



OPTIMIZED CONCRETE PAVER BLOCKS UTILIZING MICRO SILICA AS A PARTIAL REPLACEMENT OF CEMENT

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Abstract- In this study micro-silica was used in concrete paving block as a partial substitute of cement. Fresh, mechanical and durability properties of concrete paving blocks is investigated in this study. For this study, micro-silica was replaced with cement, at replacement rates of 2.5% ,5% ,7.5% and 10% (by weight). The result shows that the workability of concrete is decreased with increase in replacement percentage of cement with micro-silica. The compressive strength test at 28 days showed the highest compressive strength at 2.5% replacement showed increase in 21% of strength of control mix. The results of mechanical property tests showed that the specimen with 5% micro-silica showed comparable performance to that of the control concrete sample. Test results of water absorption and water penetration of all the mixes is less than that of control concrete paving blocks.

Keywords: Concrete Paver blocks, Durability Properties, Micro-silica, Mechanical properties, fresh concrete properties.

1. INTRODUCTION

Concrete paver blocks are precast in factories are of various shapes and sizes. Concrete paver blocks have excellent surfaces, are durable, economic and requires less maintenance when arranged properly. Concrete paver blocks are the replacement of flexible and rigid pavements. Concrete paver blocks have high strength, good wear and tear resistance and toughness. Concrete paver blocks are widely used in industrial, municipal and government buildings. The concrete paver blocks have very low maintenance cost and can be replaced if broken with the new concrete paver block.

There is a big problem associated with the wastes produced by the industries which are responsible for environmental pollution. Duty of construction industry is to support the world to control the pollution as well as utilization or disposal of industrial wastes. This can be done by utilizing the industrial wastes and other waster in production of concrete and other construction related materials like concrete paver blocks. There are various materials that can be used as substitute of cement up to certain percentage in concrete like Fly ash, Micro-silica, etc. In this study micro-silica is used as partial replacement of cement in concrete paver blocks. Micro-silica is a by-product of processing of coal and high-purity quartz in electric submerged-arc furnace machine. Micro-silica was released into the atmosphere prior to 1960, causing environmental contamination. Breathing in very small particles of crystalline silica causes many diseases, including silicosis which is an incurable lung disease that leads to impairment and death. The significance of this research study is to minimize the accumulation and disposal problems associated with micro silica and utilizing micro silica as partial substitute of cement. Further this substitution of cement will reduce the consumption of cement and will also reduce the depletion of limited natural resources.

2. LITERATURE REVIEW

Song [1] observes the effect of micro-silica as a mineral admixture on durability of high-performance concrete. "There is reduction in permeability of concrete due to pore size refinement, dense matrix formation, Ca(OH)₂ content reduction and cement-aggregate interfacial zone refinement. The permeability of concrete is reduced when micro-silica replacement ratio is between 8% to 12%. Fineness of micro-silica also affects the permeability of concrete. If the fineness of micro-silica increases the permeability gets decreased" [1].

Zhang [2] studied the effect of micro-silica(mS) on cement pastes, mortars and concrete by determining the non-evaporative water content of cement pastes, by determining the compressive strength of cement pastes, mortars and concrete by adding 5% micro-silica and 10% micro-silica with 0.29 and 0.24 water cement ratios. "Micro-silica increases the rate of hydration of paste. Micro silica also increases the compressive strength of pastes, mortars and concrete specimen. The strength activity index of micro silica is highest in concrete and lowest in cement paste. Agglomeration of micro-silica is found out in cement paste while agglomeration in concrete is negligible. Micro-silica improves the interface band between aggregates and cement paste. Micro-silica increases the non-evaporable water content of cement pastes at later stage due to its pozzolanic activity" [2].

Karein [3] added micro-silica as partial substitute of cement in concrete. "Micro-silica improves concrete durability and reduces the dose of cement. The result showed that the strength, durability and surface electrical resistivity increased after use of micro-silica, and permeability also decreased. The mean and maximum depth of

the water absorption test at 28 and 90 days was reduced using micro-silica. The compressive strength test showed that 7.5 percent cement replacement with micro-silica leads to a 20 percent improvement in compressive strength” [3].

Li [4] investigates the combined effects of micro-silica(mS) and nano-silica(nS). Concrete samples were produced with varying water-cement ratios, content of nano-silica and content of micro-silica, but at constant workability. The results showed that “superplasticizer demand for nano-silica was high in comparison to micro-silica. Without adjusting the water cement ratio, the addition of micro-silica and nano-silica will decrease workability, but this can be adjusted by increasing the dosage of superplasticizers. The compressive strength and elastic modulus increased when both micro-silica and nano-silica were paired together” [4].

Massana [5] explores the impact of nano-silica and micro-silica mixtures on the durability of self-compacting high-performance concrete. Compressive strength test accelerated carbonation test, resistance test for freeze and thaw and capillary suction tests have been performed. Ten samples were cast as reference, three with 2.5 percent, 5 percent and 7.5 percent of nano-silica, three with 2.5 percent, 5 percent and 7.5 percent of micro-silica, and three with 2.5 percent / 2.5 percent, 5 percent / 2.5 percent and 2.5 percent / 5 percent of the respective nano-silica and micro-silica. “The maximum compressive strength is achieved in ternary mixture with 2.5%/2.5%. A wide particle size distribution causes low porosity, increase packing density, reduce water demand and improved durability. In concrete with nano-silica provides higher compressive strength. The concrete with micro-silica reduce the porosity with an average pore size that of reference concrete. The concrete has smaller average pore size and low porosity in the ternary mixture, forcing concrete to be more compact and enhancing durability with low capillary absorption and less susceptible to carbonation and freeze-thaw cycle, thus increasing concrete life under adverse environmental conditions” [5].

Baharami [6] “In self-compacting concrete, the impact of optimum recycled concrete aggregate and micro-silica content has been studied. In this study, rheological, mechanical and microstructural properties of concrete were studied. The results showed that the mix of 25 percent recycled aggregates and 5 percent micro-silica showed similar performance to that of plain concrete, while the rheological properties were negatively affected by the use of a higher micro-silica material. An improvement in mechanical properties is observed by increasing the amount of micro-silica, which is followed by a small decrease in rheological properties. The use of micro-silica increases the viscosity of the mixture, but due to the micro-filling effect and pozzolanic reactivity, it improves the mechanical properties” [6].

“Rezaei [7] studies the impact of Micro Silica on compacted concrete roller pavement made from recycled materials for asphalt paving. The study evaluates the effect of recycled asphalt pavement materials and micro-silica on the properties of RCC mixtures. A total of four different mixtures were prepared for this purpose by replacing natural aggregates in various proportions with recycled asphalt pavement material. 3%, 6%, 9%, and 12% were used to increase the mechanical strength of concrete micro silica (MS) with partial cement replacement. The addition of MS was found to contribute to an improvement in mechanical strength” [7].

3. MATERIALS

3.1 Fine Aggregates

Graded sand of a nominal size of 4.75 mm was used as concrete fine-aggregates. The fine-aggregates were as per Indian-Standard-code BIS:383(2016) [8]. The properties of fine aggregates are compatible with the BIS 383(2016) [8] recommendation. In Table 3.1, the properties of fine aggregates are shown.

Table-3.1 Properties of Fine Aggregates

Properties	Observed values
Maximum size of aggregates	4.75
Specific gravity	2.65
Water absorption	0.82
Fineness modulus	2.43
Grade of sand	Grade II

3.2 Coarse Aggregates

Broken stone aggregates are being used in this research. In the analysis, the highest nominal size of coarse aggregates used in the manufacture of paver blocks is 10 mm. The physical characteristics of the coarse aggregate used have been checked and are given in Table 3.2.

Table-3.2 Properties of Coarse Aggregates

Property	Observed value
Specific Gravity	2.7

Net Soaking up of water	0.85
Fineness Modulus	6.26
Maximum size of aggregate	10mm
Water absorption	0.48%
Shape	Angular
Colour	Grey

3.3 Cement

In our study, OPC (Shree Cement) of 43 Grade cement is used. Cement used was fresh and lumps were not present in it. Cement used in this study carefully in the absence of moisture.

3.4 Water

In this research, drinking water is used for mixing and curing.

3.5 Micro-Silica

Micro-silica is a waste obtained in a submerged-arc electric furnace as a result of the processing of silicon and ferrosilicon alloys from high-purity quartz and coal. The micro-silica properties used in this study are given in Table 3.3.

Table-3.3 Properties of Micro-Silica Used

Parameter	Test Result
SiO ₂	86.2%
Loss on Ignition	3.1%
Moisture Content	0.15%
Particle Size	0.05 micron
Retention in 45 microns	1.1%
Dry bulk density	615 Kg/m ³

4. MIX DESIGN

Mix design of concrete is done to achieve a certain concrete strength and workability so that it is easy to compact, place and transport concrete mix. For the casting of concrete samples for various studies, the concrete mix is constructed in compliance with IS 10262:2019 [9]. In order to cast the M40 grade of concrete, mix design is approved. The preliminary data needed for the design of the mix is as mentioned above. The quantity of materials needed per cubic metre is determined and the quantities for the concrete batch are calculated by multiplying the sum of the batch. It measures the quantity of various products. The quantity of materials needed per cubic metre is as shown in Table 4.1 below.

Table-4.1 Mix Design

Material	Quantity (Kg/m ³)
Cement	440
Fine aggregates	862
Coarse aggregates	990
Water	154
Water cement ratio	0.35

5. MIX COMPOSITION

Concrete samples with constant amount cement content, coarse aggregate and fine aggregate were made and paver blocks were casted. 28 days curing is done for paver blocks and Maximum 28 days strength achieved was 53.2 MPa. To find out optimum content of micro-silica without compromising the strength different attempts were made. During the mix proportioning of different mixes, the cement content was varied with micro-silica in proportion of 0%, 2.5%, 5%, 7.5% and 10% respectively at water cement ratio of 0.35.

Then its fresh properties, mechanical properties and durability properties were evaluated and compared with that of control mix.

Table-5.1 Mix Composition

S. No.	Mix Notation	Cement in percentage (%)	Micro-silica in Percentage (%)
1	MS ₀	100	0
2	MS _{2.5}	97.5	2.5
3	MS ₅	95	5
4	MS _{7.5}	92.5	7.5
5	MS ₁₀	90	10

6. RESULTS AND DISCUSSIONS

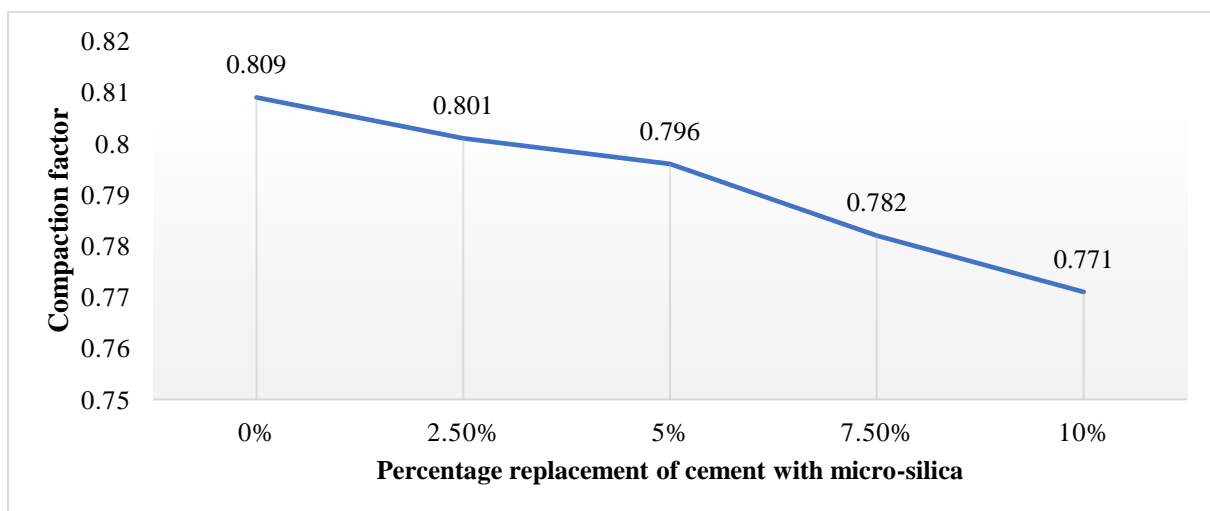
6.1 Workability

In order to assess the workability of the concrete mix with micro-silica as a partial cement substitute at various percentages, compaction factor testing of the different mixing proportions was carried out. The outcomes are shown in table 6.1 and in the bar graph in Fig. 6.1.

The addition of micro-silica to concrete decreases the workability of fresh concrete. The decrease in concrete workability is due to the absorption by micro-silica particles of the mixing water. Due to large specific surface areas and high reactivity, water molecules are attracted to micro silica particles. Therefore, a drop in free water is observed in the mix due to an increase in mix viscosity and a drop in workability due to the addition of micro-silica.

Table-4.1 Compaction Factor Test Result

S. No.	Percentage replacement of cement with micro-silica (%)	Compaction factor
1	0	0.809
2	2.5	0.801
3	5	0.796
4	7.5	0.782
5	10	0.771

**Fig. 6.1 Compaction Factor Test Results**

6.2 Compressive Strength Test

To evaluate the mechanical properties of the concrete mixture mixed with micro-silica as a partial replacement of cement at various percentages, compressive strength testing of the interlocking concrete paver blocks was carried out. Table 6.2 and Fig. 6.2 display the findings. At 7 days and 28 days, compressive strength tests were performed, showing that the addition of micro-silica improved compressive strength at an early age.

The 2.5% micro-silica sample showed a 32.7% improvement in compressive strength over 7 days. The compressive strength rise is due to the rapid pozzolanic action of micro-silica particles of $\text{Ca}(\text{OH})_2$, which densifies the microstructure. Due to the high reactivity of micro-silica particles, the addition of micro-silica particles fastens the hydration phase of C_3S .

Compressive strength results at 28 days showed the maximum compressive strength at 2.5 percent replacement, which is 59.01 MPa, indicating an improvement in the control mix strength of 21 percent. The strength of the 5 percent cement substitution with micro-silica is almost equal to the strength of the control mixture. However, as the substitution ratio exceeds 7.5 percent, the compressive strength reduces such that the larger replacement of cement with micro-silica does not contribute to an improvement in compressive strength due to excessive dispersion of micro-silica particles in the mixture. There is a significant tendency for agglomeration due to the increasing surface energy of micro-silica particles.

When micro-silica particles are added in excess these are not uniformly dispersed in the mix due to which results into weak areas in concrete due to agglomeration.

Another reason for reduced compressive strength with a rise in micro-silica substitution is that the extent of micro-silica in the mixture is higher than that needed for $\text{Ca}(\text{OH})_2$ consumption and that the excessive quantity of micro-silica does not contribute to the concrete strength.

Table-6.2 Compressive Strength Test

Days	MS ₀	MS _{2.5}	MS ₅	MS _{7.5}	MS ₁₀
7	31.78	42.17	35.04	31.63	29.02
28	48.85	59.01	49.07	40.86	39.34

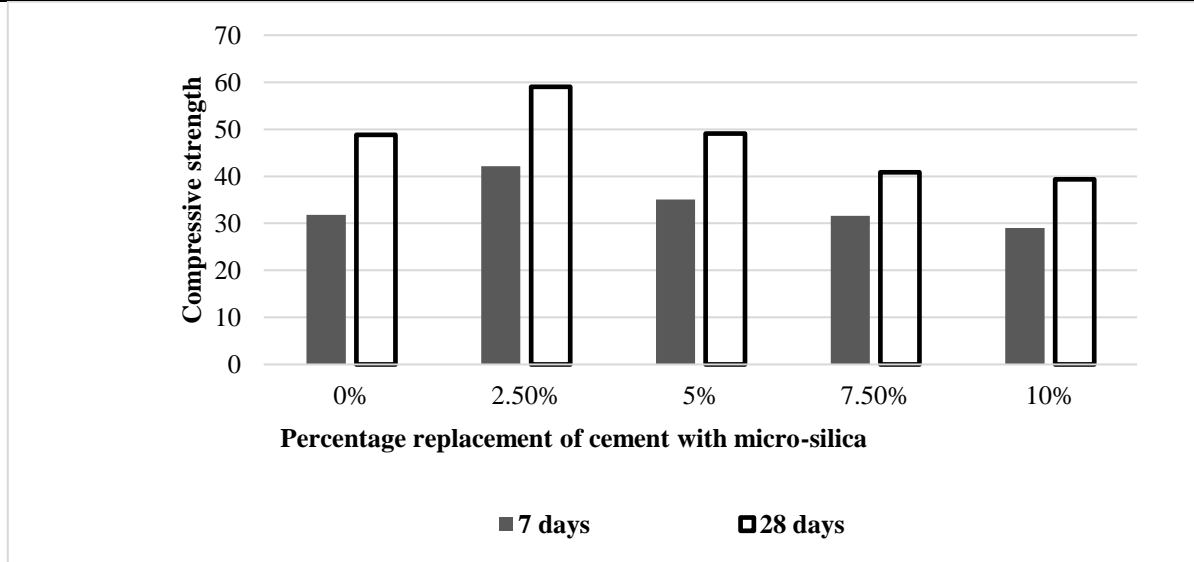


Fig. 6.2 Compressive Strength Test Result

6.3 Flexural Strength Test

The findings of flexural strength testing indicate that the production of flexural strength is close to the compressive strength of micro-silica-constituted concrete paver blocks. MS_{2.5} showed a 19.83% increase in flexural intensity relative to the control mix at 28 days. M₅ flexural strength is about the same as control mix strength.

The decrease in flexural strength with more than 5 percent replacement of micro-silica particles is due to the excess of micro-silica than the amount needed for the $\text{Ca}(\text{OH})_2$ hydration process, resulting in no contribution to the production of strength and producing poor concrete zones.

Table-6.3 Flexural Strength Test

S.No.	Specimen	Flexural strength (MPa)
1	MS ₀	6.02
2	MS _{2.5}	7.26
3	MS ₅	6.04
4	MS _{7.5}	5.03
5	MS ₁₀	4.84

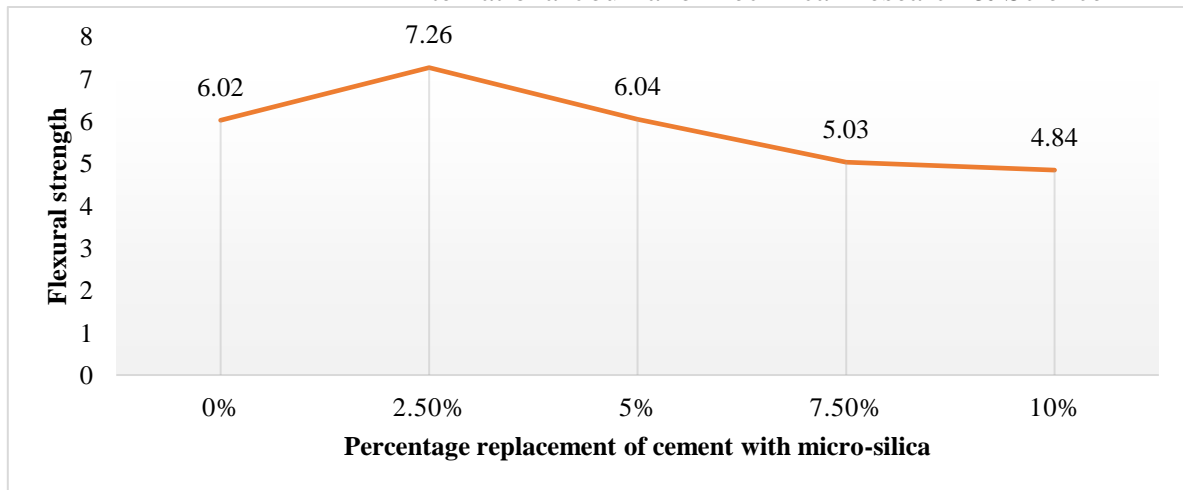


Fig. 6.3 Flexural Strength Results

6.4 Water Absorption Test

The outcome of the water absorption test showed that water absorption decreased from 0 percent to 2.5 percent from 2.38 percent to 1.84 percent for micro-silica replacement. For weight replacement of 5 percent at 28 days, then marginally increased to 1.92 percent. All the mixes showed low absorption of water relative to the control mix. The low absorption of water in micro-silica mixes results from a higher micro-silica pozzolanic effect, resulting in a more compact and dense mix. The effect of fine micro-silica pore filling increases the concrete pore structure, which decreases concrete water absorption.

Table-6.4 Water Absorption Test Results

S. No.	Specimen	Water absorption (%)
1	MS ₀	2.38
2	MS _{2.5}	1.84
3	MS ₅	1.92
4	MS _{7.5}	2.035
5	MS ₁₀	2.203

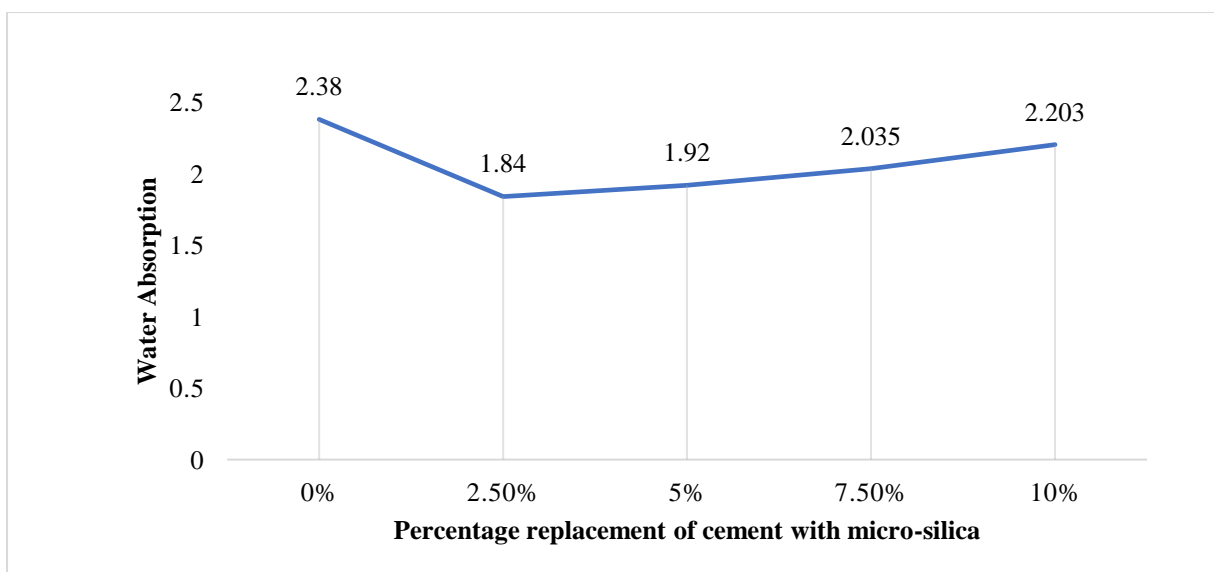


Fig. 6.4 Water Absorption Test

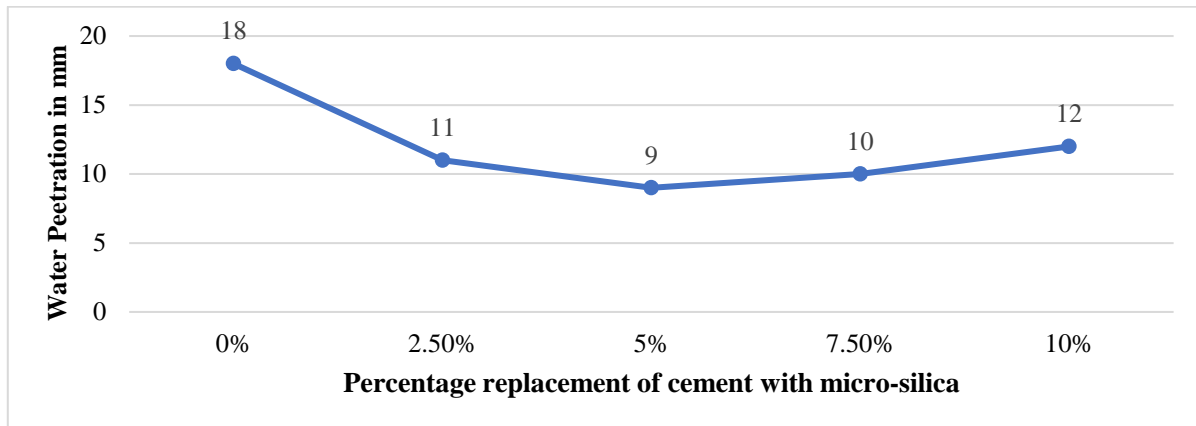
6.5 Water Penetration Test

The result of the water penetration test showed that water penetration decreased from 0 percent to 2.5 percent from 18 mm to 11 mm for micro-silica replacement. Then, at 28 days, the 5 percent weight replacement decreased significantly. All the mixes showed low penetration of water relative to the control mix. Due to the effect of pore

filling of fine micro-silica, low water penetration increases the pore structure of concrete, which decreases the penetration of water into concrete.

Table-6.5 Water Penetration Test

S. No.	Specimen	Water penetration(mm)
1	MS ₀	18
2	MS _{2.5}	11
3	MS ₅	9
4	MS _{7.5}	8
5	MS ₁₀	12

**Fig. 6.5 Water Penetration Test Results**

CONCLUSIONS

This research explores fresh properties, durability characteristics and the mechanical characteristics of concrete paver blocks. It takes into account the addition of micro-silica as a partial cement substitute (0%, 2.5%, 10%, 7.5% and 10%). The properties of concrete are improved by the incorporation of micro-silica in the concrete mix. The following conclusions may be drawn on the basis of the present examination: -

- From the present research on fresh properties of concrete, it was shown that the incorporation of micro-silica in concrete decreases the workability of concrete. All the combinations demonstrate lower workability than the control mix. The rise in the percentage of replacement of cement with micro-silica contributes to a decrease in workability.
- From the investigation of the compressive strength of concrete paver blocks, it can be concluded that the compressive strength of the concrete paver block increases by up to 5 percent cement replacement with micro-silica replacement ratio for a constant water-cement ratio, both 7 days and 28 days. The 2.5 percent substitution of cement with micro-silica shows the maximum improvement in strength.
- At 2.5 percent replacement of cement with micro-silica, the flexural strength of concrete paver blocks is greatest. The flexural strength is almost equal to the control mix at 5 percent replacement of cement with micro-silica and further increases in replacement percentage decrease the flexural strength.
- The water absorption of all mixtures is below the limits laid down in IS:15658(2008)[10]. Therefore, all the mixes pass the criteria for water absorption testing. Water absorption is smaller than the control sample with all the substitution percentages.
- The water penetration depth of all samples with various micro-silica cement substitution percentages is smaller than that of the control samples.

Therefore, it can be concluded that in concrete paver block cement can be replaced with micro-silica up to 5 percent and At 2.5 percent cement substitution with micro-silica, the best mechanical and durable properties of concrete paver blocks can be achieved.

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