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Effect of Microsilica Incorporation on The Fresh and Hardened Properties of Ordinary Portland Cement Concrete

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ABSTRACT

This study investigated the effects of microsilica incorporation on the fresh and hardened properties of Ordinary Portland Cement Concrete (OPCC). Microsilica, a highly reactive pozzolanic material, was used to partially replace cement at 5%, 10%, and 15% by weight. The concrete samples were cured under normal conditions for seven days. The fresh properties were evaluated using the slump test, and hardened properties were determined through density, porosity, and rebound hardness tests. Results indicated that the addition of microsilica significantly reduced workability due to its high surface area but improved density and surface hardness up to 10% replacement. Porosity decreased consistently with increasing microsilica content, demonstrating enhanced compactness and reduced permeability. The study concludes that an optimal replacement level of 10% microsilica enhances both the mechanical and durability-related characteristics of OPCC.

Keywords: Microsilica, Workability, Density, Porosity, Rebound Hardness, Concrete Durability.

INTRODUCTION

Concrete is still the most popular building material worldwide, and the microstructure that forms when it hydrates has a significant effect on how long it lasts (Al-saffar et al., 2023; Druta, 2020). Owing to its high reactivity and very small particle size, microsilica makes packing denser, less porous, and stronger (Kumar et al., 2023; Elrahman et al., 2019; Li et al., 2018). Nevertheless, its ability to resist wear and tear and its microstructural density are two of the most important things that affect how well it will work over time (Bansal et al., 2024; Altawaiha et al., 2023; Davolio et al., 2023; García et al., 2020). Adding more cementitious materials, like microsilica (also known as silica fume), has recently gotten a lot of attention as a way to improve these properties (Ahmed, 2024; Allah et al., 2023; Khan et al., 2023; Kim et al., 2019). Microsilica is a very fine, amorphous form of silicon dioxide that is made as a by-product of making silicon and ferrosilicon alloys (Luo et al., 2021; Kim & Ann, 2020; Liang et al., 2023; Long et al., 2022). Its particles are about 100 times smaller than those of regular Portland cement are. They act as both micro-fillers and pozzolanic agents, reacting with calcium hydroxide to make more calcium silicate hydrate (C–S–H) gel (Kim & Moon, 2023; Martins et al., 2023; Carneiro et al., 2022).

This dual action greatly improves the pore structure, makes it denser, and makes it stronger and more durable (Trebukhin et al., 2024; Khan et al., 2024; Cuesta et al., 2018; Miah et al., 2023; Tavares et al., 2020). The same fineness that makes things stronger also makes them harder to work with, which makes mixing and placement harder (Ashokan et al., 2023; Kuncoro et al., 2023; Li et al., 2018). To get the best performance, you need to balance these effects (Aakash et al., 2024; Ashokan et al., 2023; Afzali-Naniz & Mazloom, 2018). This study

ISSN 2278-2540 | DOI: 10.51583/IJLTEMAS | Volume XIV, Issue XII, December 2025

looks at how replacing some OPC with microsilica affects both the fresh properties, like workability, and the hardened properties, like density, porosity, and surface hardness (Bansal et al., 2024; Ahmed, 2017; Pinheiro et al., 2023). Burhan et al. (2019), Husain et al. (2021), and Burhan et al. (2019) investigated the relationship between microsilica content and concrete performance under standard curing conditions in order to determine the replacement levels that offer the best overall structural and durability benefits.

OBJECTIVE

This study's primary goal is to assess the effects of partially substituting microsilica for cement on the fresh and hardened properties of OPCC.

LITERATURE REVIEW

The ultrafine by-product known as microsilica, or silica fume, is mostly made up of amorphous silicon dioxide (Kancharla et al., 2021; Gerasimova & Berdysheva, 2018; Shyam et al., 2017). In electric arc furnaces, it is produced while silicon metal or ferrosilicon alloy is being produced (Gupta et al., 2020). The microsilica particles are 100 times smaller than the Portland cement grains Gerasimova & Berdysheva (2018), with an average diameter of 0.1 to 0.3 µm (Hou et al., 2020; Shyam et al., 2017). They fill in the gaps between cementitious materials; increasing packing density (Li et al., 2018). Because of its large specific surface area, microsilica has a high reactivity (Hou et al., 2020; Li et al., 2018). Its bulk density is between 150 and 700 kg/m³, and in a viscous liquid state with up to 50% solid phase content, it can reach 1315 kg/m³ (Gerasimova & Berdysheva, 2018). Usually a powder that is light grey. Microsilica consists of spherical particles Szcześniak et al. (2024), according to (Zaid et al., 2021). Research indicates that the mix design determines the precise optimum, which is between 10 and 15 percent (Wu et al., 2019; Cheng et al., 2018). However, too much of it can make the mixture less workable and result in uneven mixtures (Bansal et al., 2024; Mostofinejad et al., 2024; Wu et al., 2019; Breesem et al., 2018).

Concrete's workability, which is frequently evaluated using the slump test, indicates how simple it is to mix, pour, and compact concrete (Gerges et al., 2023; Mahajan et al., 2020). Because microsilica has a high surface area and ultrafine particle size, which raise water demand and internal friction in the mix, it typically reduces slump (Suda & Rao, 2020; Ramdani et al., 2018). Concrete gets harder to work with and less workable as the microsilica content increases, according to studies by Arasteh-Khoshbin et al. (2022) and Soukal et al. (2022). To maintain the desired flow, superplasticizers are needed (Thatikonda et al., 2024). By filling in gaps and improving pore distribution, the same properties that make concrete less workable also improve its microstructure (Kumar et al., 2020, 2023; Shen et al., 2019; Li et al., 2018).

Improved particle packing because of this densification directly raises density and mechanical performance (Ashokan et al., 2023; Kumar et al., 2023). The structural quality and durability of concrete are primarily determined by its density, porosity, and surface hardness (Ottosen et al., 2024; Pellenq et al., 2021; Hooton, 2019). Microsilica's pozzolanic and filler properties increase density, resulting in a compact matrix with fewer capillary pores (Kashyap et al., 2023; Kim & Moon, 2023; Kumar et al., 2020, 2023; Elrahman et al., 2019). Long-term durability, resistance to chloride ingress, and reduced permeability are all improved by lower porosity (Huang et al., 2024; Miah et al., 2023; Lian et al., 2021). Conversely, surface hardness, which is frequently assessed using the rebound hammer test, has a strong correlation with both near surface and compressive strength (Abazarsa & Yu, 2025; Debbakh et al., 2024; Kouddane, 2024; Badarloo & Lehner, 2023). Generally speaking, higher rebound values indicate better cohesion and resistance to surface wear when the microsilica content is increased (Ali et al., 2025; Gebre et al., 2023; Kashyap et al., 2023; Kim et al., 2019; Esmailpour et al., 2018).

METHODOLOGY

Microsilica at 5%, 10%, and 15% by weight was used to partially replace GHACEM (Type II 42.5N) ordinary portland composite cement and the 400 kg/m³ total binder content. Additionally, a control mix with 0% microsilica was made. All mixes had the same mix proportions and water-to-cement ratio of 0.40. As soon as

ISSN 2278-2540 | DOI: 10.51583/IJLTEMAS | Volume XIV, Issue XII, December 2025

the concrete was mixed, its slump was checked. Prior to performing density, porosity, and rebound hardness tests, the specimens were cured in water for 7 (seven) days under standard laboratory conditions.

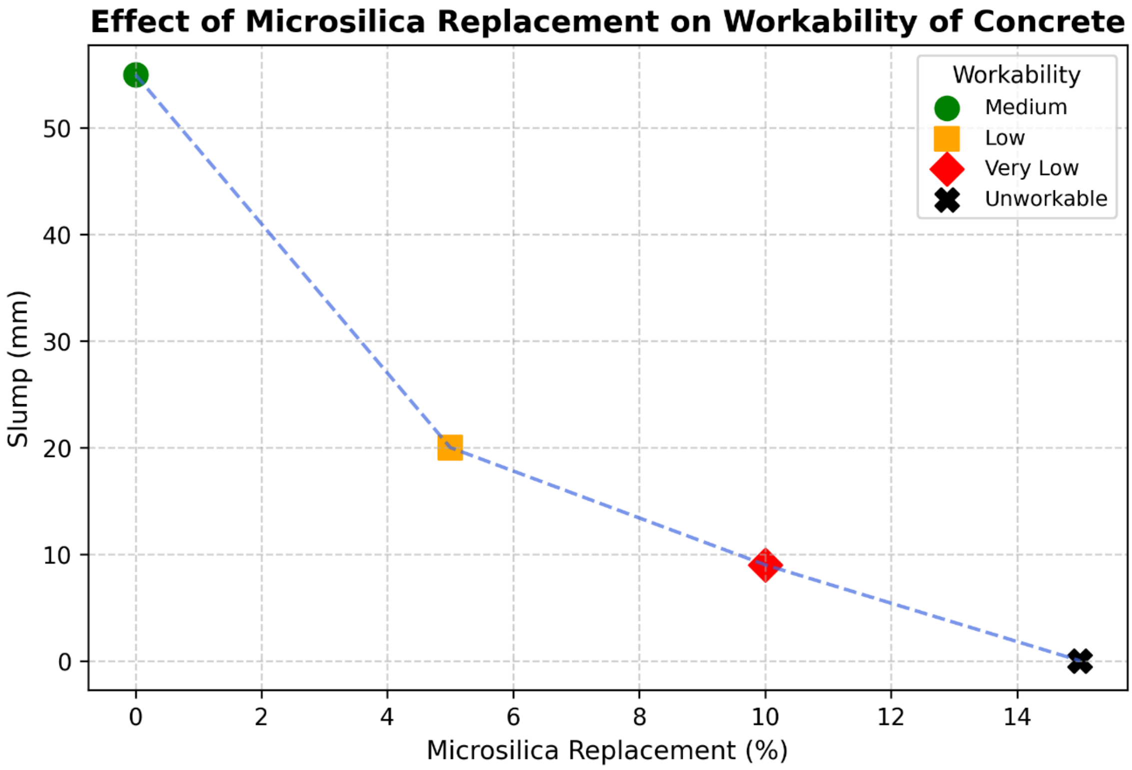
RESULTS AND DISCUSSION

Workability (Slump Test)

Table 4.13 Workability of Concrete (Slump Test) with Partial Replacement of Cement by Microsilica.

Microsilica Replacement (%)	Slump (mm)	Workability Description
0	**55**	Medium
5	**20**	Low
10	**9**	Very Low
15	**0**	Unworkable

Figure 4.5 Average Workability (Slump) Of Concrete With Partial Replacement Of Cement By Microsilica.



The slump test, which examines the concrete's height decrease upon lifting the slump cone, is used to assess workability (Mahajan et al., 2020; Franci & Zhang, 2018). This test evaluates the concrete's consistency and ease of handling (Roy et al., 2018).

The slump test indicates that Ordinary Portland Cement Concrete's workability decreases as its microsilica content rises (Suda & Rao, 2020; Thatikonda et al., 2024). The control mix (0%) showed medium workability with a slump of 55 mm (Gerges et al., 2023; Oyebisi et al., 2021). At 5%, the slump decreased to 20 mm due to the high surface area and water absorption of microsilica (low workability) (Arasteh-Khoshbin et al., 2022; Liu et al., 2021; Suda & Rao, 2020). The concrete was unworkable at 15% (0 mm slump), and at 10% (very low workability), the slump further decreased to 9 mm (Bansal et al., 2024; Ebert et al., 2021; Suda & Rao, 2020). This non-linear decrease in workability indicates that while small additions (up to 5%) are manageable, higher

ISSN 2278-2540 | DOI: 10.51583/IJLTEMAS | Volume XIV, Issue XII, December 2025

percentages necessitate the use of superplasticizers or mix modifications to maintain consistency (Tran et al., 2025; Labaran et al., 2024; Ahmed et al., 2021; Suda & Rao, 2020).

Hardened Properties

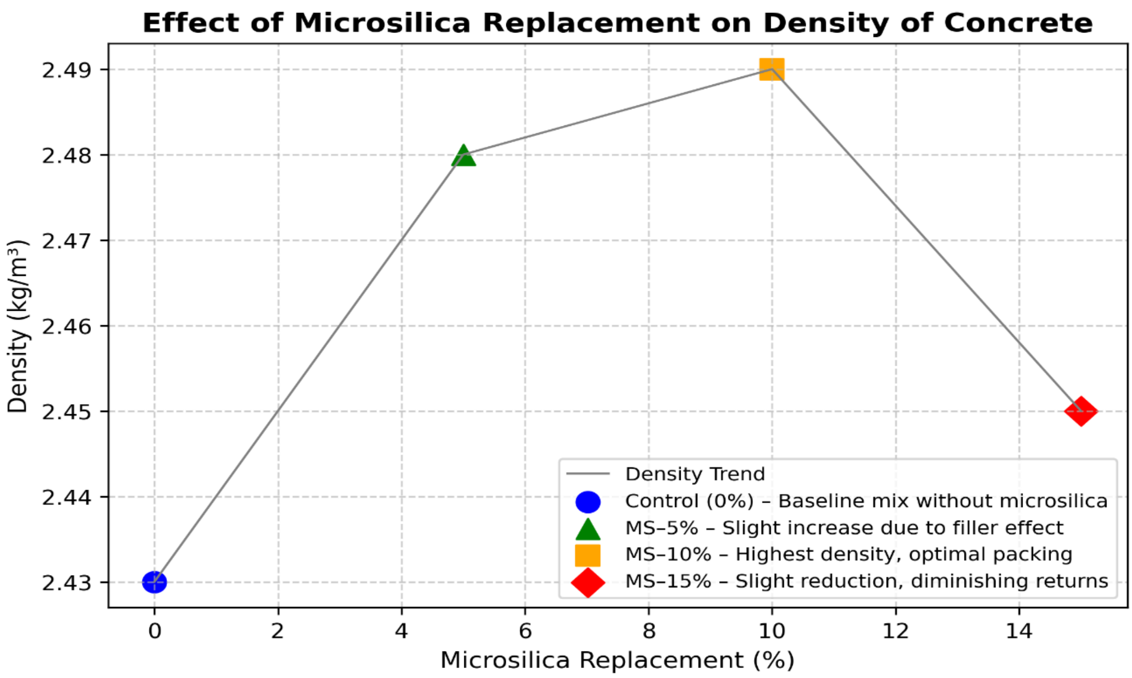
Density, porosity, and surface hardness were evaluated to assess the effect of microsilica on the internal structure and strength of OPCC.

Density: Average Density of Concrete with Partial Replacement of Cement by Microsilica.

Table 4.14 Average Density of Concrete with Partial Replacement of Cement by Microsilica.

Mix ID	Microsilica Replacement (%)	Density (kg/m³) – Average	Description
(OA)	Control (0%)	**2.43**	Baseline mix without microsilica
A	MS-5%	**2.48**	Slight increase due to filler effect
B	MS-10%	**2.49**	Highest density, optimal packing
C	MS-15%	**2.45**	Slight reduction, diminishing returns

Figure 4.6 Average density of concrete with partial replacement of cement by microsilica.



The density of microsilica directly affects the strength and durability of concrete. Microsilica enhances these qualities by filling in the gaps between particles and refining the structure, making it stronger and more resistant to damage (Akhmetov et al., 2022; Karimipour et al., 2022).

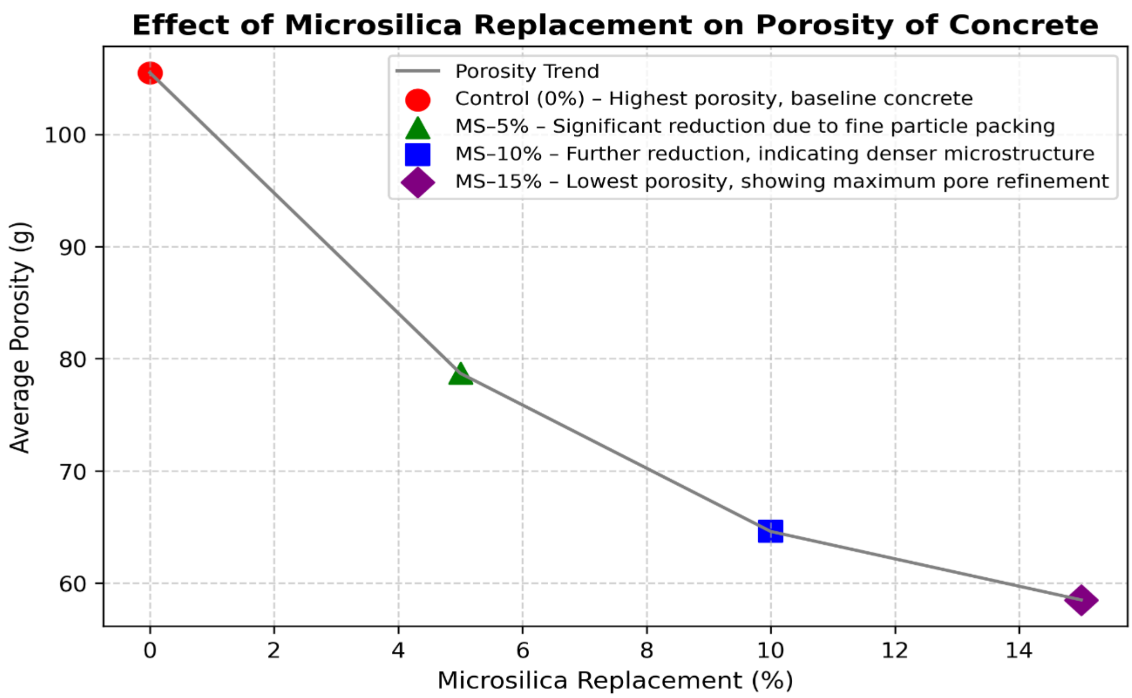
The density results show that adding microsilica to concrete affects its density (Bansal et al., 2024; Ashokan et al., 2023). The control mix's density was 2.43 kg/m³. Density increased to 2.48 kg/m³ with 5% microsilica and peaked at 2.49 kg/m³ with 10% replacement due to improved particle packing and pozzolanic effects (Kashyap et al., 2023; Li et al., 2018). However, with 15% replacement, density somewhat decreased to 2.45 kg/m³ due to agglomeration issues (Kumar et al., 2023; Niewiadomski et al., 2021). The results show that density and compaction can be enhanced by up to 10% microsilica; beyond those Ashokan et al. (2023), the benefits diminish (Niewiadomski et al., 2021).

Porosity: Porosity consistently decreased with increasing microsilica, suggesting enhanced compactness and durability.

Table 4.15 Average Porosity of Concrete with Partial Replacement of Cement by Microsilica

Mix ID	Microsilica Replacement (%)	Average Porosity (g)	Description
(OA)	Control (0%)	105.5	Highest porosity, baseline concrete
A	MS-5%	78.7	Significant reduction due to fine particle packing
B	MS-10%	64.6	Further reduction, indicating denser microstructure
C	MS-15%	58.5	Lowest porosity, showing maximum refinement of pores

Figure 4.7 Average Porosity of Concrete with Partial Replacement of Cement by Microsilica



Porosity affects the strength and durability of concrete; a high porosity leaves it vulnerable to chloride and water attacks (Yuan et al., 2024; Ghantous et al., 2023; Hou et al., 2020). To reduce porosity and improve compactness and pore structure, a small pozzolanic particle known as microsilica fills in the spaces between cement particles (Mohamed et al., 2025; Ranjan et al., 2024; Altawaiha et al., 2023).

The study's findings indicate a significant correlation between the porosity and microsilica content of concrete (Olivia et al., 2023; Tian et al., 2022). The porosity results, which demonstrate a discernible decline with increasing microsilica percentages, validate its densifying effect on concrete (Bansal et al., 2024; Vandhiyan et al., 2020). The control mix (0%) had the highest porosity at 105.5g (Miah et al., 2023; Olivia et al., 2023). A significant improvement in compactness was indicated by the porosity, which decreased to 78.7 g at 5%

ISSN 2278-2540 | DOI: 10.51583/IJLTEMAS | Volume XIV, Issue XII, December 2025

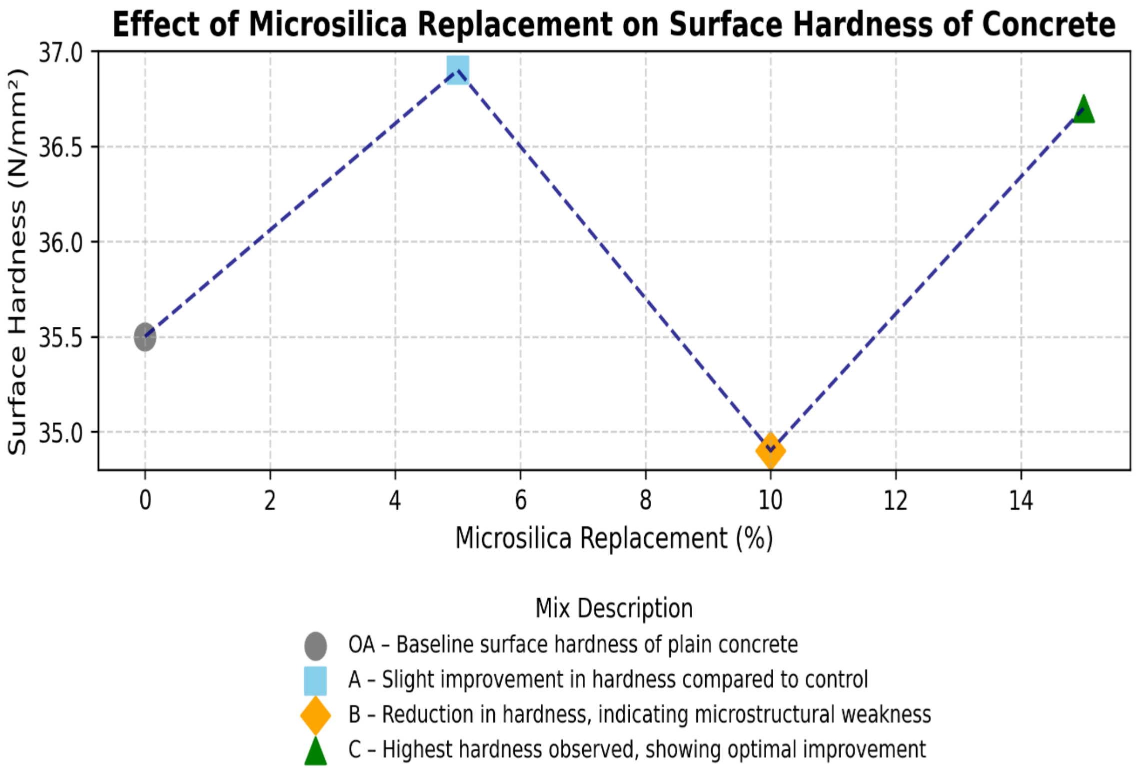
microsilica and then to 64.6g at 10% (Khan et al., 2023; Olivia et al., 2023). At 15%, the lowest porosity of 58.5g was recorded, indicating optimal pore refinement (Niewiadomski et al., 2021; Uzbas & Aydın, 2020). A surplus of microsilica may hinder workability and negatively influence mechanical performance, despite the fact that this decrease in porosity indicates increased density and durability (Suda & Rao, 2020; Wu et al., 2019). Adding microsilica results in a denser concrete matrix by drastically reducing porosity (Kashyap et al., 2023; Li et al., 2018).

Surface Hardness: Rebound hammer tests.

Table 4.16 Average Surface Hardness of Concrete with Partial Replacement of Cement by Microsilica

Mix ID	Microsilica Replacement (%)	Surface Hardness (N/mm²)	Description
(OA)	Control (0%)	35.50	Baseline surface hardness of plain concrete
(A)	MS-5%	36.90	Slight improvement in hardness compared to the control
(B)	MS-10%	34.90	Reduction in hardness, indicating possible microstructural weakness
(C)	MS-15%	36.7	Highest hardness observed, showing optimal improvement

Figure 4.8 Average Surface Hardness Of Concrete With Partial Replacement Of Cement By Microsilica.



Surface hardness, which has a direct correlation with compressive strength, is a crucial indicator of concrete quality (Abed et al., 2021). Abed et al. (2021) and Jedidi (2020) explained that, concrete with higher bounce

ISSN 2278-2540 | DOI: 10.51583/IJLTEMAS | Volume XIV, Issue XII, December 2025

values is more compacted and stronger. The Schmidt hammer is a non-destructive method for measuring bounce. This study used the rebound hammer test to investigate how microsilica affected concrete (Brencich et al., 2020).

The study found a nonlinear relationship between concrete's surface hardness and microsilica content (Niewiadomski et al., 2021; Wu et al., 2019). The microsilica-free control mix had a hardness of 35.50 N/mm² (Olivia et al., 2023). Because of improved particle packing and densification, hardness increased to 36.90 N/mm² at 5% replacement (Bansal et al., 2024; Li et al., 2018). However, at 10%, the hardness dropped to 34.90 N/mm², suggesting potential defects brought on by insufficient dispersion (Husain et al., 2021; Wu et al., 2019). By increasing to 15%, a recovery to 36.7 N/mm² was achieved, suggesting that surface properties are best improved in the 5–15% range (Husain et al., 2021; Wu et al., 2019). The results emphasise the benefits of microsilica in terms of durability and abrasion resistance Ahmed (2024), while acknowledging the influence of external factors such as aggregate type and moisture (Khan et al., 2023; Miah et al., 2023; Sivamani & Neelakantan, 2021). This is in line with previous research that has demonstrated the positive effects of microsilica on mechanical performance (Suda & Rao, 2020; Kim et al., 2019).

CONCLUSION

The characteristics of Ordinary Portland Cement Concrete, both fresh and hardened, are significantly influenced by microsilica. The slump test revealed reduced workability with a higher microsilica content because microsilica contains fine particles and needs more water. While additions of up to 5% are manageable, mixes that are unworkable at levels of 10-15% require additives. Through improved surface and internal structure, microsilica increases density (up to 10% replacement) and reduces porosity (from 105.5g in the control mix to 58.5g at 15%) in solidified properties. Surface hardness peaks at 5% and 15% replacements indicate better compaction and abrasion resistance. In order to maximise the advantages of durability and mechanics without compromising workability, the ideal microsilica content is ultimately between 5% and 10%.

FUTURE RESEARCHES

Future work should include longer curing periods to capture strength development more accurately and align results with typical structural applications. Introducing microstructural analyses such as SEM, XRD, or MIP would help validate explanations for density, porosity, and hardness trends. Clarifying testing standards, mix procedures, and sample counts would improve transparency and reproducibility. It would also be beneficial to express porosity in conventional units and compare results with supplementary cementitious materials like slag or fly ash to position microsilica performance within broader sustainability frameworks.

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ISSN 2278-2540 | DOI: 10.51583/IJLTEMAS | Volume XIV, Issue XII, December 2025

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