

STUDYING THE STRENGTH CHARACTERISTICS OF SCC BY SUBSTITUTING METAKAOLIN FOR CEMENT AS WELL AS ADDING NANO SILICA

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.

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I. BACKGROUND OF SCC

SCC was created in Japan starting in 1983 with an emphasis on the eradication of inadequate compaction, which Ouchi (1998) highlighted as a significant factor in the lacklustre durability of concrete buildings. Okamura announced in 1986 the need for SCC, which can be compacted into every corner of a formwork purely using its weight and without the need for vibrating compaction by Okamura and Ozawa, due to a lack of skilled workers and a significant number of durability damages caused by inadequate compaction.

II. INTRODUCTION

The field of material science is rapidly developing new technologies. Over the past three decades, several research have been carried out worldwide to improve the strength and durability of concrete. 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:

III. 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.

1. **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 report offers laboratory observations and a detailed description of the Project. By weight, microsilica is used to replace 10% of cement. To calculate specific gravity, bulk density, fineness modulus of aggregate, and concrete mix percentage design utilising this parameter, various tests on fine and coarse aggregate were carried out.
2. **B. Karthikeyan et.al (2014):** Portion of the experimental studies on employing nano-sized mineral admixtures in concrete as a partial replacement for cement is reported in the current inquiry, "Microstructural analysis of strength properties of concrete with nano-silica." Strength tests on specimens cast with various amounts of ground and unground micro-silica in partial replacements, such as 5%, 10%, and 15% by weight of cement, were used to determine the mechanical characteristics. According to the findings, cubes that were cast with 10% more nano-silica than cement by weight are performing better in terms of strength.

3. **M.Iyappan.et.al(2014):** Report on a research on "high strength self-compacting concrete with nano-silica" The advantages of SCC with nano-silica are discussed in this article. Both the fresh and hardened characteristics of SCC are established, and nano-silica is employed as a partial substitute for Portland cement in SCC at various percentages. In this investigation, three different Nanosilica replacement percentages (0%, 2%, 4%, and 6%) are employed. A 28-day evaluation of the hardened properties, including compressive strength, splitting tensile strength, and flexural strength.
4. **Dr. D .V. Prasada Rao et.al(2014):** The cement is partially replaced by 20% and 30% of Fly Ash and Nano-Silica 1.5%, 3%, and 4.5% by weight in the current experimental research, "A Study on the Influence of Fly Ash and Nano-Silica on Strength Properties of SCC." It is demonstrated that the use of Fly Ash and Nano-Silica together has an impact on the compressive strength, split tensile strength, flexural strength, and elastic modulus of concrete of the M25 grade.
5. **A.Heidari et.al(2015):** The study is on the "Properties of Self-compacting Concrete Incorporating Alginate and Nano-silica" This article includes an experimental investigation into the endurance and qualities of self-compacting concrete (SCC) that contains alginate in a range of concentrations together with synthetic stone resin, micro, and nano-silica. Alginate concentrations of 0.5%, 0.1%, 10%, 0.5%, and 0.5% of artificial stone resin are utilized. Compressive, split tensile, flexural, and water absorption properties of hardened SCC are evaluated and visually displayed.
6. **Sanga Kranthi Kumar et.al (2015):** he modified Nan-Su technique of mix design is used to create 40Mpa self-compacting concrete in the current inquiry on "Influence of nano-silica on strength and durability of self-compacting concrete." Without nano-silica and with two different grades of nano-silica that are in a colloidal condition with 16% and 30% nano, content is added in different amounts (1%, 1.5%, and 2% by weight of cement) to SCC specimens of dimensions 150x150x150mm.

IV. PRINCIPAL GOALS OF THE CURRENT INQUIRY

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

1. Met kaolin and nano-silica are used to create SCC mixtures.
2. Study of the properties of freshly made and hardened SCC mixes in a lab.
3. Results of generated mixes compared to the Control Mix

V. 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.

When compared to other mix design techniques, the planned mix design is a modified Nan-us approach since it is flexible. Three alternative additive Nanosilica percentages (0%, 0.5%, 1.0%, and 1.5%) are chosen as well as a replacement percentage for metakaolin in the range of 10%.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

- 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.
- 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. 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%
- 4. Water:** For mixing and curing the concrete specimen, regular drinkable water with a pH of 7 is utilized.
- 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
- 6. NanoSilica:** The greatest size of nano-silica particles, which have a specific gravity of 1.03, is 10 nm. Additionally, nano-silica is a water emulsion with a PH of 10 and a 50% dry solid content. Nano-silica was not included in the control mixture. It is purchased from Chennai's Astro Chemicals.

Table 1: Properties of Nano silica

Solid content (SiO ₂ -content)	50 wt %
Density	1.4 g/cm ³
Ph	9.5
Viscosity	<15cPS
Specific surface Area m ² /gm	650

- 7. Metakaoline:** Metakaolin, a synthetic pozzolana, is created by igniting chosen kaolinite clay at a particular temperature (650–800 C). Kaolin is calcined at temperatures between 700 and 900 C, losing up to 14% of its hydroxyl water content and converting into MK.

The reaction between lime and the specific gravity of 2.5 is 780 mg Ca(OH)₂. It is acquired from Chennai's Astro Chemicals.

Table 2:Chemical properties of metakaolin

Constituents	Percent
CaO	0.78
SiO ₂	52.68
Al ₂ O ₃	36.34
Fe ₂ O ₃	2.14
MgO	0.16
SO ₃	-
K ₂ O	0.62
Na ₂ O	0.26
LOI	0.98
Specific Gravity	2.5
BET Fineness (m ² /kg)	12000

VI. 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: 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

VII. 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.

VIII. FINDINGS AND DISCUSSION

Tables and graphs are used to display the investigation's evaluation findings. The test results of the materials, trial mixes, fresh properties of SCC, and hardened characteristics of SCC are calculated for different 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%).

IX. 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. **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.
2. **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.

3. **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: 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

X. 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 5: 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

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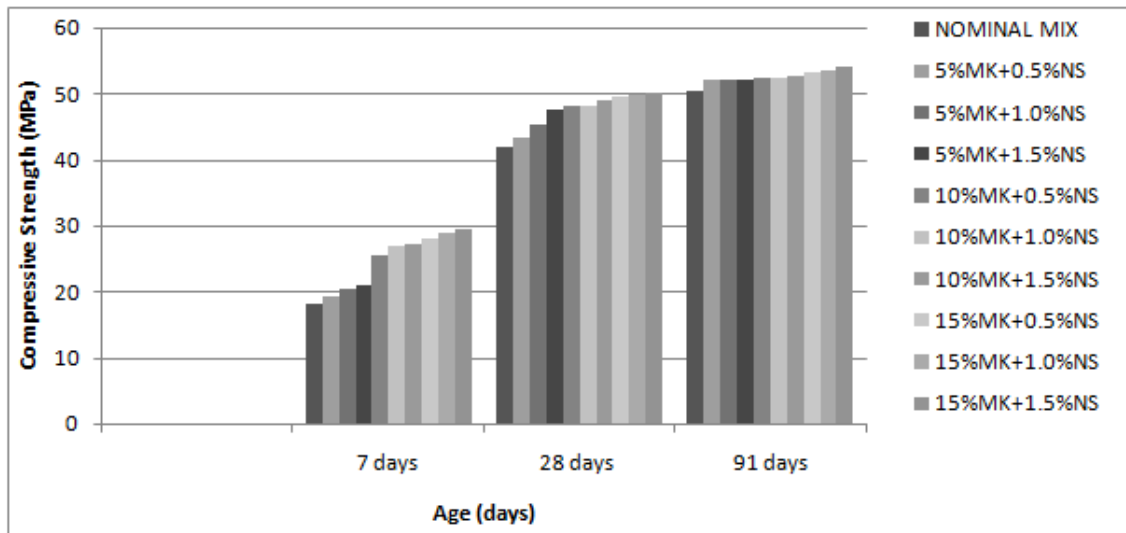


Figure:1 Graph of variation of compressive strength versus age in days.

- Observations:** From **Figure 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.

XI. SPLIT TENSILE STRENGTH

By splitting a concrete cylinder specimen along its vertical diameter, the split tensile strength of the concrete may be indirectly calculated. With the removal of metakaolin and the addition of nano-silica content at 7, 28, and 91 days, respectively, Table 4.3 illustrates the fluctuation in split tensile strength.

Table 6: 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

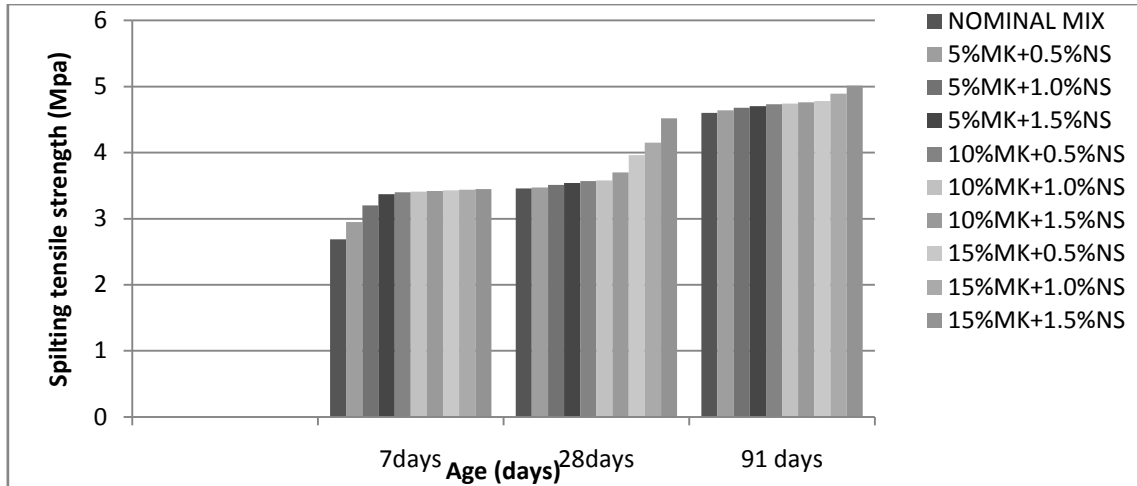


Figure 2: Graph of variation of splitting tensile strength versus age in days.

- 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.

XII. CONCLUSIONS

The laboratory examination has led to the following significant findings.

- Strong rheological qualities need SCC mixes to have a high powder concentration and a range of superplasticizer dosages.
- 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% Metakaolin.

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