

Eco-Friendly Self-Compacting Concrete: Exploring the Feasibility of Replacing Cement with Cashew Nut Shell Ash

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Abstract

Large amounts of waste byproducts are produced annually by the agro-industrial sector, but since they are poorly managed and their values are not understood, they pose risks to the environment, society, and the economy. Thus, using a mix design ratio of grade 40 MPa concrete (M 40), this study investigated the ash from cashew nutshell waste and substituted it with Ordinary Portland cement (OPC) at 35%, 50%, and 75%. To create cashew nutshell ash (CNSA), the cashew nutshell was sun-dried for 14 days before being burned in a gas furnace for 5 hours at 750 C. While investigating the workability of the fresh concrete, the CNSA's chemical and physical characteristics were looked at. Additionally, the hardened concrete's mechanical characteristics were examined. The results of the experiment showed that CNSA satisfies the criteria for usage as a pozzolanic material. Additionally, when the percentage of CNSA grew, the hardened concrete's compressive, splitting, tensile, and flexural strengths improved, reaching their peak at a 35% replacement level. The benefit of this study is that construction joints would be reduced as fresh concrete would be used for extended periods of time. Additionally, using CNSA concrete in environments with high sulfate concentration is advantageous.

Keywords- *Agro-industrial waste, CNSA, Green concrete, SCC, partial-cement replacement*

INTRODUCTION

Concrete is a versatile construction product made of cement, aggregates, water, and admixtures. Ordinary Portland cement (OPC) is widely used but emits CO₂ into the atmosphere. To reduce CO₂ emissions, initiatives aim to reduce OPC production by 2030. Agro-industrial wastes, such as fly ash, ground granulated blast furnace slag, corncob ash, and rice husk ash, have been used to partially or completely replace OPC in concrete production. This reduces environmental and economic threats associated with OPC production. Sustainable concrete solutions aim to address environmental concerns by incorporating supplementary cementitious materials, reducing carbon footprint, and utilizing recycled aggregates and waste materials. Life cycle assessment studies evaluate concrete's environmental impact throughout its life. As concrete evolves, challenges arise in durability, longevity, and resistance to environmental factors. Advancements in materials, reinforcement techniques, and mix design have expanded construction possibilities, with specialized types like HPC, FRC, SCC, and UHPC. Sustainable practices and technologies aim to reduce the environmental impact of concrete production.

Self-Compacting Concrete

Self-compacting concrete (SCC) is an innovative and highly flowable construction material that eliminates the need for vibration during placement, offering numerous advantages. SCC's unique mix design incorporates superplasticizers and stabilizers to achieve high flowability and self-leveling properties. It can effortlessly fill complex formworks and densely reinforce intricate structures. SCC enhances construction efficiency and worker safety by reducing labor and noise pollution. Its superior flowability ensures proper compaction around congested reinforcement, resulting in improved durability and structural integrity. The self-consolidating nature of SCC also minimizes surface defects and air voids, leading to enhanced aesthetics and long-term performance. Despite its benefits, SCC requires meticulous mix design and thorough quality control to prevent segregation and excessive bleeding. Proper handling and curing are essential to achieve its full potential. SCC is a cutting-edge concrete technology that revolutionizes construction practices, offering a cost-effective, durable, and aesthetically pleasing solution while streamlining construction processes.

Cashew Nut Shell Ash

When cashew nut shells are burned, they produce cashew nut shell ash (CNSA), a plentiful and sustainable cementitious material. Due to its high silica and oxide content, it can substitute some cement in the formation of concrete. By increasing compressive strength, lowering permeability, and minimizing alkali-silica interactions, CNSA enhances the mechanical qualities and durability of concrete. By recycling a waste product that would otherwise be thrown away, it also lessens its impact on the environment. To avoid negative impacts on the performance of concrete, however, it is essential to optimize the quantity of CNSA. For concrete to be successfully used as a green building material, proper testing and quality control must be carried out throughout manufacture utilizing CNSA.

Table 1 – Chemical Composition of CNSA

Chemical Components	Percentage
SiO ₂	63.95%
Al ₂ O ₃	14.95%
Fe ₂ O ₃	12.51%
CaO	0.86%

CNSA as Cement replacement in SCC:

Self-compacting concrete (SCC) can benefit from using cashew nut shell ash (CNSA) as a partial cement substitute to increase workability, strength, durability, and minimize environmental effect. The pozzolanic activity of CNSA combines with calcium hydroxide to strengthen and prolong the life of the concrete. Improved workability and flowability follow from this, particularly in SCC where self-leveling and filling of intricate shapes without external compaction are sought. As a result of the pozzolanic interaction between CNSA and calcium hydroxide, which results in the development of extra hydration products and increased mechanical characteristics as well as decreased permeability, CNSA also improves the long-term strength and durability of SCC. This causes the concrete structure's service life to be extended, durability to improve, and cracking resistance to enhance.

SCOPE OF PRESENT STUDY

General

In this part the purpose and scope of the current study are discussed, which is concerned with the characteristics aspects of the partial replacement of CNSA, and strength prediction.

Scope

- Firstly, the study will involve an in-depth investigation of the physical, chemical, and mechanical properties of cashew nut shell ash.
- Understanding these properties will provide insights into the suitability of CNSA as a partial replacement for cementitious materials in SCC.
- The scope also includes conducting a comprehensive experimental program to evaluate the fresh and hardened properties of SCC incorporating CNSA.
- In summary, the scope of the work encompasses evaluating the physical and chemical properties of CNSA, investigating the fresh and hardened properties of CNSA-based SCC, assessing the mechanical and durability characteristics, analyzing the sustainability aspects, and providing practical recommendations for its application.
- The aim is to contribute to the development of sustainable and high-performance SCC mixtures using CNSA as a partial cement replacement.

METHODOLOGY

- The methodology for producing self-compacting concrete is divided into several steps.
- The steps follow, like material mix design, workability tests, mechanical tests, and a microstructure study of the concrete.
- The concrete mix included coarse aggregates, fine aggregates, CNAs, fly ash, cement, and chemical admixtures.
- The above-mentioned materials are tested for basic material testing to satisfy the basic criteria for using those materials. The material test results are used to prepare the mix design.
- The mix design for M40-grade concrete is created per IS 10262:2009.
- The slump flow test, the V-funnel test, and the J-ring test are used to determine the properties of self-compacting concrete mixes.
- The compressive strength of the mixes is determined by testing 9 cubes of fly ash replacement and 9 cubes of CNA replacement at 7, 14, and 28 days.

- Using cylinders 150mm in diameter and 300mm in length, the splitting tensile strength of the mixtures is assessed.
- Beams measuring 100mm by 100mm by 500mm are used to measure the flexural strength of the mixtures.

Results and Discussions

The study examined the effects of Flyash and CNA replacement levels on SCC mixes while keeping the concentration of superplasticizer and the water-cement ratio constant. Table 2's findings highlighted new characteristics. Slump flow tests demonstrated that SCC had flow capability in the 500–650 mm range, classifying them as SF1. The T650 slump flow test revealed that all combinations were free of bleeding, segregation, and honeycombing and that they all satisfied the flow time requirements for the VF1 class.

Table 2 – Fresh Properties of Self-Compacting Concrete

Mix designation	Slump test(sec)	Slump test(mm)	V-funnel test(sec)	J-ring test(mm)
EFNARC	<60	650-800	6-12	<10
FA35	25	>650	40	7
FA50	26	>650	32	5
FA75	25	>650	38	6
CNA35	27	>650	36	8
CNA50	25	>650	42	4
CNA75	29	>650	35	8

Compression Test

Compressive strength tests are carried out according to IS 516-1959 on 150 mm concrete cubes after 7, 14, and 28 days of curing. The compressive strength of various replacement percentages is shown on the graph. After 14 and 28 days of curing, the strength increases, demonstrating that the compressive strength of SCC declines as CNA replacement rises. However, the strength grows up to 28 days as the curing time lengthens.

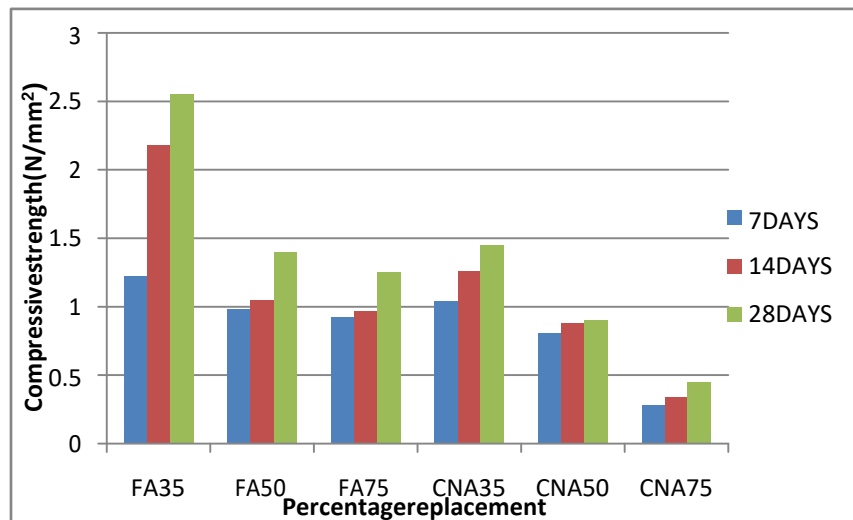


Fig 1 - compressive strength of SCC with various replacement of flyash and CNSA

Split Tensile Test

The concrete's capacity to endure tensile pressures that are applied perpendicular to its axis, or splitting tensile strength, indicates how well it can bear tensile stresses without breaking. It is essential for figuring out how long concrete pieces will last and how they will behave structurally, especially in situations where there will be bending or direct tension. The quality of the concrete mixture, the water-cement ratio, the curing environment, and the reinforcing elements all affect splitting tensile strength. By identifying fracture initiation, spread, and resistance to tensile stresses, measurement aids in assessing the integrity and performance of concrete structures. It is frequently used in conjunction with other mechanical parameters to evaluate the material's ability to support loads and with tensile forces.

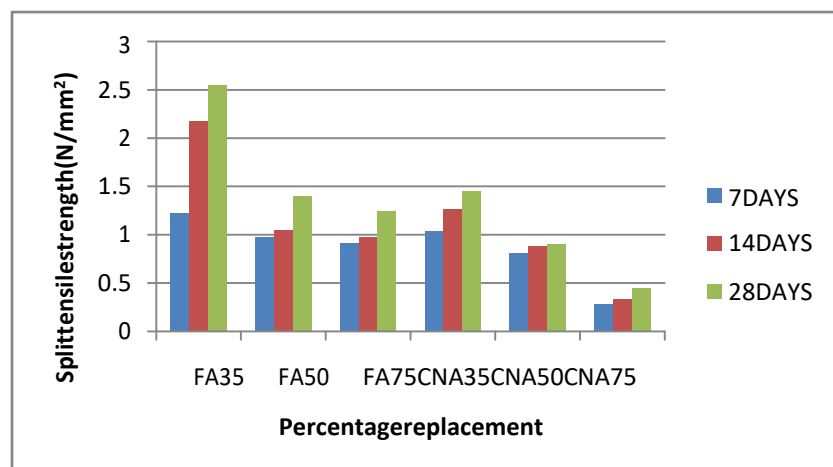


Fig 2 - Split tensile strength of SCC with various replacement of flyash and CNSA

Flexural Strength

Flexural strength is the ability of concrete to resist bending or deformation under applied loads, determining the structural integrity and load-bearing capacity of reinforced concrete elements like beams, slabs, and columns. It is influenced by factors such as compressive strength, reinforcement, quality, and curing conditions. Flexural strength is tested using a three-point or four-point bending test on standardized specimens. High flexural strength is crucial for withstanding bending forces and ensuring structural stability, especially in applications involving bending moments in bridges, beams, and floor slabs. Improving flexural strength is essential for designing and evaluating concrete structures, as inadequate strength can lead to excessive deflection, cracking, or failure under applied loads.

Proper quality control measures and testing are necessary to accurately determine flexural strength and comply with design requirements and industry standards. Fig 3 shows that the variation in flexural strength increases with curing days, with 35% strength being higher than 75% replacement.

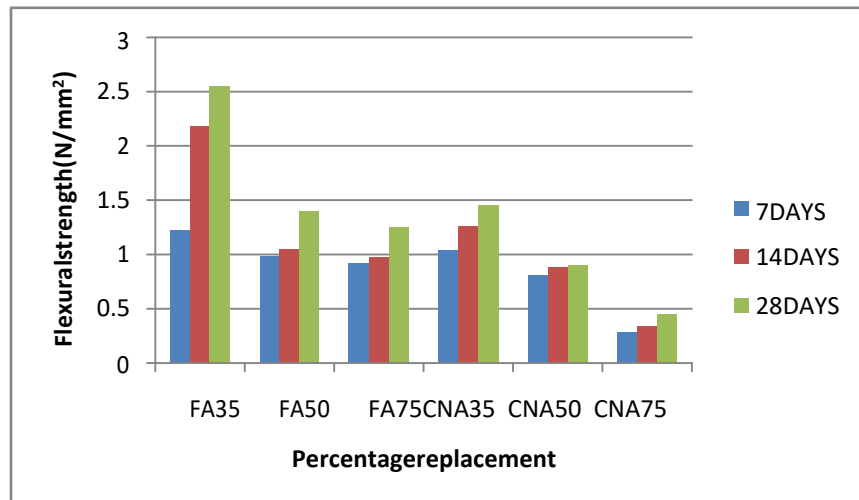


Fig 3 – Flexural strength of SCC with various replacement of flyash and CNSA

CONCLUSIONS

In conclusion, this experiment offers insightful information on CNSA replacement in SCC.

- The study's goals were effectively met, and the findings add to the body of knowledge already known about self-compacting concrete.
- The results emphasize the importance and prospective uses of CNSA.

- To increase our knowledge and improve the field of eco-friendly concrete, further study and investigation in this area are encouraged.
- The compressive strength of all SCC mixes has significantly decreased as a result of the rise in CNA content.
- Cylinders underwent 7-, 14-, and 28-day split tensile strength tests.
- A high splitting tensile strength of 1.82 MPa, 2 MPa, and 2.44 MPa over 7 days, 14 days, and 28 days, respectively, is discovered for the mix CNA35.
- Additionally, it was discovered that the mix CNA75 will have the lowest compressive strength, measuring 0.86 MPa, 1.1 MPa, and 1.30 MPa for the durations of 7 days, 14 days, and 28 days, respectively.
- It has been discovered that the mix CNA35 will have high flexural strength for 7 days, 14 days, and 28 days at 52 MPa, 63 MPa, and 72.5 MPa, respectively.
- Additionally, it was discovered that the mix CNA75 will have the lowest compressive strength, measuring 35.5 MPa, 37.5 MPa, and 42 MPa for the durations of 7 days, 14 days, and 28 days, respectively.

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