**Studying the Strength characteristics of SCC by substituting Metakaolin for cement as well as adding Nano silica**

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**Abstract**

The use of self-compacting concrete (SCC) has increased significantly over the last few years, and extensive study and modification have been made to create self-compacting concrete with the appropriate properties. The use of treated and untreated industrial byproducts, household garbage, etc. as raw materials in concrete is currently popular throughout the world. These not only assist in recycling waste products but also improve the environment by being cleaner and greener. The use of metakaolin and nano-silica in SCC is the main topic of the current investigation. The steel bar corrodes when reinforced concrete is exposed to severe environments such chloride-bound air, which damages the concrete through its pore structure.

The usage of pozzolanic materials, such as metakaolin (MK) and nano-silica (NS), can be utilised as a partial cement replacement material that enhances the mechanical, durability, and microstructure of concrete while also reducing the number of pores in it. Work was done on an experimental study of the flowability, passing ability, compressive strength, split tensile strength, and flexural strength of SCC in this project. In this study, metakaolin and nano-silica were used to partially replace cement in the creation of SCC. Five mixtures with varying amounts of nano-silica (0%, 0.5%, 1.0%, and 1.5%) and metakaolin (5%, 10%, 15%, and 20%) as a partial replacement for cement are taken into consideration. Workability and toughened tests are conducted for each combination, and the findings for hardened attributes are reported.

Keywords: Self-compacting concrete, metakaolin, and rheological properties Self-compacting concrete, metakaolin, and rheological properties mechanical attributes, Mechanical characteristics of pores, pores.

**1.1 History of SCC**

SCC was developed in Japan, beginning in 1983, has been focused on the elimination of poor compaction which was identified as a major cause of poor durability of concrete structures by Ouchi, (1998). Motivated by a lack of skilled workers and a substantial number of durability damages due to insufficient compaction, Okamura announced in 1986 the necessity to employ SCC, which can be compacted into every corner of a formwork, purely employing its weight and without the need for vibrating compaction by Okamura and Ozawa.

**1.2 Introduction:**The development of new technology in the field of material science is advancing quickly, Numerous studies have been conducted globally over the past three decades to enhance the performance of concrete in terms of strength and durability attributes. Since the 1980s, concrete technology has been the subject of macro to micro-level research to improve its strength and durability features. Up until 1980, concrete technologists' attention was mostly focused on improving the flowability of the material while paying less attention to durability. SCC, a much-needed revolution in the concrete industries, was developed as a result of this type of research.

According to Okamura (1997), SCC is highly designed concrete that has a significantly higher fluidity without segregation and can fill every corner of formwork while bearing its own weight. As a result, SCC does away with the necessity for internal or external vibration to compact concrete without sacrificing its engineering qualities. SCC is a fluid mixture that can be used in dense reinforcement and challenging situations without vibrating. The following characteristics are necessary for self-compacting or self-consolidating concrete in theory:

**2.0 Literature review:** A literature review has been done to get an over review of the project of the subject and analysis the research gap for the research. The objective for the study has been framed by considering the research gap from the literature review.

**Prof. R.V.R.K. PRASAD et.al (2012)** in the present investigation on "Experimental investigation of the use of micro silica in self-compacting concrete" This paper is described the Project in detail and presents laboratory observation. Microsilica is used as a 10% replacement of cement by weight. Various tests were conducted on fine aggregate & coarse aggregate, to determine specific gravity, bulk density, fineness modulus of aggregate, concrete mix proportion design using this parameter.

**B. KARTHIKEYAN et.al (2014)** in the present investigation on “Microstructural analysis of strength properties of concrete with nano-silica" the study reports part of the experimental investigations on using nano-sized mineral admixtures in concrete as a partial replacement of cement. Mechanical properties were obtained by performing strength tests for specimens cast with different percentages of ground and unground micro-silica in partial replacements such as 5%, 10% and 15% by weight of cement. From the results, it is understood that cubes cast with 10% replacement of nano-silica for cement by weight are showing better strength performance.

**M.IYAPPAN.et.al(2014)** present an investigation report on "high strength self-compacting concrete with nano-silica" This article presents the benefits of SCC with Nano silica, nano-silica used as partial replacement of Portland cement in Self-compacting concrete with different percentage, fresh and hardened properties of SCC are established. There are three different replacement percentages of Nanosilica (0%,2%,4%,6%) is used in this study. The Hardened Properties like compressive strength, splitting tensile strength, Flexural strength were evaluated at 28 days.

**Dr. D .V. PRASADA RAO et.al (2014)** In the present experimental investigation "A study on the influence of fly ash and nano-silica on strength properties of SCC”the cement is partially replaced by 20% and 30% of Fly Ash and Nano-Silica 1.5%, 3% and 4.5% by weight. The influence of the combined application of Fly Ash and Nano-Silica on compressive strength, split tensile strength, flexural strength, and modulus of elasticity of M25 grade of concrete is established.

**A.HEIDARI et.al (2015)** study on "Properties of Self-compacting concrete incorporating alginate and nano-silica" This paper presents an experimental study on the properties and the durability of self-compacting concrete (SCC) containing alginate in variety values with artificial stone resin, micro, and nano-silica. The values of 0.5 and 1% alginate, 10% micro silica, 0.5% nano-silica and 0.5% artificial stone resin are used. . Properties of hardened SCC such as compressive, split tensile, flexural strength and water absorption are assessed and represented graphically.

**SANGA KRANTHI KUMAR et.al (2015)** In the present investigation on “Influence of nano-silica on strength and durability of self-compacting concrete" In this work 40Mpa self-compacting concrete is developed using modified Nan-Su method of mix design. Specimens of dimensions 150x150x150mm were cast without nano-silica and with two different grades of nano-silica which is in a colloidal state with 16% and 30% nano, content is added in different percentages (1%, 1.5%, and 2% by weight of cement) to SCC.

**2.1 Main objectives of present investigation:**

Based on exhaust relevant literature review, the main objectives derived is as follows,

⮚ Metakaolin and nano-silica are used to create SCC mixtures.

⮚ Study of the properties of freshly made and hardened SCC mixes in a lab.

⮚ Results of generated mixes compared to the Control Mix

**3.0 Methodology**

In the current inquiry, M40 grade SCC is being designed using EFNARC-required principles. Rheology and hardened characteristics of newly created mixes are investigated for both standard SCC and the replacement of cement with metakaolin and nano-silica. The first step of the methodology, which comprises of three phases, deals with the design of SCC mixes utilising an appropriate mix design approach in accordance with the literature study. The second stage deals with achieving the appropriate design SCC mix through a process of trial and error while satisfying all the rheological requirements. The examination of the laboratory-developed SCC mixtures' toughened qualities is covered in the third step. Additionally, a schedule for casting several cubes and cylinders is established.

The mix design planned is a modified Nan-us method because it is flexible when compared to other methods of mix design. The percentage replacement of metakaolin is chosen in the range from 10% and three different additive percentages of Nanosilica (0%, 0.5%, 1.0%, 1 .5%).

3.1 Different test were conducted for OPC 53 grade cement,metakaolin, Nanao silica, fine aggregate, coarse aggregate, water as specified by relevant IS Codes

**3.1.1 Cement:** The cement used for the investigation was Ordinary Portland cement (OPC) 43grade with specific gravity 3.13 and fineness 4% was used. It confirmed the requirements of Indian Standard Specification IS: 269 2015.

**3.1.2 Fine aggregate:** M.sand was used as fine aggregate and tests were conducted on fine aggregate to determine physical properties a per IS 383-2.16. The specific gravity of fine aggregate 2.65and belongs to zone II. The fineness modulus was found to be 2.85.

**3.1.3 Course Aggregates:** The maximum size of aggregate is generally limited to 20mm. The aggregate of size 12 mm is desirable for structures having congested reinforcement. The properties of coarse aggregate are specific gravity 2.80, fineness modules 7.06 and water absorption was 0.48%

**3.1.4 Water:** Ordinary potable water of normally pH 7 is used for mixing and curing the concrete specimen.

**3.1.5 Superplasticizer:** In the present study by using **CONPLAST SP430** is used because it is an essential component of SCC to provide necessary workability. The specific gravity -1.25

**3.1.6 Nano Silica:** The specific gravity of nano-silica is 1.03, and they are silica particles with a maximum size of 10 nm, In addition, nano-silica is a water emulsion with 50 % dry solid and PH of 10. The control mix was excluding nano-silica. It is obtained from Astro chemicals, Chennai.

**Table 2.1: Properties of Nano silica**

|  |  |
| --- | --- |
| Solid content (SiO2-content) | 50 wt % |
|  Density | 1.4 g/cm3 |
| Ph | 9.5 |
| Viscosity | <15cPS |
| Specific surface Area m2/gm | 650 |

**3.1.7 Metakaoline:-**Metakaolin is an artificial pozzolana produced by burning selected kaolinite clay within a specific temperature range (between 650 and 800 C). When heated to 700–900 C, kaolin becomes calcined, losing up to 14% hydroxyl water and changing into MK. The specific gravity of 2.5 and lime reactivity 780mgCa(OH)2. It is obtained from Astro chemicals, Chennai.

**Table 2.2: Chemical properties of metakaolin.**

|  |  |
| --- | --- |
| **Constituents** | **Percent** |
| CaO | 0.78 |
| SiO2 | 52.68 |
| Al2O3 | 36.34 |
| Fe2O3 | 2.14 |
| MgO | 0.16 |
| SO3 | - |
| K2O | 0.62 |
| Na2O | 0.26 |
| LOI | 0.98 |
| Specific Gravity | 2.5 |
| BET Fineness (m2/kg) | 12000 |

**3.2 Mix proportion**

To investigate the impact of MK and NS inclusion on compressive strength and splitting tensile strength, ten different mixes were used.The water-cement ratio was 0.40, and the mix was created for 40 MPa. The Nan-Su method's design mix ratio is then utilised to create SCC through trial mixes. According to EFNARC criteria, the produced mixtures must fulfil the fresh property. The final developed ratio, which replaces cement with metakaolin by amounts of (5%, 10%, and 15%) and adds nanosilica at intervals of 0.5% for the best mix, satisfies all EFNARC criteria. Additionally, fresh and hardened properties will be studied.

With a quantity of fine aggregate, coarse aggregate, water content, and a water to binder ratio that will not change (fine aggregate 910Kg/m3, coarse aggregate, 910Kg/m3, water 160 ka/m3), conventional mix and all SCC mixes have a cement content of (400 kg/ m3 varies replacement MK and additive of NS). The marsh cone test was used to determine the ideal superplasticizer dosage, which was determined to be 1%.Details are provided in Table.3.1

**Table 3.1: Cementitious Materials of SCC**

|  |  |  |
| --- | --- | --- |
| **Mix proportions** |  | **Cement replacement and additive**  |
| **Cement (kg)** | **Metakaolin (gms)** | **Nano silica (gms)** |
| NOMINAL MIX |  | 400 | - | - |
| 5%MK+0.5%NS |  | 380 | 20 | 2 |
| 5%MK+1.0%NS |  | 380 | 20 | 2 |
| 5%MK+1.5%NS |  | 380 | 20 | 2 |
| 10%MK+0.5%NS |  | 360 | 40 | 4 |
| 10%MK+1.0%NS |  | 360 | 40 | 4 |
| 10%MK+1.5%NS |  | 360 | 40 | 4 |
| 15%MK+0.5%NS |  | 340 | 60 | 6 |
| 15%MK+1.0%NS |  | 340 | 60 | 6 |
| 15%MK+1.5%NS |  | 340 | 60 | 6 |

**3.3 Casting, Curing, and Testing of Specimens**

Workability tests are conducted on each blend. By measuring the fresh properties of the different SCC mixes in accordance with the EFNARC criteria (Slump Flow, T50 Slump Flow, V-Funnel, and J-Ring tests), as well as the hardened concrete properties such compressive strength and splitting tensile strength test, the workability of the various SCC mixes was evaluated. In the instance of the strength research, 90 specimens of each type were demolded after being cast in for 24 hours, and they were then stored in a curing tank for water curing until the test ages were attained.

**4.0 Results and Discussion:** The investigation's evaluation results are presented in the form of tables and graphs. For various percentages of MK as a partial replacement to cement ranging from 5 to 15% at an interval of 5% and additive of NS (0.5%-1.5%), the test results of materials, trial mixes, fresh properties of SCC, and hardened characteristics of SCC are worked out

**4.1 Fresh properties of SCC:** In the laboratory, the filling ability, passing ability, and segregation resistance of various mixes were used to observe the fresh self-compacting concrete qualities.according to table 4.1

**(i) Filling ability:** Using a filling ability, passage ability, and segregation resistance of various mixes in the laboratory, the fresh self-compacting concrete qualities were studied.as displayed in table 4.1..

**(ii) Passing ability (resistance to blocking):** SCC must navigate a variety of challenges and fill any gaps in the formwork without being obstructed by aggregates that cannot fit through the small gaps.

**(iii) Stability (segregation resistance):** SCC needs to be statically stable throughout finishing and curing, exhibit dynamic stability during mixing and transportation, and be homogeneous during placement.

**Table 4.1:** Fresh properties of SCC

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Mix Notions  | Slump flow | T50 Slump | v-funnel | J ring |
| Range of Suggested Valve | **(650-800mm)** | **(2-5 sec)** | **(6-12 sec)** | **(0-10 sec)** |
| NOMINAL MIX | 675 | 3.46 | 9.47 | 6 |
| 5%MK+0.5%NS | 673 | 3.34 | 8 | 7 |
| 5%MK+1.0%NS | 670 | 3.12 | 7.5 | 5 |
| 5%MK+1.5%NS | 699 | 3.04 | 9 | 6 |
| 10%MK+0.5%NS | 696 | 2.97 | 10 | 7 |
| 10%MK+1.0%NS | 693 | 2.90 | 11 | 8 |
| 10%MK+1.5%NS | 692 | 2.82 | 12 | 6 |
| 15%MK+0.5%NS | 687 | 3.45 | 10 | 4 |
| 15%MK+1.0%NS | 683 | 3.34 | 8 | 5 |
| 15%MK+1.5%NS | 678 | 3.12 | 9 | 6 |

**4.2 Cube Compressive Strength**

The concrete cube specimen of size 150mm×150mm×150mm was tested for each mix with replacement and without replacement, The test was according to IS Specifications and done on the 7th,28th, and 90th days of casting. Table 4.2 shows the compressive strength gained with age.

**Table 4.2: Comparisons between 7, 28 & 91 days Compressive Strength**

|  |  |  |
| --- | --- | --- |
| **Mix Proportions** |  | **Compressive strength ( MPa)** |
| **7 days** | **28 days**  | **91 days** |
| NOMINAL MIX |  | 18.05 | 41.98 | 50.35 |
| 5%MK+0.5%NS |  | 19.32 | 43.25 | 51.99 |
| 5%MK+1.0%NS |  | 20.32 | 45.23 | 52.08 |
| 5%MK+1.5%NS |  | 20.98 | 47.63 | 52.17 |
| 10%MK+0.5%NS |  | 25.58 | 47.98 | 52.27 |
| 10%MK+1.0%NS |  | 26.76 | 48.20 | 52.48 |
| 10%MK+1.5%NS |  | 27.27 | 48.83 | 52.58 |
| 15%MK+0.5%NS |  | 28.15 | 49.59 | 53.26 |
| 15%MK+1.0%NS |  | 28.74 | 49.71 | 53.49 |
| 15%MK+1.5%NS |  | 29.35 | 50.03 | 53.94 |

**Fig.4.1** Graph of variation of compressive strength versus age in days.

**Observations:** From **Fig.4.1,** The control SCC mixes were compared to MK and NS based mixes with replacement amounts of MK and NS by weight of cement, respectively, at 7, 28, and 90 days of compressive strength vs age. Bar charts are used to display additional replacement levels for MK and NS in the ranges of 5-15% and 0.5%-1.5% for different ages. Therefore, it can be seen that the variance of compressive strength is generally lower for nominal mixtures and slightly larger for MK and NS-based mixes. Additionally, it should be remembered that strength increases slightly with age (15.MK+1.5%NS) when compared to younger years.

**4.3 Split Tensile Strength**

The split tensile strength is the tensile strength of concrete determined indirectly by splitting a concrete cylinder specimen across its vertical diameter. Table 4.3 shows the variation of split tensile strength with replacement of metakaolin and addition of nano-silica content at 7, 28, and 91 days respectively.

**Table 4.3: Comparisons between 7, 28 & 91 days Split Tensile Strength**

|  |  |  |
| --- | --- | --- |
| **Mix Proportions** |  | **Split Tensile Strength (MPa)** |
| **7days** | **28days** | **91 days** |
| NOMINAL MIX |  | 2.69 | 3.46 | 4.60 |
| 5%MK+0.5%NS |  | 2.95 | 3.47 | 4.64 |
| 5%MK+1.0%NS |  | 3.20 | 3.51 | 4.68 |
| 5%MK+1.5%NS |  | 3.37 | 3.54 | 4.70 |
| 10%MK+0.5%NS |  | 3.40 | 3.57 | 4.73 |
| 10%MK+1.0%NS |  | 3.41 | 3.58 | 4.74 |
| 10%MK+1.5%NS |  | 3.42 | 3.70 | 4.76 |
| 15%MK+0.5%NS |  | 3.43 | 3.96 | 4.78 |
| 15%MK+1.0%NS |  | 3.44 | 4.15 | 4.89 |
| 15%MK+1.5%NS |  | 3.45 | 4.52 | 5.01 |

**Fig.4.2** Graph of variation of splitting tensile strength versus age in days.

**Observations:** From Fig.4.2,it is observed that a comparison of 7, 28 &90 days splitting tensile strength versus age in days, the control SCC mixes compared to MK and NS based mixes with replacement levels of MK and NS by weight of cement respectively. Further replacement levels of MK and NS in the ranges of 5-15% and 0.5%-1.5% for various ages are presented in the form of bar charts. Hence it is observed that the variation of compressive strength is lower in the case of Nominal mixes and marginally higher in the case of MK and NS-based mixes in all cases. Also, it is noted that there is a marginally increase in strength 15%MK+1.5%NS at a higher age than compared to lower ages.

**5.1 Conclusions**

Based on the laboratory investigation the following important conclusions have arrived.

* For SCC mixes to have strong rheological properties, a high powder content and a wide range of superplasticizer dosage are necessary..
* It's crucial to add the superplasticizer at the right moment, which is typically between 50 and 70 percent of the water. SCC fills the formwork and encapsulates the reinforcements without vibration, to achieve compaction by its own weight and gives an excellent surface finish.
* Based on test results, cement can be replaced up to 15% by a mixture of NS and MK without weakening the mixes.
* Experimental results have been made by employing NanoSilica to improve the porosity of the developed concrete mix. It is noted that compressive strength increases up by increasing the replacement of cement by adding 1.5% NanoSilica and 15% Metakoline.
* **References**

[1]. M .Iyappan. “high strength self compacting concrete with nano silica”International Journal of Emerging Trends in civil engg.

[2]. Sanga kranthi kumar “Influence of nano silica on strength and durability of self compacting concrete” International Journal of Advanced and Applied Sciences

[3].B. H. Venkataram Pai, Maitreyee Nandy, A. Krishnamurthy, Pradip Kumar Sarkar,C. Pramukh Ganapathy, Philip George “Development of self compacting concrete with various mineral admixtures”,

[4]. A.HEIDARI e(2015) “Properties of Self compacting concrete incorporating alginate and nano silica” . Asian journal of civil engineering vol. 16, pp 1-11.

[5]. Dr. D .V. Prasada rao (2014) “A study on influence of fly ash and nano silica on strength properties of SCC”.IJART,Issn 0976 - 6480 (Print) ,ISSN 0976 - 6499 (Online)Volume 5, Issue 7, July (2014), pp. 94-102

[6]. B. Karthikeyan et.al (2014) “Microstructural analysis of strength properties of concrete with nano silica” International Journal of ChemTech Research CODEN (USA): IJCRGG, Vol.6, No.5, pp 3004-3013

[7]. Prof. R.V.R.K. Prasad et.al(2012) “Experimental investigation of use of microsilica in self compacting concrete” Indian Streams Research Journal Vol.2,Issue.IV/May; 12 pp.1-4.

[8]. Ozawa K., and Maekawa, K, (1989), “Development of high performance concrete based on durability design of concrete structure,” Proceeding of the Second East- Asia and Pacific Conference (EASEC-2), Vol.1, pp. 445-450.

[9]. Okamura, H.and Ozawa, K., (1995), “Mix-design for self-compacting concrete,” Concrete Library, JSCE, Vol. 25, pp.107-120.

[10]. Rame Gowda, Narasimhan.M.C; and Karisiddappa, (2011), “Development and study of the strength of self-compacting mortar mixes using local materials”, 526 / Journal of Materials in Civil Engineering ,ASCE / May, pp. 526-532.

[11. IS 269-2015 Indian Standard Specification for 43 Grade Ordinary Portland cement, First revision, BIS, New Delhi, 1989.

[12]. IS 383-2016, Specification for coarse and fine aggregate for natural sources for concrete, second revision, 9th reprint, 1993.

[13]. <http://www.efnarc.org/pdf/SCCGuidelinesMay2005.pd>