4: Apparatus for fineness Test

Procedure:

- Get a sample of the cement, and then work it in between your fingers. The sample that is being tested for fineness should be completely lump-free.
- Take a sample of cement weighing one hundred grams and record it as the W1 weight.

- Place one hundred grams of cement in a sieve with a mesh size of ninety microns and cover it with the lid.
- Now, using your hands and moving the sieve in circular and linear motions for fifteen minutes, shake the sieve to remove any debris.
- After that, W2 is equal to the weight of the cement that passes through the sieve with a particle size of 90 microns. The formula to calculate the fineness of cement is presented in the following:

Fineness = $\frac{W2}{W1}$ X100

After that, compute the percentage of the cement's weight that was kept on the sieve.

Carry out the method with each of the three distinct samples of cement and then take the average of the findings to ensure accuracy

The calculation of cement's degree of fineness **(Table 4.2):**

Sr. No.	**Weight of cement sample**	**Weight of residual on 90u sieve**	**Fineness of cement**
01	100 gm	4.65 gm	4.65%
02	100 gm	8.25 gm	8.25%
03	100 gm	7.95 gm	7.95%
		Average	**6.95%**

According to the IS recommendations, the standard value of fineness of cement should have a fineness that is less than 10%, or the fineness of cement should not be higher than 10%.

4.3.2 Tests on Aggregate

Aggregate tests play a crucial role in ensuring the quality and performance of pervious concrete, a type of concrete specifically designed to allow rainwater to infiltrate through its interconnected voids. These tests evaluate various properties of the aggregates, such as gradation, strength, durability, and cleanliness, ensuring that they meet the specified requirements for pervious concrete applications.

4.3.2.1 Water absorption test:

The water absorption test for aggregates is a method used to determine the amount of water absorbed by aggregates under specific conditions. The process involves soaking the aggregate in water for a specific duration, allowing the material to saturate. After a designated period, the excess water is drained, and the aggregates are surface-dried to remove any water not absorbed. The weight of the damp aggregates is measured. The water absorption is then calculated as the ratio of the weight of water absorbed to the dry weight of the aggregate. This test is crucial in evaluating the quality of aggregates for concrete production, as high water absorption can impact the workability, strength, and durability of concrete mixtures.

4.3.2.2 Aggregate Crushing Test:

The strength of aggregate is defined as the resistance of the aggregate against gradual loading. The strength of aggregate is determined by the Crushing Value Test on aggregates. The aggregates passing through a 12.5 mm IS sieve and retained on a 10 mm IS sieve are taken. These aggregates are subjected to gradual loading of 40 tonnes with the help of a plunger.

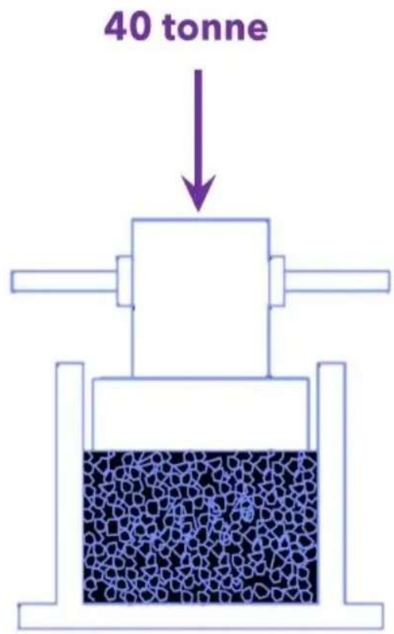

Figure 4.5: Aggregate Crushing Test

The crushed aggregates are then passed through a 2.36 mm sieve. The weight of the aggregates passing through the 2.36 mm sieve, expressed as the percentage of the total weight of aggregates, is referred to as Aggregate Crushing Value (ACV). Lesser is the ACV, more will be the strength of aggregate. ACV less than 10 indicates exceptionally strong aggregate whereas, ACV greater than 35 indicates weak aggregate.

Aggregate Crushing Value (ACV) =weight of material passing through 2.36 mm sieve/ weight of total aggregate

4.3.2.3 Aggregate Impact Test

The toughness of the aggregate is defined as the ability to resist impact loading. The toughness of the aggregate is determined by Impact Value Test on aggregates. The aggregates passing through a 12.5 mm IS sieve and retained on a 10 mm IS sieve are taken. This sample of aggregate is subjected to 15 blows with the help of a metallic hammer having a mass of 13.5-14 kg, free-falling from a height of 38 cm.

Figure 4.6: Aggregate Impact Test

The aggregates after impact are passed through the sieve of size 2.36 mm. The weight of aggregates passing through the 2.36 mm sieve, expressed as the percentage of the total weight of aggregates is referred to as Aggregate Impact Value (AIV). Lesser is the AIV, more will be the toughness of the aggregate. The AIV of aggregate should not exceed 30% for wearing course, 35% for bituminous macadam and 40% for water-bound macadam.

Aggregate Impact Value (AIV)=weight of material passing through 2.36 mm sieve/weight of total aggregate

4.3.2.4 Aggregate Abrasion Test

Hardness is the property of aggregate that allows it to withstand wear and tear (abrasion). The hardness of the aggregates can be determined by Deval Abrasion Test, Dorry's Abrasion Test and Los Angeles Abrasion Test. The Los Angeles Abrasion Test on aggregates is the standardized method for determining the hardness of aggregates in India. In this test, aggregates passing through a 12.5 mm sieve and retained on a 10 mm sieve are placed in a cylinder having steel balls in it. The sample is subjected to abrasion by rotating the cylinder 500 times at the speed of 30 to 33 rpm.

Figure 4.7: Aggregate Abrasion Test

The aggregates after the test are passed through a 1.7 mm sieve and the weight of the aggregates passing through the sieve is noted, which when expressed in terms of percentage of the total weight of aggregates is referred to as Aggregate Abrasion Value. Lesser abrasion value means more hardness of aggregate. Abrasion value should not exceed 35% for bituminous macadam and 40% for WBM base course.

Los Angeles Abrasion Value =weight of material passing through 1.7 mm sieve/weight of total aggregate

4.4 Methodology

4.4.1 Introduction

The term pervious concrete typically describes a zero slump, open graded material consisting of Portland cement, coarse aggregate, little or no fine aggregate, admixture and water. The combination of these ingredients will produce a hardened material with connected pores that allow water to pass through easily. The void content can range from 15-35% with typical compressive strength of 5 MPa to 25 MPa. The drainage rate of pervious concrete pavement will vary with aggregate size and density of the mixture and will generally fall in the range of 0.135 to 1.22 cm/sec. Higher the fine content lesser will be the void contents and permeability. The concrete with low void contents are prone to clogging by water containing soil particles.

4.4.2 Materials

Pervious concrete is composed of cement or a combination of cement, coarse aggregate, and water. A small amount of fine aggregate may be incorporated to increase compressive strength. All materials should conform to the appropriate IS Specifications. A combination of cementitious materials that each conform to the appropriate IS Specifications can be used. Chemical admixtures are commonly used to improve various characteristics of pervious concrete. They should meet the appropriate IS Specifications or other Specifications that produce an acceptable mixture.

4.4.3Flow chart showing methodology of making Pervious concrete (Figure 4.8)

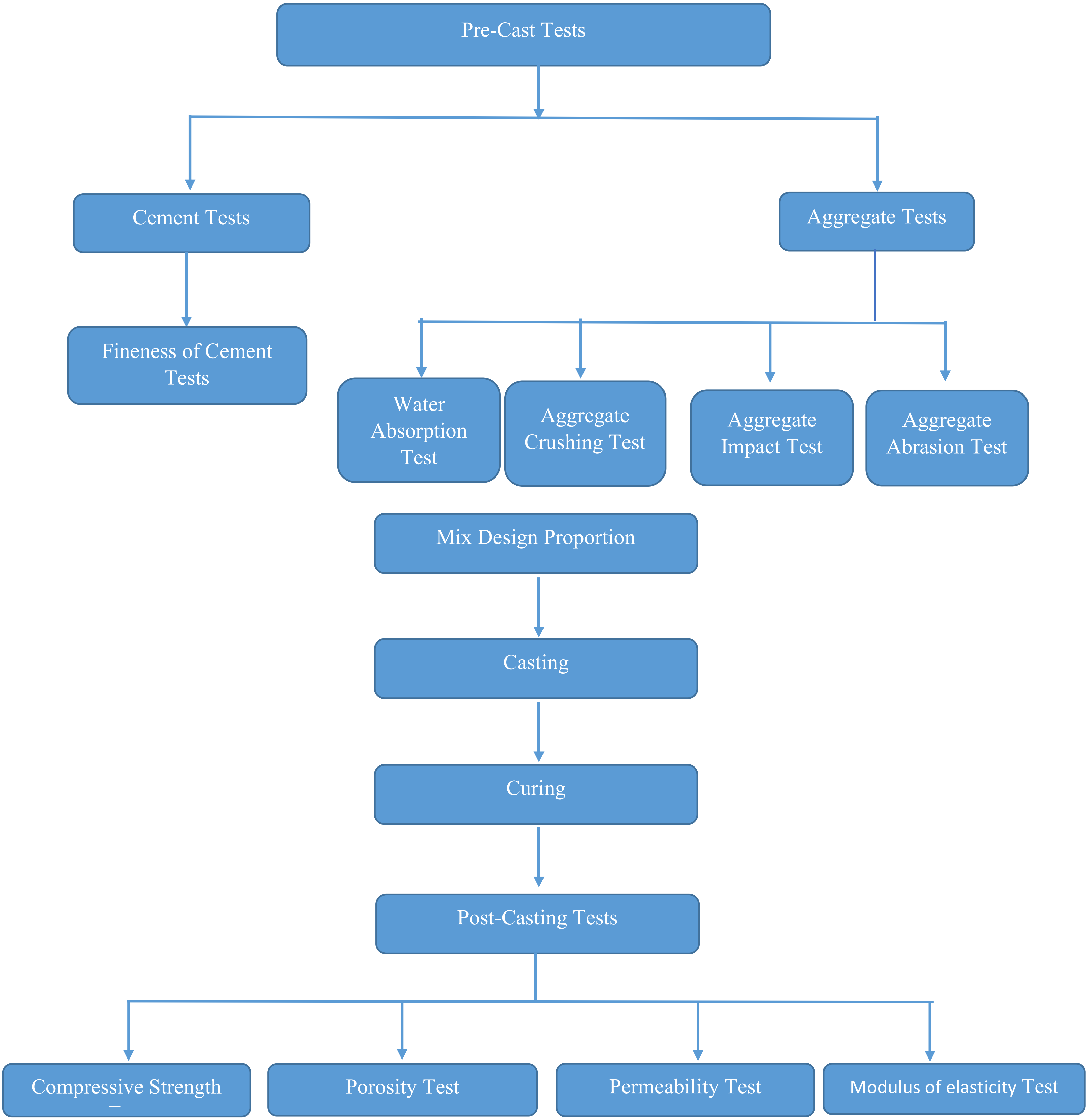

Figure 4.8: Methodology of making pervious concrete

4.4.3 Materials

Pervious concrete is composed of cement or a combination of cement, coarse aggregate, and water. A small amount of fine aggregate may be incorporated to increase compressive strength. All materials should conform to the appropriate IS Specifications. A combination of cementitious materials that each conform to the appropriate IS Specifications can be used. Chemical admixtures are commonly used to improve various characteristics of pervious concrete. They should meet the appropriate IS Specifications or other Specifications that produce an acceptable mixture.

4.4.4 Mix Proportioning

4.4.4.1 Data for mix proportioning

The following data are required for mix proportioning of a particular grade of pervious concrete: a) Grade designation (required compressive strength) b) Range of water permeability c) Type of cement d) Maximum nominal size of aggregate e) Whether a chemical admixture shall or shall not be used and the type of chemical admixture and the extent of use. f) Whether a mineral admixture shall or shall not to be used and the type of mineral admixture and the extent of use.

4.4.4.2 Target strength for mix proportioning

In order that not more than the specified proportions of test results are likely to fall below the characteristic strength, the concrete mix has to be proportioned for higher target mean compressive strength (f'_{ck}). The margin over characteristic compressive strength is given by the following relation:

$\mathbf{f'_{ck} = f_{ck} + 1.65 \times (S_c)}$ …………………………..Eq-4.1

Where: f'_{ck} = target mean compressive strength at 28 days, N/mm^2

f_{ck}= characteristic compressive strength at 28 days, N/mm^2

S_c = standard deviation of compressive strength, N/mm^2

4.4.4.3 Assumed standard deviation

Where sufficient test results for a particular grade of concrete are not available the value of standard deviation given in Table 3 for mix designs based on compressive strength may be assumed for proportioning of mix.

Table 4.3: Assumed Standard Deviation Values for mix designs based on compressive strength (considering good quality control)

Sl. No.	Grade of concrete	Assumed Standard Deviation (N/mm^2)
01	M 10	2.5
02	M 15	3.0
03	M 20	4.0

4.4.4.4 Selection of water- cementitious materials ratio

The water-cementitious material ratio (w/cm) is an important consideration for obtaining desired strength and void structure in pervious concrete. A high w/cm reduces the adhesion of the paste to the aggregate and causes the paste to flow and fill the voids even when lightly compacted. A low w/cm will prevent good mixing and tend to cause balling in the mixer, prevent an even distribution of cement paste, and therefore reduce the ultimate strength and durability of the concrete. Experience has shown that w/cm in the range of 0.26 to 0.45 will provide the best aggregate coating and paste stability. The conventional w/cm-versus compressive strength relationship for normal concrete does not apply to pervious concrete. Careful control of aggregate moisture and w/cm is important to produce consistent pervious concrete.

4.4.4.5 Void content

To ensure the water will percolate through pervious concrete, the void content should be 15 per cent or greater, as given in Table 4. If void content is lower than that of 15 per cent, there is no significant percolation thought the concrete and there is not sufficient interconnectivity between the voids to allow for rapid percolation. Higher the void content, higher is the percolation rate and lower is the compressive strength. The lower the void content, lower is the percolation rate and higher the compressive strength. The compressive strength increases as the nominal maximum-size aggregate decreases. Compressive strength of pervious concrete is also a function of the aggregate strength, paste bonding characteristics, and strength of the cement paste itself. Some caution should be used when applying these quantitative numbers to practical design, as standardize methods do not yet exist for these properties of pervious concrete; prior discussion should be taken as purely qualitative.

Void content can be calculated by using Table 4.4 and Table 4.5 as void ratio will be average of voids obtained from percolation criteria and compressive strength criteria

Table 4.4: Estimation of Approximate Void Content for Different Rates of Percolation (Percolation Rate as Measured by Permeability Test Method)

Percolation (mm/min)	Void content, per cent by volume
50	15
150	20
350	25
1000	30
2250	35

Table 4.5: Estimation of Approximate Void Content for Different Strength of Pervious Concrete

Compressive Strength (MPa)		Void content, per cent by volume
19 mm MSA	9.5 mm MSA	
5	8	30
10	12	25
15	18	20
20	23	15

4.4.4.6 Estimation of paste volume (V_p), cement (c), and water content (w)

The proportioning of pervious concrete seeks to establish the minimum volume of paste necessary to bind aggregate particles together, while maintaining the necessary void structure, strength, and Table 4.6 can be used to estimate the volume of the paste for a mixture using maximum size of aggregate 9.5 mm.

Table 4.6: Estimation of Paste Content Using Void Content Value for MSA 9.5 mm Aggregate

Void content, per cent by volume	Paste volume, per cent by volume	
	for well compacted pervious concrete	for lightly compacted pervious concrete
15	18	25
20	15	22
25	10	17
30	5	14

The above value of paste volume is for the mixes having no fine aggregate. When the fine aggregate is used, the paste volume should be reduced by 2 per cent for each 10 per cent fine aggregate of the total aggregate for well compacted pervious concrete and by 1 per cent for each 10 per cent fine aggregate of the total aggregate for lightly compacted pervious concrete. These reductions are necessary to maintain the same per cent voids by volume.

Light compaction - Compact the concrete in three equal layers by the rammer of 2.6 kg and free fall 31 cm with 25 evenly distributed blows in each layer of 10 cm diameter mould and 56 blows for 15 cm diameter mould.

Heavy compaction - In this we compact the pervious concrete using the rammer of mass 4.89 kg and free fall 45 cm in five layers, each layer being given 25 blows for 10 cm diameter mould and 56 blows for 15 cm diameter mould.

Once the paste volume is determined from Table 4.6, and the w/cm selected, the cement and water quantities can be determined from the following absolute volume relationships:

Paste volume Vp = cement volume + water volume

$$Vp = \frac{c}{3.15*1000} + \frac{w}{1*1000} \text{ (kg/m}^3\text{)}$$

Substituting w= (w/c)*c,

$$Vp = \frac{c}{3.15*1000} + \frac{\left(\frac{w}{c}\right)*c}{1*1000} \text{ (kg/m}^3\text{)} \text{ ....Eq-4.2}$$

c can be determined quickly by trial and error on spreadsheet or algebraically reduced to

$$c = \frac{Vp}{0.315+\left(\frac{w}{c}\right)} X1000 \text{ (kg/m}^3\text{) .... Eq.-4.3}$$

Therefore, once the paste volume is determined from Table 6, and the w/cm is selected, the mass of cement can be calculated from Eq. From the mass of cement, the water content can be computed.

4.4.4.7 Estimation of coarse aggregate proportion

With the completion of procedure given above, all the ingredients have been estimated except the coarse aggregate content. The absolute volume of pervious concrete shall be determined by subtracting the volume of voids from the unit volume. The volume of cementitious material, water and the chemical admixture shall be determined by dividing their mass by their respective specific gravity and multiplying by 1/1000. The volume of aggregate shall be determined by subtracting the volume of cementitious material, water and chemical admixture from the absolute volume of pervious concrete. The value so obtained is then multiplied by specific gravity of coarse aggregate and multiplied by 1000 to obtain the mass of coarse aggregate

4.4.4.8 Trial mixes

Minimum three trials shall be conducted with paste content determined as above and ± 10 per cent paste content. Cylinder specimens of size 100 mm x 200 mm or 150 mm x 300 mm (3 for each trial) shall be cast for permeability testing (as per procedure given in Annexure A) and concrete cubes of size 150 mm x 150 mm x 150 mm shall be cast for compressive strength (to be tested as per procedure similar to IS:516). Testing to be done after 7-Day/28-Day water curing as per specifications.

4.4.5 Overview of the Tests Conducted on Pervious concrete

Both tests are essential for evaluating different properties of pervious concrete. The permeability test assesses its ability to allow water to flow through, a vital characteristic for drainage and environmental purposes. On the other hand, the compressive strength test determines its load-bearing capacity, providing insight into its suitability for structural applications.

Compressive Strength Test on Pervious Concrete: The compressive strength test is used to evaluate the load-bearing capacity of pervious concrete. It involves subjecting cylindrical or cubic specimens of pervious concrete to increasing compressive loads until failure occurs. The maximum load-bearing capacity at the point of failure determines the compressive strength. This test is crucial for assessing the structural integrity and load-bearing capacity of the concrete.

Permeability Test on Pervious Concrete: The permeability test on pervious concrete measures its ability to allow water to pass through. This test involves applying a certain pressure and measuring the flow rate of water passing through a specific area of the concrete sample. The primary methods for conducting permeability tests include constant head tests or falling head tests. Both methods involve applying water pressure and observing how quickly water passes through the concrete sample.

Both tests are essential for evaluating different properties of pervious concrete. The permeability test assesses its ability to allow water to flow through, a vital characteristic for drainage and environmental purposes. On the other hand, the compressive strength test determines its load-bearing capacity, providing insight into its suitability for structural applications.

4.4.6 Compressive strength test

A compression Testing Machine (CTM) is used to measure the compressive strength of a material. The CTM is designed to apply a compressive load to the sample until it fails. The machine consists of a piston that moves up and down inside a cylinder, applying the load to the sample.
The CTM machine is used in construction industries to test the quality of concrete. The compressive strength of concrete is determined by testing concrete cubes or cylinders using the CTM machine. The CTM machine can also be used to test the compressive strength of other materials such as bricks, rocks, and metals.

Figure 4.9: Compression Testing Machine

Procedure for Cube Test

1. Remove the specimen from the water after specified curing time and wipe out excess water from the surface.

2. Take the dimension of the specimen to the nearest 0.2m

3. Clean the bearing surface of the testing machine

4. Place the specimen in the machine in such a manner that the load shall be applied to the opposite sides of the cube cast.

5. Align the specimen centrally on the base plate of the machine.

6. Rotate the movable portion gently by hand so that it touches the top surface of the specimen.

7. Apply the load gradually without shock and continuously at the rate of 140 kg/cm2/minute till the specimen fails

8. Record the maximum load and note any unusual features in the type of failure.

Note: Minimum three specimens should be tested at each selected age. If the strength of any specimen varies by more than 15 percent of average strength, the results of such specimens should be rejected. The average of three specimens gives the crushing strength of cube. The strength requirements of concrete.

Compressive Strength Formula:

Compressive strength formula for any material is the load applied at the point of failure to the cross-section area of the face on which load was applied.

Compressive Strength = $\frac{Load}{Cross\ sectional\ area}$ ………………………Eq-4.4

4.4.7 Modulus of elasticity of Pervious concrete Test

The Modulus of elasticity modulus test serves as a fundamental tool in assessing the mechanical properties of various materials, including soils, aggregates, and asphalt concrete. Its primary application lies in evaluating the material's ability to withstand deformation under load and recover its original shape once the load is removed.

The Modulus of elasticity modulus test is frequently used in evaluating the mechanical properties of pervious concrete. Pervious concrete is unique compared to traditional concrete due to its porous nature, which allows water to pass through it. Consequently, its mechanical behaviour, such as its ability to withstand load and deformation, differs from that of conventional concrete.

The Modulus of elasticity test in pervious concrete used because it assesses its ability to recover its original shape after deformation. This is crucial for applications such as pavements, where the material must endure repetitive loading cycles while maintaining its structural integrity.

Breaking down the components of the Modulus of elasticity test for pervious concrete:

LVDT (Linear Variable Differential Transformer): The LVDT is a type of sensor commonly used in materials testing to measure displacement or strain. In the context of a Modulus of elasticity test for pervious concrete, the LVDT is used to measure the deformation or strain of the specimen under load. It consists of a primary coil and two secondary coils wound on a hollow form, and a ferromagnetic core. As the core moves within the coil, it induces a differential voltage output proportional to its displacement.

Load Cell: A load cell is an electronic device used to convert a force into an electrical signal. In the Modulus of elasticity test, the load cell is employed to measure the load applied to the pervious concrete specimen during the test. It provides accurate and precise measurements of the applied force, allowing for the calculation of stress on the specimen.

Test Procedure:

- Preparation: Prepare the pervious concrete specimen according to standard procedures, ensuring proper dimensions (Height=200mm and Diameter=100mm), and compaction.

- Setup: Place the specimen in the testing apparatus, ensuring proper alignment and support.
- LVDT Calibration: Calibrate the LVDT to establish a reference point for measuring deformation.
- Load Application: Apply load gradually to the specimen using the testing machine equipped with the load cell. Incrementally increase the load in predetermined increments.
- Data Collection: Simultaneously record the applied load (force) from the load cell and the corresponding deformation (strain) from the LVDT at each load increment.
- Unload: After reaching the maximum load, gradually unload the specimen while continuing to record the load and deformation.
- Data Analysis: Calculate the Modulus of elasticity of the pervious concrete specimen using the collected data, typically by plotting stress vs. strain curves and performing regression analysis.

Data Logger, Graph, and Data:

- Data Logger: Use a data logger to collect and store the load and deformation data automatically throughout the test. The data logger ensures accuracy and consistency in data collection.
- Graph: Plot the stress vs. strain curve using the collected data. This graph illustrates the behaviour of the pervious concrete under load, showing the relationship between applied force and deformation.
- Data Analysis: Analyse the plotted curve to determine key parameters such as Modulus of elasticity, which quantifies the material's ability to recover its original shape after deformation. Additionally, other parameters like stiffness and resilience can be derived from the curve.
- Data Interpretation: Interpret the test results in the context of the material's performance and suitability for specific applications, such as pavement design or erosion control.

By following this procedure and utilizing the LVDT, load cell, and data logging equipment, engineers can accurately assess the mechanical properties of pervious concrete and optimize its design and application.

4.4.8 Porosity test

The porosity was determined by the water displacement method using ASTM C1754 (2012). In this method, the porosity was estimated by measuring the difference between the dry weight and the submerged weight. After proper curing underwater, the submerged weight of the samples was taken, and then the samples were allowed to dry for at least 24 hours in a controlled oven at a temperature of 110°C. The porosity was calculated using the formula given below.

$$\emptyset = \left[1 - \frac{(A-B)}{\rho_w \times D^2 \times L}\right] \times 100 \text{.........Eq-4.5}$$

Where Φ = porosity of the mix, A dry weight of the specimen; B = submerged weight of the specimen; p density of water, D average diameter of the specimen; L length of the specimen.

4.4.9 Determination of Permeability

The falling head method (FHM) is a pressure-decay method used to test the water permeability of pervious concrete. The FHM involves the flow of water through a soil sample connected to a standpipe, which provides the water head and measures the volume of water passing through the sample. Figure shows the diagram of the permeability test setup. water heads were adopted for measuring permeability of pervious concrete. For measuring permeability of pervious concrete cylinder of size 200 x 100 mm are casted. Cylinders are casted and we use cello tape to cover the outside voids so that water does not come from side pores. In this study permeability of pervious concrete is measured at the end of the 28 days. Permeability of pervious concrete is calculated using equation 1.

$$\mathbf{K} = \frac{A_1 L}{A_2 t} \log \frac{h_1}{h_2} \text{...................... Eq-4.6}$$

Where,

K = Water permeability

A_1 = Cross-sectional area of the specimen

A_2 = Cross-sectional areas of the tube

L = Length of the specimen

T = Time

h_1 = initial water head

h_2 = final water head

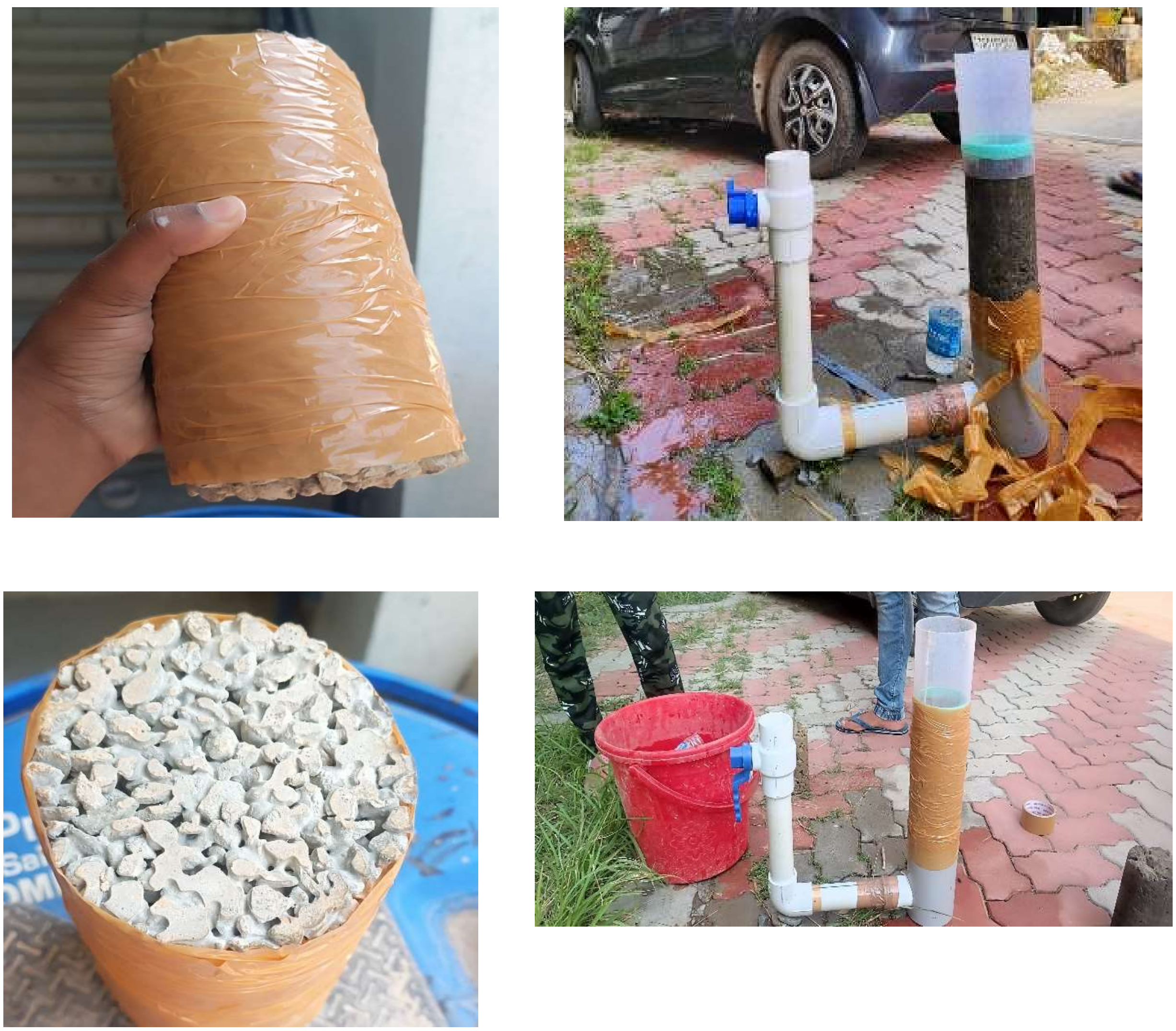

Figure 4.10: Permeability test setup by Falling Head Method (IS 3085:1965)

4.5 References

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- IRC 44:2017- Guidelines for Cement Concrete Mix Design For Pavements.
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Chapter 5

Experimental Investigation

5.1 Sieving of aggregate

- Utilized four different sieve sizes: 19 mm, 12.5 mm, 9.5 mm, and 4.75 mm for the sieve analysis process.
- Prepared three pervious concrete samples by casting each sample with aggregates meeting specific passing and retention criteria based on the sieve sizes.
- The first sample comprised aggregates that passed through the 19 mm sieve but were retained on the 12.5 mm sieve.
- The second sample consisted of aggregates passing through the 9.5 mm sieve but retained on the 4.75 mm sieve.
- The third sample was crafted using 50% of aggregate that passed through 19mm sieve and retained on 12.5mm sieve and 50% aggregate that pass through 9.5 mm sieve but retained on the 4.75 mm sieve.

Figure 5.1: Sieving of aggregate

This approach enabled the evaluation and segregation of aggregates based on distinct particle sizes, facilitating the creation of unique pervious concrete samples and to observe the variation in compressive strength and permeability of the sample with different gradation of aggregate. The variation in particle size distribution aimed to analyse the impact of different aggregate distributions on the properties of the pervious concrete samples.

5.2 Calculations of mix design

Assuming,

- Void=15%
- $\left(\frac{water}{cement}\right)$= 0.3
- Sand=10%

Calculating Paste volume from Table 4.6 (for 15% void and lightly compacted)

- Paste volume (V_p)= (25-1)%=24%

From Eq.-4.3 we got:

- Weight of cement= 388.68 kg/m^3

For cube of size (150*150*150) mm^3

- Weight of cement= 1.312 kg

For cylinder of height 200mm and diameter 100mm

- Weight of cement=0.610 kg

Total weight of cement= (1.312+0.610) =1.922 kg

Using water-cement ratio we got

- W=0.576 kg

Now calculating volume of coarse aggregate and fine aggregate using **4.4.4.7**

- Weight of coarse aggregate=5.002 kg
- Weight of fine aggregate=0.556 kg

Using admixture as 1% of cementitious material

- Admixture=8.0032 gram

Using silica fumes as 7%

- Silica fumes=134.54 gram

5.3 Casting procedure

- We begin the casting procedure by greasing the cube mould (150mm x 150mm x 150mm) to prevent the concrete from sticking to its sides.
- Required weights of cement, aggregates, water, admixture and silica fumes are calculated as shown above according to the specific proportions needed. We take all materials and mix these materials thoroughly.
- The thoroughly mixed concrete is gently poured into the greased cube mould by ensuring that it's poured evenly and without air gaps.
- The mixture is poured in the cube in three layers, lightly compacting each layer. This helps remove air bubbles and ensures a well-packed concrete mix.
- The top surface of the concrete cube is made flat and even by scraping off excess material with a trowel or any flat tool.
- After levelling, the concrete-filled cube mould is allowed to rest and set. This setting period allows the concrete to solidify and gain strength.

Figure 5.2: Mixing and placing

5.4 Curing

- Once the concrete cube is cast, it's left to set for 24 hours and then demoulded
- After the initial 24-hour setting period, the concrete cube is placed in water for curing. This process helps the concrete gain strength and durability.
- The cube is then subjected to compressive strength tests after 7 and 28 days. These tests help evaluate how strong the concrete has become over time.
- Additionally, a permeability test is conducted. This test assesses how easily water can pass through the concrete, providing insights into its porosity and drainage capabilities.

Figure 5.3: Curing

By conducting these tests at different intervals after casting, we assess the concrete's strength development and its ability to allow water to pass through, both are essential factors in assessing its quality and performance.

5.5 Compressive strength, Permeability and Porosity test of cast specimen

- Sample 1 of Aggregate size 19mm passing and 12.5mm retaining

Table 5.1: Compressive Strength variation of Sample-1 (with Silica Fumes)

Specimen 1	7 days strength (MPa)	28 days strength (MPa)
1	11	16.1
2	15	17.2

Table 5.2: Compressive Strength variation of Sample-1 (without Silica Fumes)

Specimen 1	7 days strength (MPa)	28 days strength (MPa)
1	10.1	11.2
2	12.5	16.3

Permeability: 1.106cm/s

Porosity=19%

Figure 5.4: Casting and Compressive Strength Test of Sample 1

- Sample 2 of Aggregate size 9.5mm passing and 4.75mm retaining

Table 5.3: Compressive Strength variation of Sample-2 (with Silica Fumes)

Specimen	7 days strength (MPa)	28 days strength (MPa)
1	13.77	18.28
2	14.7	19.1

Table 5.4: Compressive Strength variation of Sample-2 (without Silica Fumes)

Specimen	7 days strength (MPa)	28 days strength (MPa)
1	12.46	16.2
2	12.8	18.1

Permeability: 0.726cm/s

Porosity=16%

Figure 5.5: Casting and Compressive Strength Test of Sample 2

- Sample 3 of Aggregate size 50% passed through 19mm sieve and retained on 12.5mm sieve and 50% that pass through 9.5 mm sieve but retained on the 4.75 mm sieve

Table 5.5: Compressive Strength variation of Sample-3 (with Silica Fumes)

Specimen	7 days strength (MPa)	28 days strength (MPa)
1	16.2	23
2	17.3	25.1

Table 5.6: Compressive Strength variation of Sample-3 (without Silica Fumes)

Specimen	7 days strength (MPa)	28 days strength (MPa)
1	14.4	21.7
2	15.3	22.3

Permeability: 0.3cm/s

Porosity=12.5%

Figure 5.6: Casting and Compressive Strength Test of Sample 3

5.6 Modulus of elasticity Test

The Modulus of elasticity test is a fundamental material property used to characterize the stiffness of unbound and bound pavement materials, including asphalt mixtures. It is a measure of a material's "elastic" behaviour, or load-unload response, under different conditions.

Figure 5.7: Modulus of elasticity Test Apparatus and failure of specimen

Sample 1 of Aggregate size 19mm passing and 12.5mm retaining

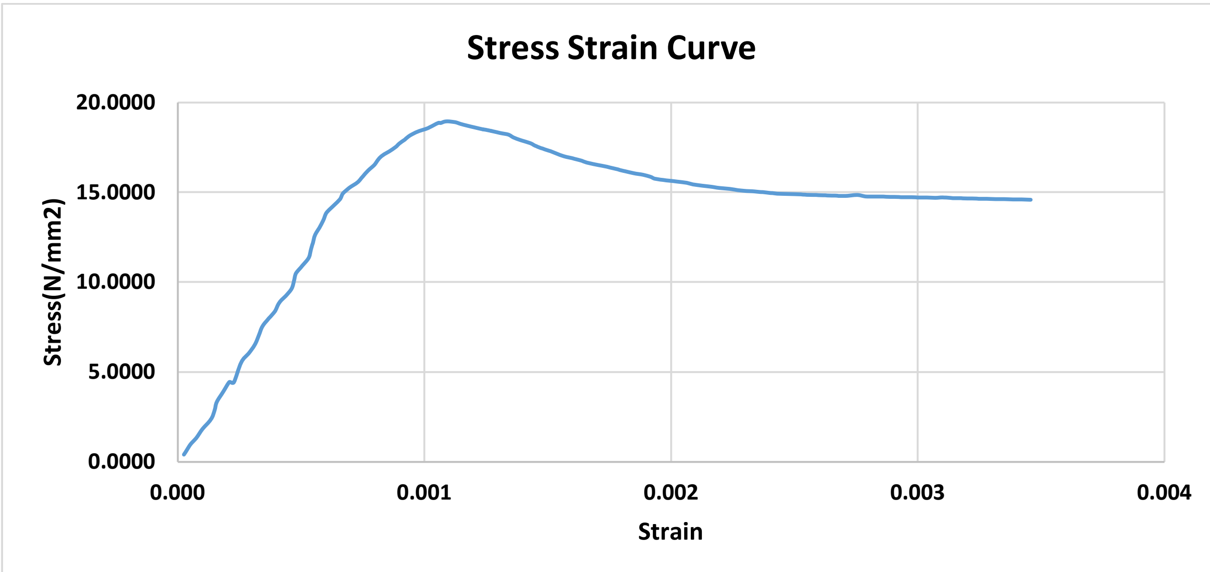

Figure 5.8*:* Stress Strain Curve of Sample - 1

Table 5.7: Modulus of elasticity of Sample-1:

Stress(N/mm^2)	8.864
Strain	0.0004
Modulus of elasticity (N/mm^2)	21551.21

Sample 2 of Aggregate size 9.5mm passing and 4.75mm retaining

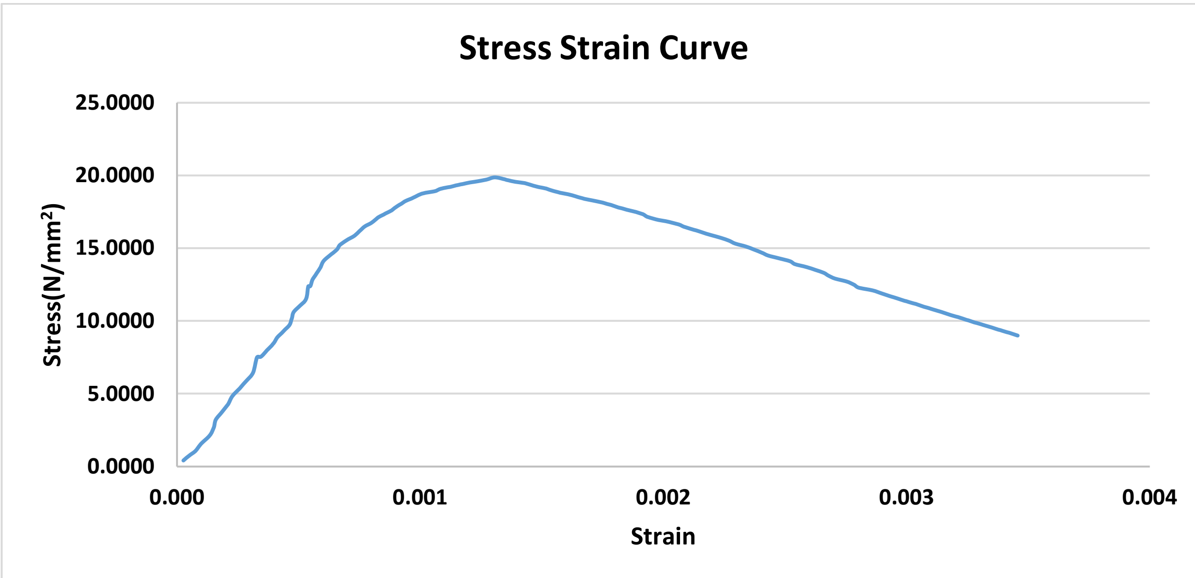

Figure 5.9: Stress Strain Curve of Sample – 2

Table 5.8: Modulus of elasticity of Sample-2:

Stress(N/mm^2)	12.3781
Strain	0.00054
Modulus of elasticity (N/mm^2)	22970.04

Sample 3 of Aggregate size 50% passed through 19mm sieve and retained on 12.5mm sieve and 50% that pass through 9.5 mm sieve but retained on the 4.75 mm sieve

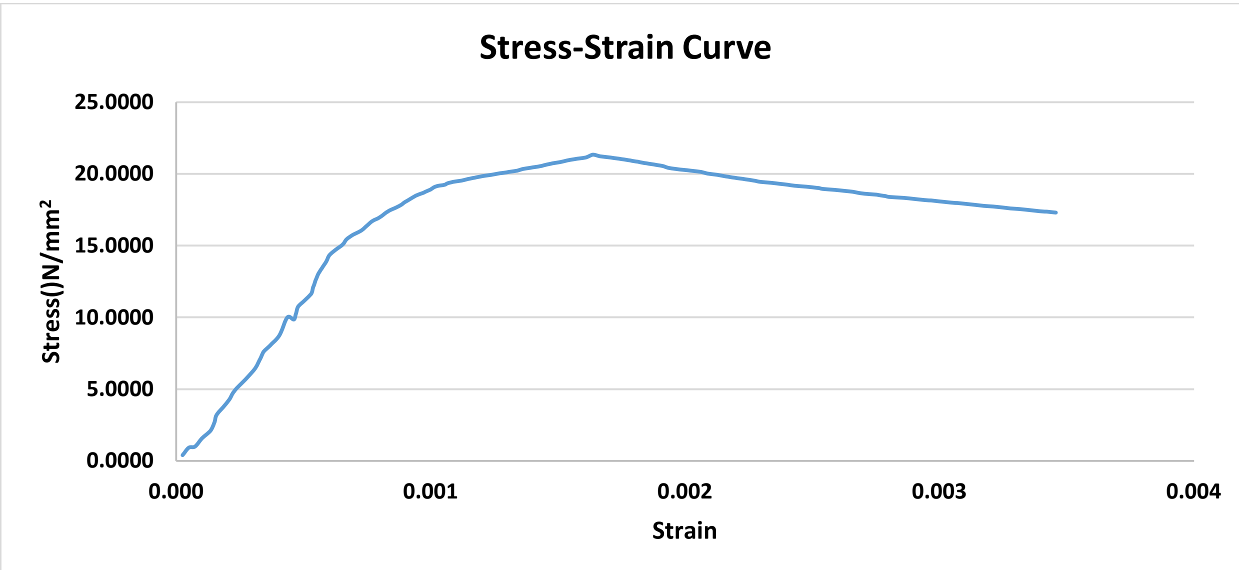

Figure 5.10: Stress Strain Curve of Sample – 3

Table 5.9: Modulus of elasticity of Sample-3:

Stress(N/mm^2)	12.9429
Strain	0.00055589
Young's modulus(N/mm^2)	23283.34251

Chapter 6

Results

The following table presents the compressive strength values at 7 days and 28 days for samples without silica fumes, as well as samples with silica fumes. Additionally, it includes permeability and porosity values, along with Young's modulus for each sample. Sample 1 consists of aggregate sizes passing 19mm and retaining 12.5mm, Sample 2 has aggregate sizes passing 9.5mm and retaining 4.75 mm, and Sample 3 comprises a blend of aggregate sizes, with 50% passing through a 19mm sieve and retaining on a 12.5mm sieve, and the remaining 50% passing through a 9.5mm sieve but retaining on a 4.75mm sieve.

Table 6.1: Variation of different parameters with Aggregate Size

Samples	Compressive Strength (MPa)				Permeability (cm/s)	Porosity	Young's Modulus (N/mm^2)
	Without Silica Fumes		With Silica Fumes				
	7 days	28 days	7 days	28 days			
Sample-1	11.3	13.75	13	16.65	1.106	19%	21551.21
Sample-2	12.63	17.15	14.24	18.69	0.726	16%	22970.04
Sample-3	14.85	22	16.75	24.05	0.3	12.5%	23283.34

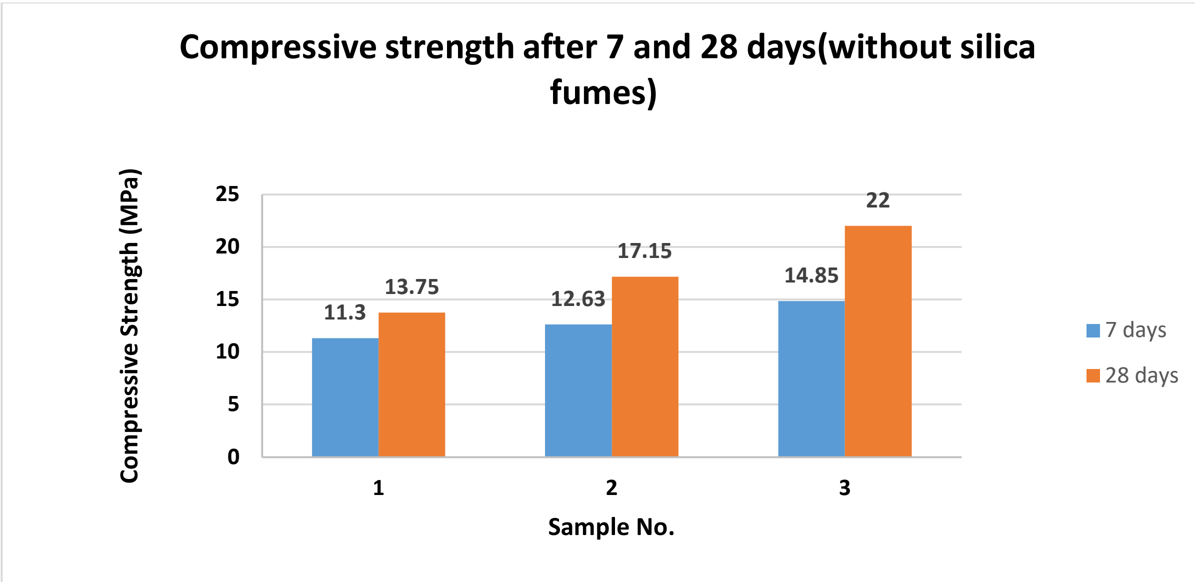

Fig 6.1: The graph illustrates the changes in compressive strength at both 7 days and 28 days for samples without silica fumes.

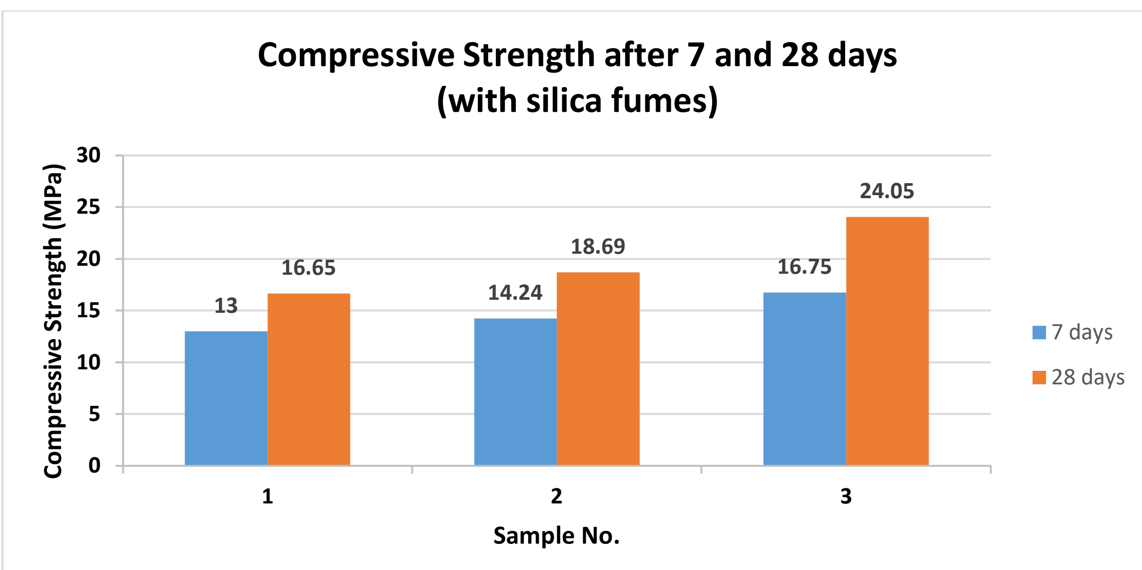

Fig 6.2: The graph illustrates the changes in compressive strength at both 7 days and 28 days for samples with silica fumes.

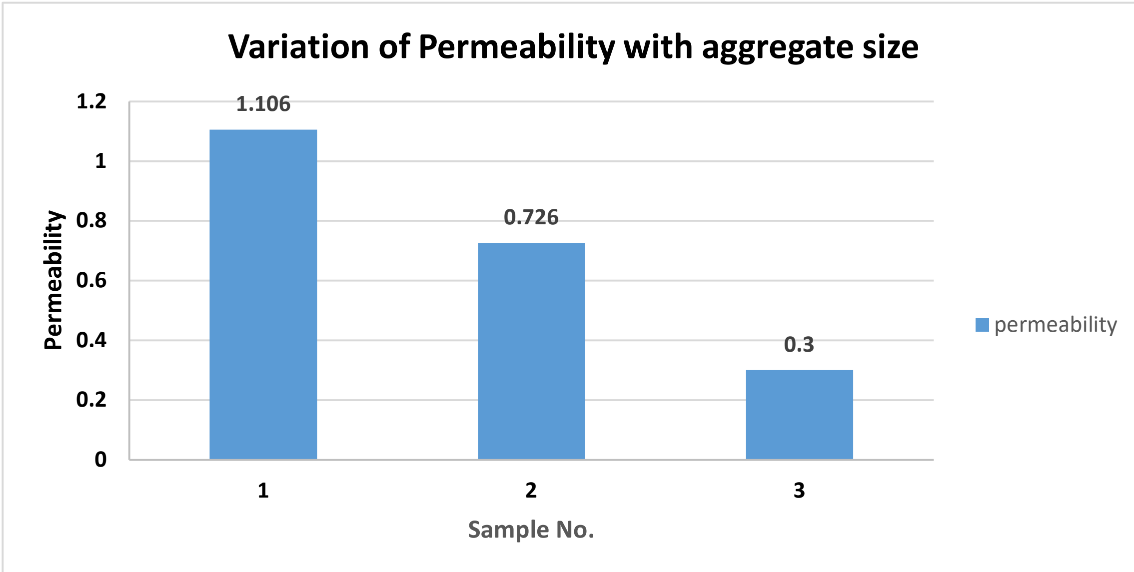

Fig 6.3: The graph illustrates the variation in permeability of pervious concrete of different samples.

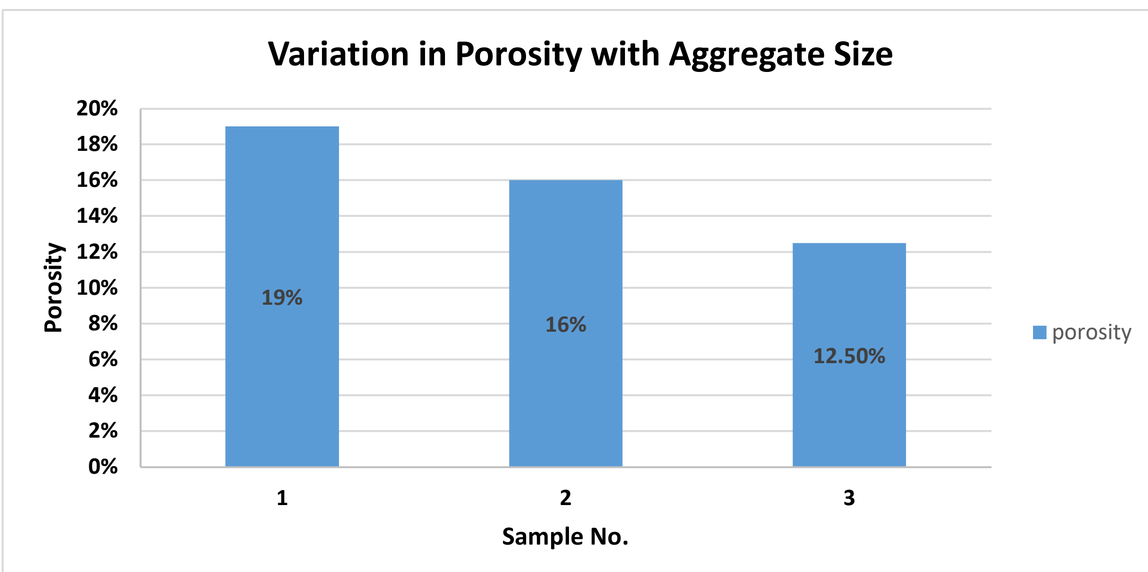

Fig 6.4: The graph illustrates the variation in porosity of pervious concrete of different samples.

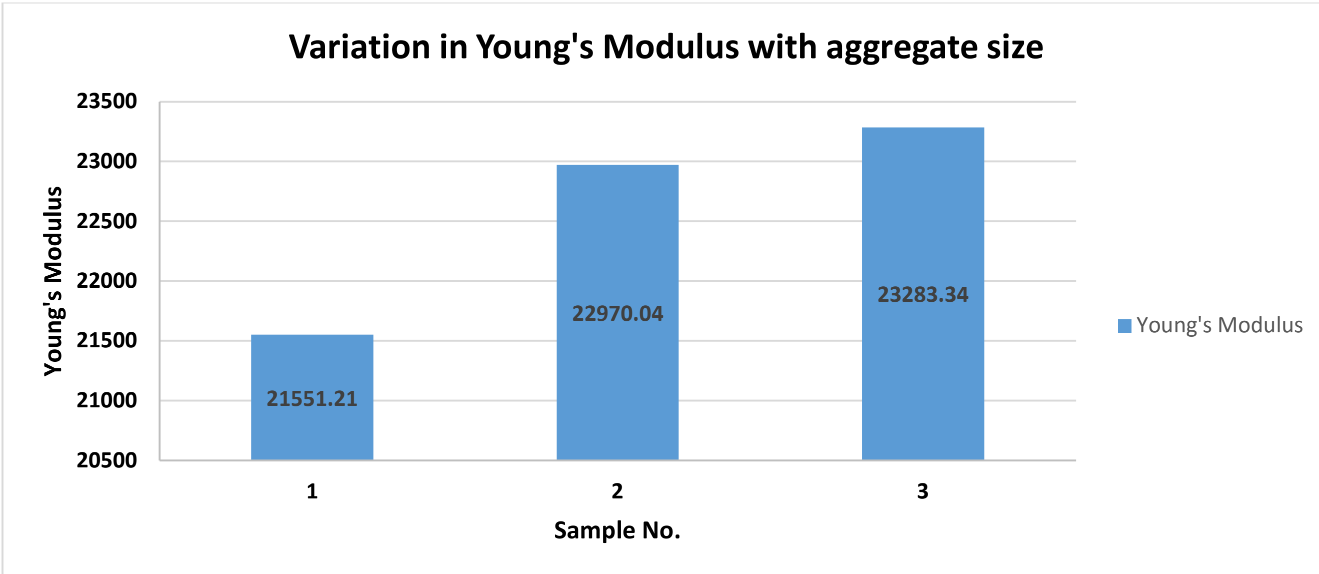

Fig 6.5: The graph illustrates the variation in Modulus of elasticity of pervious concrete of different samples.

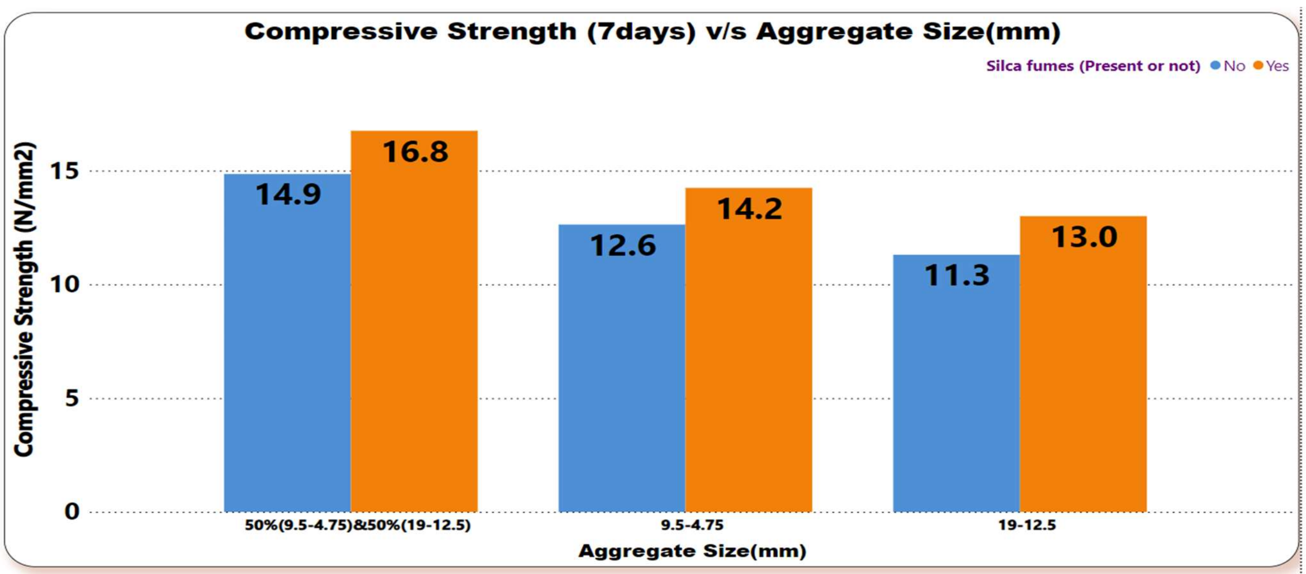

Fig 6.6: Comparision of 7 day strength of pervious concrete with and without silica fume

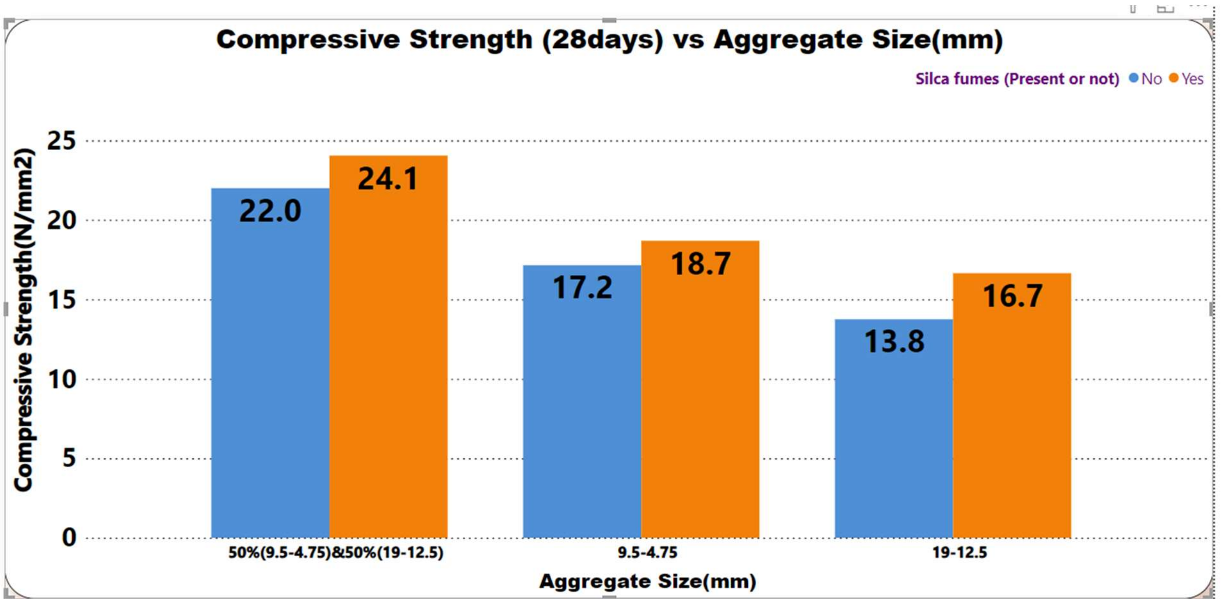

Fig 6.7: Comparision of 28 day strength of pervious concrete with and without silica fumes

Chapter 7

Conclusion

The study was carried out to prepare Pervious Concrete and study its properties. The size and grading of aggregates and mix properties were finalized after conducting literature review and following different codes and guidelines.

The article studied the qualities of pervious concrete such as compressive strength, permeability, porosity and Young's Modulus. The smaller the size of coarse aggregate should be able to produce a higher compressive strength and at the same time produce a higher permeability rate because when larger aggregate combines it produces more voids which reduces the strength. The mixtures with higher aggregate/cement ratio are considered to be useful for a pavement that requires low compressive strength and high permeability rate. The ideal pervious concrete mix is expected to provide the maximum compressive strength, and the optimal infiltration rate.

In summary, the study on pervious concrete reveals significant insights. Smaller aggregate sizes enhance compressive strength while reducing permeability and porosity. This suggests improved durability and stiffness. These findings offer valuable guidance for designing pervious concrete mixtures to meet specific engineering needs.

- **Compressive Strength**: Smaller aggregate sizes result in increased compressive strength, with Sample 2 exhibiting higher strength than Sample 1. Sample 3, a blend of different aggregate sizes, demonstrates the highest compressive strength among the samples.

  The compressive strength of sample with silica fumes is approximately 10% higher than that of sample without silica fumes.

- **Permeability**: Decrease in aggregate size leads to a reduction in permeability due to the decrease in total volume of voids.

- **Porosity**: Aggregate size reduction correlates with a decrease in porosity as the volume of voids diminishes.

- **Young's Modulus**: Young's Modulus shows a moderate increase, indicating improved stiffness with the decrease in aggregate size and increase in compressive strength.

Chapter 8

Future scope

Future Scope

- Custom mix designs exploring varied aggregate proportions: Investigating different combinations of aggregate sizes and proportions to optimize the strength-permeability balance in pervious concrete.
- Extended compressive strength tests at different days: Conducting extended compressive strength tests over a longer period, including multiple days or weeks, to assess the durability and long-term performance of pervious concrete.
- In-depth analysis of porosity and permeability concerning various aggregate sizes: Conducting a thorough examination of porosity and permeability, relating them to different aggregate sizes to gain a deeper understanding of water drainage efficiency and fluid permeation in pervious concrete.
- Utilize flaky aggregate for water passage and groundwater recharge: Exploring the use of flaky aggregate to create simplified water passages and enhance groundwater level and aquifer recharge through pervious concrete installations.
- Applications for building cooling and stormwater management: Investigating the potential of pervious concrete for building cooling and stormwater management applications, leveraging its permeability and drainage capabilities.
- Utilization in various settings: Expanding the range of applications for pervious concrete, including highway borders, subterranean parking lots, parks, and low-traffic highways.
- Long-term cost-effectiveness: Emphasize the long-term cost-effectiveness of pervious concrete systems compared to traditional pavements.

Future Adoption: With increasing urbanization, declining groundwater levels, and a growing focus on sustainability, pervious concrete and similar technologies are likely to gain further popularity in India and other countries. Investing in research and development to optimize pervious concrete's performance and adapt it to local conditions will be crucial for its widespread adoption.