e-ISSN:2582 - 7219

INTERNATIONAL JOURNAL OF MULTIDISCIPLINARY RESEARCH

IN SCIENCE, ENGINEERING AND TECHNOLOGY

Volume 5, Issue 1, January 2022

INTERNATIONAL
STANDARD
SERIAL
NUMBER
INDIA

Impact Factor: 5.928

9710 583 466 | 9710 583 466 | ijmrset@gmail.com | www.ijmrset.com

International Journal Of Multidisciplinary Research In Science, Engineering and Technology (IJMRSET)

| ISSN: 2582-7219 | www.ijmrset.com | Impact Factor: 5.928| Monthly, Peer Reviewed & Referred Journal |

| Volume 5, Issue 1, January 2022 |

|DOI:10.15680/IJMRSET.2022.0501021 |

Incorporating Nano-Silica (NS) into Concrete Mixtures

Guru Sharan Mishra[1*], Manish Tiwari[1*], Dr. Parth Verma[1], Vaibhav Hoonka[1], Dr. Arun Kumar Khare[1], Bhupendra Sirbaiya[1]

Department of Civil Engineering, Baderia Global Institute of Engineering and Management, Jabalpur, Madhya Pradesh, India[1]

ABSTRACT: Concrete is the most widely used material in construction, and its design accounts for a significant portion of global cement production. However, the extensive use of cement significantly contributes to CO_2 emissions, exacerbating the greenhouse effect. One strategy to mitigate this environmental impact involves reducing cement content in concrete mixes by incorporating silica fines. Among these fines, nano-silica (NS) shows promise as a cement substitute and concrete additive. Nonetheless, the complex synthesis process of commercial NS makes it impractical for the construction industry, and the precise impact of NS on concrete is not yet fully understood**.**

In a recent research endeavor, a novel nano-silica derived from olivine has been developed and will be compared with commercially available NS through application and testing. Additionally, modifications to a mix design tool used for self-compacting concrete (SCC) will be made to accommodate particles ranging from 10 to 50 nm in size. This paper aims to provide an up-to-date overview of NS application in concrete, focusing on optimizing its properties for effective integration. Topics covered include the NS production process, its influence on concrete properties, and potential applications. Furthermore, an outline of the experimental setup and proposed future research directions is presented.

KEYWORDS: Self-Compacting Concrete, Nano-Silica, Concrete, Burnt Rice Husk Ask, Micro-Silica

I. INTRODUCTION

The construction industry extensively uses concrete, with about 14 billion tons consumed in 2007. Concrete is crucial for infrastructure and building projects, composed of granular materials of various sizes. The overall mix grading, which includes particles ranging from 300 nm to 32 mm, greatly affects concrete properties. Particle size distribution (PSD) influences fresh state properties like flow characteristics and workability, while mix grading and particle packing impact hardened state properties such as strength and durability.

Improving particle packing by extending the solid size range to include particles smaller than 300 nm can enhance concrete performance. Materials available for this purpose include limestone and silica fines such as silica flavor (Sf), silica fume (SF), and nano-silica (NS). However, the complex synthesis processes for these products yield high purity but make them impractical for widespread use in the construction industry.

In this doctoral research project, a newly developed nano-silica derived from olivine will be applied and evaluated. Additionally, a mix design tool used for self-compacting concrete (SCC) will be adapted to accommodate nano-sized particles, which may introduce unique effects. The objective of this study is to establish practical application methods and models for incorporating newly developed NS into concrete.

II.THE PROCESS OF PRODUCING NANO-SILICA (NS)

In contemporary times, various methodologies exist for the production of nano-silica (NS). One notable technique is the sol-gel process, either organic or aqueous, performed under ambient conditions. In this process, starting materials like Na2SiO4 and organometallic compounds such as TMOS/TEOS are dissolved in a solvent. The solution's pH is then adjusted, causing silica gel to precipitate. This gel matures over time and is then filtered to produce a xerogel, which is subsequently dried. It may be further processed by incineration or dispersion with a stabilizing agent (such

| ISSN: 2582-7219 | www.ijmrset.com | Impact Factor: 5.928| Monthly, Peer Reviewed & Referred Journal |

| Volume 5, Issue 1, January 2022 |

|DOI:10.15680/IJMRSET.2022.0501021 |

as Na, K, NH3, etc.), resulting in a concentrated dispersion (20 to 40% solid content) suitable for use in the concrete industry.

Another method involves vaporizing silica at temperatures between 1500 to 2000 °C by reducing quartz (SiO_2) in an electric arc furnace. Additionally, NS can be obtained as a byproduct during the production of silicon metals and ferrosilicon alloys, where it is collected by condensation into fine particles using a cyclone. Nano-silica produced through this method typically consists of very fine powder with spherical particles or microspheres about 150 nm in diameter, offering a high specific surface area (15 to 25 m^2/g).

Estevez et al. developed a biological method for producing NS with a narrow and bimodal distribution, derived from the digested humus of California red worms. The particle size ranges from 55 nm to 245 nm, depending on the calcination temperature. This method achieves nanoparticles with a spherical shape and 88% process efficiency. The nanoparticles are produced by feeding worms with rice husk, a biological waste material containing approximately 22% SiO_2.

Furthermore, NS can be produced via a precipitation method, where it is precipitated from a solution at temperatures between 50 to 100 °C (forming precipitated silica). This method, pioneered by Iller in 1954, uses various precursors such as sodium silicates (Na_2SiO_3), burned rice husk ash (RHA), semi-burned rice straw ash (SBRSA), magnesium silicate, among others.

Additionally, an alternative production route for nano-silica (NS) involves combining olivine and sulfuric acid, resulting in precipitated silica with extreme fineness but in agglomerate form. The particles typically range between 6 to 30 nm in size, and this method is more cost-effective than contemporary micro-silica. The feasibility of this process has been demonstrated in previous PhD theses and published data. Currently, a parallel PhD project is underway to scale up the production of NS on an industrial scale, focusing on optimizing raw materials and process parameters for concrete production.

II.INFLUENCE OF INCORPORATING NANO-SILICA INTO CONCRETE & MORTARS

In concrete formulations, the inclusion of micro-silica (Sf and SF) plays two critical roles. Firstly, it participates chemically in a pozzolanic reaction with calcium hydroxide, producing additional CSH-gel at later stages. Secondly, it functions physically due to its much smaller size compared to cement. Micro-silica fills the residual voids in fresh and partially hydrated cement paste, thereby increasing its overall density. Studies have shown that adding 1 kg of micro-silica can reduce cement usage by approximately 4 kg, and this reduction may be even greater with the inclusion of nano-silica (NS). Another approach is to maintain the same cement content while optimizing particle packing using residual stone materials to achieve a wider particle size distribution, enhancing concrete properties such as strength and durability due to the accelerating effect of NS on the cement paste.

The addition of nano-silica to cement pastes and concrete has various effects. Its accelerating impact on cement paste hydration is well-documented in literature. The primary mechanism behind this acceleration is attributed to the large surface area of NS, which acts as nucleation sites for CSH-gel formation. However, the exact cause of the accelerated hydration, whether due to chemical reactivity (pozzolanic activity) or surface reactivity, remains unclear. The acceleration effect has also been indirectly confirmed through rheological studies, which show that cement paste and mortar with NS require more water to maintain workability, suggesting a higher tendency for ionic species adsorption and agglomerate formation. In such cases, a dispersing agent or plasticizer is needed to counteract this effect.

Research by Ji investigated the impact of NS on water permeability and microstructure of concrete. Various mixes with NS particles (10 to 20 nm in size) showed improved microstructure and reduced water permeability. Lin et al. demonstrated that NS addition reduces permeability in eco-concrete, and similar results were observed in concrete with high fly ash content. Microstructural analyses revealed that NS concrete is more uniform and compact than normal concrete. Additionally, NS interacts with $Ca(OH)_2$ crystals, reducing their size and quantity, thus densifying the interfacial transition zone (ITZ) between aggregates and cement paste. NS particles fill the voids in the CSH-gel structure and act as nuclei for bonding with CSH-gel particles, enhancing durability by reducing calcium leaching from cement pastes.

The most commonly reported effect of NS addition is its impact on the mechanical properties of concrete and mortars. NS increases density, reduces porosity, and improves the bond between the cement matrix and aggregates, resulting in higher compressive and flexural strength. The effect of NS depends on its nature and production method (colloidal or dry powder). Although the beneficial effects of NS are well-documented, its concentration is typically limited to a maximum of 5% to 10% by weight of cement to avoid issues such as autogenous shrinkage and increased cracking potential. To mitigate these effects, a high concentration of superplasticizer and water must be added, along with appropriate curing methods.

III.APPLICATIONS OF NANO SILICA

Currently, due to their cost, micro-silica (Sf and SF) and nano-silica (NS) are primarily used in high-performance concretes (HPC), eco-concretes, and self-compacting concretes (SCC). These materials are especially crucial for eco-concrete and SCC. While some experimental uses of NS can be identified in specialized applications such as high-performance well cementing slurries, mortars for rock-matching grouting, and gypsum particleboard, practical utilization of NS remains limited. These advanced concretes are used in various infrastructure and building projects.

In HPC and SCC, nano-silica acts mainly as an anti-bleeding agent, enhancing concrete cohesiveness and reducing segregation tendencies. Some studies suggest that adding colloidal NS (0 to 2% by weight of cement) slightly reduces the strength development of concretes containing ground limestone but does not affect the compressive strength of mixtures with fly ash or ground fly ash (GFA). Sari et al. used colloidal NS (2% by weight of cement) to produce HPC concrete with a compressive strength of 85 MPa, along with anti-bleeding properties, high workability, and reduced demolding times (10 hours).

Another well-documented application of NS is its use in eco-concrete mixtures and tiles. Eco-concretes involve replacing cement with waste materials, such as sludge ash, incinerated sludge ash, fly ash, or other supplementary waste materials. One of the main challenges with these mixtures is their low compressive strength and extended setting period. Incorporating NS into eco-concrete mixes addresses this issue by accelerating setting and increasing compressive strength.

Roddy et al. investigated the use of particulate nano-silica (NS) in oil well cementing slurries, focusing on two distinct particle size ranges: 5 to 50 nm and 5 to 30 nm. They used NS dry powders in encapsulated form at concentrations of 5 to 15% by weight of cement. The evaluation showed that adding NS reduced setting time and increased the strength (including compressive, tensile, Young's modulus, and Poisson's ratio) of the cement compared to other silica constituents (including amorphous particles sized 2.5 to 50 µm, crystalline particles sized 5 to 10 µm, and colloidal suspension particles sized 20 nm).

IV. CONCLUSIONS

A novel nano-silica (NS) is now available in large quantities at competitive prices, enabling its widespread use in concrete. This innovation has the potential to replace cement, the most expensive and environmentally harmful component of concrete mixes. Incorporating NS makes concrete more cost-effective while also reducing its CO2 emissions. Additionally, NS improves various properties of concrete, such as workability and performance in its hardened state, supporting the development of high-performance concretes suitable for demanding construction projects. This advancement allows for the design of concrete with superior performance, lower costs, and better ecological sustainability.

Further research is needed to refine NS production methods to prevent agglomerate formation. Strategies such as developing liquid-state NS products, using surfactants, ultra sonification, and microwave drying should be explored to ensure better dispersion of synthesized NS from olivine dissolution. Moreover, investigating the impact of synthesized NS on the hydration of Portland cement-based systems through techniques like differential calorimetric analysis, adiabatic temperature measurements, pore solution analysis, and mathematical modeling is crucial for advancing our understanding of NS's role in concrete formulations.

REFERENCES

1. R.D. Schuiling, A method for neutralizing waste sulphuric acid by adding a silicate". Utrecht University, European Patent Application no 8590343.5. (1986).
2. D.J. Lieftink, "The preparation and characterization of silica from acid treatment of olivine", Ph.D. Thesis

(1997), Utrecht University, The Netherlands.
3. R.C.L. Jonckbloedt, “The dissolution of olivine in acid, a cost effective process for the elimination of waste acids”, Ph.D. Thesis (1997), Utrecht University, The Netherlands.
4. Lazaro, “Nano-silica production by a sustainable process; application in building materials”, 8th fib PhD Symposium in Kgs. Lyngby, Denmark (2010), pp 1-6.
5. H.J.H. Brouwers and H.J. Radix, “Self-compacting concrete: theoretical and experimental study”, Cement and Concrete Research 35 (2005), pp 2116–2136.
6. M. Hunger, and H.J.H. Brouwers, “Natural stone waste powders applied to SCC mix design”, Restoration of Buildings and Monuments 14 (2008), pp. 131-140.
7. Cembureau, CEMBUREAU (The European Cement Association), www.cembureau.eu, Brussels, Belgium (2008).
8. W.B. Fuller and S.E. Thompson, “The laws of proportioning concrete“, Trans. Am. Soc. Civ. Eng. 33 (1907), pp. 222-298.
9. H.W. Reinhardt, “Beton als constructiemateriaal”, Delftse Universitaire Pers. (1998), Delft, The Netherlands (in Dutch).
10. A.M. Neville, “Properties of Concrete” (4th ed.), Prentice Hall/Pearson, Harlow, U.K. (2000).
11. G. Hüsken and H.J.H. Brouwers, “A new mix design concept for earth-moist concrete: A theoretical and experimental study”, Cement and Concrete Research 38 (2008), pp 1246–1259.
12. A.Dunster, “Silica fume in concrete”, Information paper N° IP 5/09, IHS BRE Press, Garston, U.K. (2009).
13. S. Sakka and H. Kosuko, “Handbook of sol-gel science and technology, Volume I: Solgel Processing”, Kluwer Academic Publisher, New York, USA (2000), pp 9-10.
14. K. Sobolev, I. Flores and R. Hermosillo, “Nanomaterials and Nanotechnology for High- performance cement composites, “Proceedings of ACI Session on “Nanotechnology of Concrete: Recent Developments and Future Perspectives”, November 7, Denver, USA (2006), pp 91-118.
15. K. Sobolev and M. Ferrara, “How nanotechnology can change the concrete word”-Part 1, American Ceramic Bulletin, Vol. 84, N°10, (2005), pp 15-17.
16. M. Estevez, S. Vargas, V.M. Castaño, and R. Rodríguez, “Silica nano-particles produced by worms through a bio-digestion process of rice husk”, Journal of Non- Crystalline Solids 355 (2009), pp 844–850.
17. R.K. Iler, “The Colloid Chemistry of Silica and Silicate”. Edit. Ithaca, New York (1955), pp 1-250.
18. R.R. Zaky, M.M. Hessien, A.A. El-Midany, M.H. Khedr, E.A. Abdel-Aal and K.A. El- Barawy, “Preparation of silica nanoparticles from semi-burned rice straw ash”, Powder Technology 185 (2008), pp 31–35.
19. N. Thuadaij and A. Nuntiya, “Synthesis and Characterization of Nanosilica from Rice Husk Ash Prepared by Precipitation Method”, J.Nat.Sci. Special Issue on Nanotechnology (2008), Vol. 7(1), pp 59-65.
20. R.C.L. Jonckbloedt, “Olivine dissolution in sulphuric acid at elevated temperatures— implications for the olivine process, an alternative waste acid neutralizing process”, Journal of Geochemical Exploration 62 (1998), pp 337–346.
21. Y. Qing, Z. Zenan, K. Deyu and Ch. Rongshen, “Influence of nano-SiO2 addition on properties of hardened cement paste as compared with silica fume”, Construction and Building Materials 21 (2007), pp 539–545.
22. L. Senff, J.A. Labrincha, V.M. Ferreira, D. Hotza, and W.L. Repette, “Effect of nano- silica on rheology and fresh properties of cement pastes and mortars”, Construction and Building Materials 23 (2009)
23. Verma, P., Dhurvey, P., & Sundramurthy, V. P. (2022). Potential Assessment of E-Waste Plastic in Metakaolin Based Geopolymer Using Petrography Image Analysis. Advances in Materials Science and Engineering, 2022(1), 7790320.
24. Kim, J.K. and Lee, C.S., 1998. Prediction of differential drying shrinkage in concrete. Cement and Concrete Research, 28(7), pp.985-994.
25. Verma, P., Dhurvey, P., & Sundramurthy, V. P. (2022). Structural Behaviour of Metakaolin Geopolymer Concrete Wall-Type Abutments with Connected Wing Walls. Advances in Materials Science and Engineering, 2022(1), 6103595.
26. Fujiwara, T., 2008. Effect of aggregate on drying shrinkage of concrete. Journal of Advanced Concrete Technology, 6(1), pp.31-44.
27. Verma, P., Dhurvey, P., & Gour, C. P. (2023). Utilization of E-Waste as Coarse Aggregates in Geopolymer Concrete. In Sustainable Approaches and Strategies for E-Waste Management and Utilization (pp. 224-238). IGI

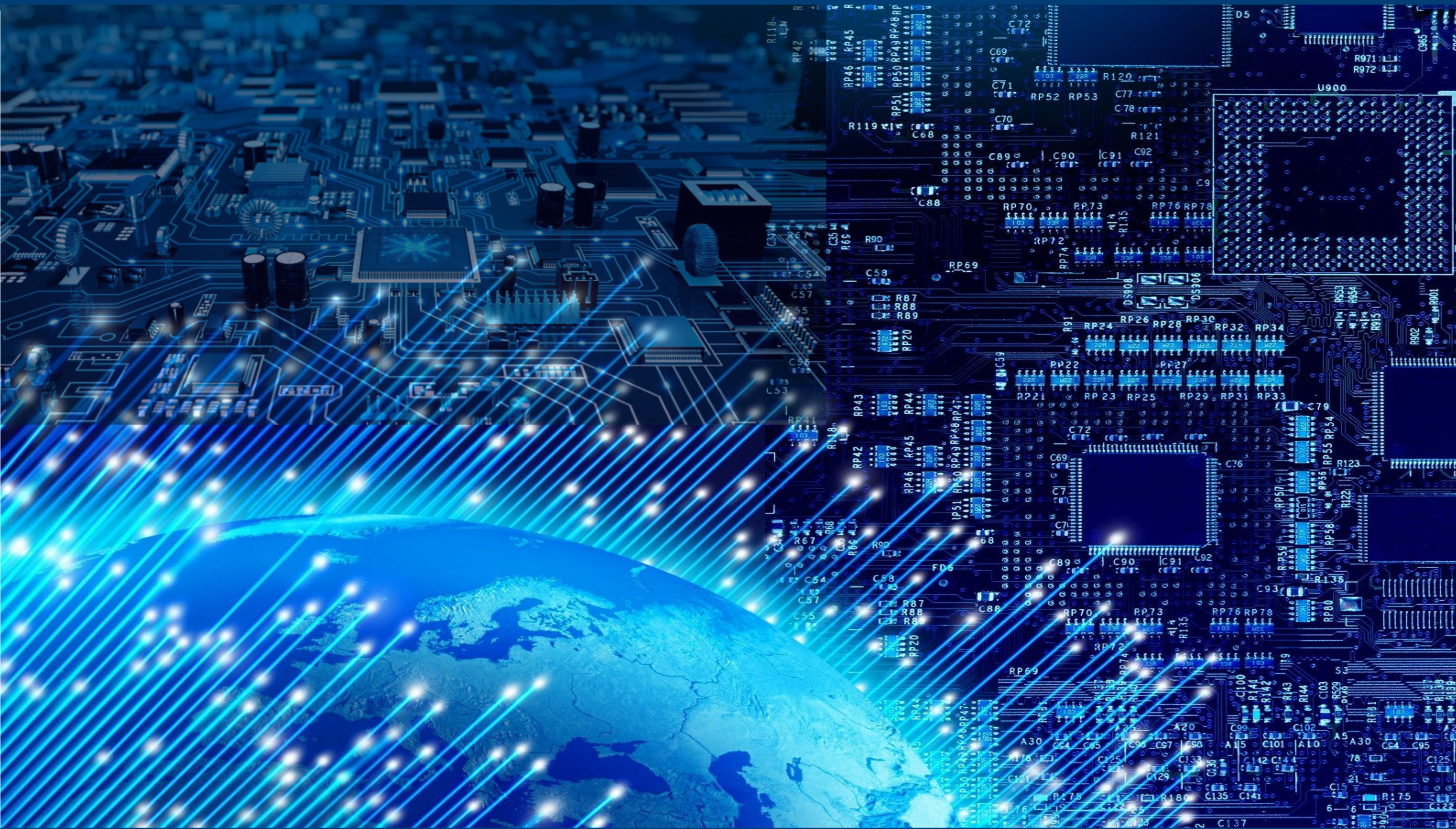
| ISSN: 2582-7219 | www.ijmrset.com | Impact Factor: 5.928| Monthly, Peer Reviewed & Referred Journal |

| Volume 5, Issue 1, January 2022 |

|DOI:10.15680/IJMRSET.2022.0501021 |

Global.

28. Li, J. and Yao, Y., 2001. A study on creep and drying shrinkage of high performance concrete. Cement and Concrete Research, 31(8), pp.1203-1206.
29. Sahu, B., Dhurvey, P., Verma, P., Raheem, J., & Bhargava, A. (2022, November). Behaviour Analysis of Layered Beam Using ANSYS. In International conference on Advances in Materials and Manufacturing (pp. 135-142). Singapore: Springer Nature Singapore.
30. Shariq, M., Prasad, J. and Abbas, H., 2016. Creep and drying shrinkage of concrete containing GGBFS. Cement and Concrete Composites, 68, pp.35-45.
31. Dhurvey, P., Panthi, H., Verma, P., & Gaur, C. P. (2023). Utilization of Waste eramic Tiles as Coarse Aggregates in Concrete. In Waste Recovery and Management (pp. 291-302). CRC Press.



INNO SPACE

SJIF Scientific Journal Impact Factor

Impact Factor: 5.928

INTERNATIONAL STANDARD SERIAL NUMBER INDIA

निस्केयर NISCAIR

INTERNATIONAL JOURNAL OF MULTIDISCIPLINARY RESEARCH IN SCIENCE, ENGINEERING AND TECHNOLOGY

9710 583 466

9710 583 466

ijmrset@gmail.com

www.ijmrset.com