TRIBHUVAN UNIVERSITY

INSTITUTE OF ENGINEERING

PULCHOWK CAMPUS

THESIS NO.: 080/MSMSE/016

Enhancing the Strength of Recycled Aggregate Concrete Incorporating Nanosilica synthesized from Rice Husk Ash.

by

Sangina Lamichhane

A THESIS

SUBMITTED TO THE DEPARTMENT OF APPLIED SCIENCES AND CHEMICAL ENGINEERING IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER IN MATERIAL SCIENCE AND ENGINEERING

DEPARTMENT OF APPLIED SCIENCES AND CHEMICAL ENGINEERING

LALITPUR, NEPAL

MAY, 2026

Recommendation

This is to recommend that **Sangina Lamichhane** (Roll No.: 080MSMSE016) has carried out project work entitled **"Enhancing the strength of Recycled Aggregate Concrete incorporating nanosilica synthesized from Rice husk Ash"** for the requirement to the thesis work in Masters of Science (M.Sc.) degree in Material Science and Engineering under my supervision in the Department of Applied Sciences and Chemical Engineering, Pulchowk Campus, Institute of Engineering (IOE), Tribhuvan University (T.U.), Nepal.

To my knowledge, this work has not been submitted for any other degree.

She has fulfilled all the requirements laid down by the Institute of Engineering (IOE), Tribhuvan University (T.U.), Nepal for the submission of the thesis work for the partial fulfillment of Masters of Science (M.Sc.) degree.

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Declaration

I hereby declare that the thesis entitled **"Enhancing the strength of Recycled Aggregate Concrete incorporating nanosilica synthesized from Rice husk Ash"** submitted to the Department of Applied Sciences and Chemical Engineering, Pulchowk Campus, Institute of Engineering (IOE), Tribhuvan University (T.U.), Nepal for the partial fulfillment of the requirement to the thesis work in Masters of Science (M.Sc.) degree in Material Science and Engineering is my original work carried out under the supervision of Prof. Dr. Gokarna Bahadur Motra and Asst. Prof. Dr. Khem Raj Shrestha in the Department of Applied Sciences and Chemical Engineering, Pulchowk Campus, Institute of Engineering (IOE), Tribhuvan University (T.U.), Nepal.

I further declare that this work has not been submitted, either in part or in full, to any other university or institution for the award of any degree, diploma, or academic qualification. All sources of information used in this Thesis have been duly acknowledged and referenced.

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Letter of Forward

On the recommendation of **Prof. Dr. Gokarna Bahadur Motra and Asst. Prof. Dr. Khem Raj Shrestha,** this project work is submitted by **Sangina Lamichhane,** (Roll No.: 080MSMSE016), entitled **"Enhancing the strength of Recycled Aggregate Concrete incorporating nanosilica synthesized from Rice husk Ash"** is forwarded by the Department of Applied Sciences and Chemical Engineering, Pulchowk Campus, for the approval to the Evaluation Committee, Institute of Engineering (IOE), Tribhuvan University (T.U.), Nepal.

She has fulfilled all the requirements laid down by the Institute of Engineering (IOE), Tribhuvan University (T.U.), Nepal for the thesis.

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The undersigned certify that they have read, and recommended to the Institute of Engineering for acceptance, a thesis entitled " **Enhancing the strength of Recycled Aggregate Concrete incorporating nanosilica synthesized from Rice husk Ash** " submitted by Master's candidate in partial fulfillment of the requirements for the degree of Master of Science in Material Science and Engineering.

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Abstract

Environmental and sustainability issues have transpired as a result of the fast population increase, ascending construction and demolition activities so there is a need for new materials and construction waste management. This study investigates the enhancement of recycled aggregate concrete (RAC) using nanosilica synthesized from rice husk ash (RHA), aiming to promote sustainable construction practices through the utilization of construction and agricultural waste materials. Recycled aggregates (RA) were collected from demolition sites and evaluated through aggregate impact value, water absorption, and Los Angeles abrasion tests to determine their suitability for concrete production. Nanosilica was synthesized from rice husk ash using the sol–gel extraction method and characterized using Fourier Transform Infrared Spectroscopy (FTIR), which confirmed the formation of amorphous silica. Concrete specimens were prepared with 50% and 100% replacement of natural aggregate by recycled aggregate, along with varying nanosilica dosages of 0.4%, 0.8%, and 1.2%. Compressive strength tests were conducted at 14 and 28 days to evaluate the mechanical performance of the concrete mixes. The results demonstrated that the incorporation of nanosilica significantly improved the compressive strength of recycled aggregate concrete by enhancing the microstructure and reducing the adverse effects associated with recycled aggregates. Among the mixes, 50% recycled aggregate replacement exhibited better overall performance compared to 100% replacement. The study confirms that rice husk ash can serve as an effective precursor for nanosilica production and that recycled aggregate concrete incorporated with nanosilica can be considered a sustainable and environmentally friendly alternative to conventional concrete.

Keywords: Compressive strength, Nanosilica, Recycled Aggregate, Rice husk, sustainable.

Acronyms

RA	Recycled aggregate
NA	Natural aggregate
RAC	Recycled aggregate concrete
NS	Nano silica
NAC	Natural aggregate concrete
P	Failure load
A	an area under compression
AIV	Aggregate impact value
N	100% NAC
A	50% RA and 0.4% NS
B	50% RA and 0.8% NS
C	50% RA and 1.2% NS
D	100% RA and 0.4% NS
E	100% RA and 0.8% NS
F	100% RA and 1.2% NS

List of Symbols

%	Percentage
°C	Degree Celsius
g	Gram
C–H	Carbon–Hydrogen bond (stretching vibration)
C–O	Carbon–Oxygen bond
C=O	Carbonyl group
O–H	Hydroxyl group
Si–O	Silicon–Oxygen bond
Si–O–Si	Siloxane bond (Silicon–Oxygen–Silicon)

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Chapter 1
Introduction

1.1 Background

The principles of Reduce, Reuse, and Recycle can be efficiently achieved by incorporating agricultural waste management practices [1]. Increasing Population, rapid urbanization and infrastructure development have left a footprint for significant increase in construction and demolition waste worldwide. The waste produced from demolition and infrastructure development contains a significant amount of concrete in which the 60-70% of its volume is the aggregate as shown in figure 1.1 so there exist a need to reduce the amount of Recycled aggregate sustainably. Recycled aggregates are those aggregate obtained from the reconstruction and demolition sites which can be retreated and used for construction again that can replace conventional or natural aggregate fully or partially.

Reduce, Reuse and Recycle can be fully promoted with using recycled aggregate concrete in concrete waste management [2]. Replacing 25% of natural aggregate with recycled aggregate in concrete has given a significant compressive strength which promotes its use [2]. Also, when the percentage increases from 30% there have seen a noticeable reduction in the compressive strength of concrete which suggests using beyond 30% is not applicable [3]. The incorporation of nanosilica with recycled aggregate concrete beyond 30% has demonstrated, the improvements in compressive strength as well as the microstructure of concrete [4].

Figure 1.1: Recycled Aggregate Concrete [15],[18],[20]

Nanosilica to ultrafine particles of silicon dioxide (SiO_2) with sizes typically ranging from 1 to 100 nanometers. Because of their nanoscale dimensions they possess a remarkably high surface area, enhanced reactivity, and unique physicochemical properties compared to conventional silica. Nanosilica can be pried from rice husk ash in a significant amount [5].There has been a question why Rice husk, rice husk despite being a waste which is often discarded or burnt that contributes on environmental pollution as shown in figure 1.3,it is the abundant agricultural byproduct illustrated in figure 1.2 which contains 15-25% of amorphous nanosilica within so rice husk can be a precursor for nanosilica [6] as there will not be a problem of source for it with Nepal being an agricultural country and it is our prime thing to do.

Figure 1.2: Rice Husk [1]

Figure 1.3: Rice Husk burning [1]

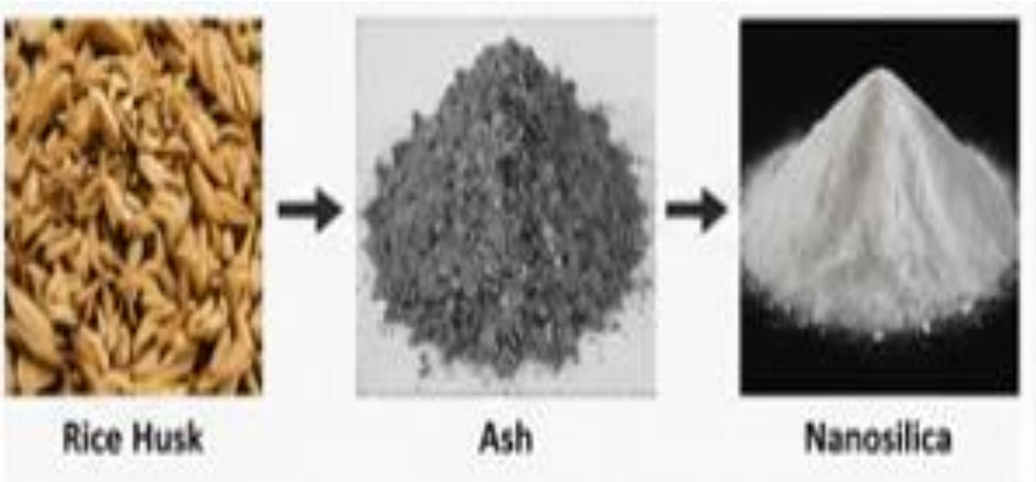

Figure 1.4: Process of Nanosilica [5],[7],[21]

Extracting nanosilica from rice husk as indicated in figure 1.4 not only promote waste management but also provides a new cost-effective and eco-friendly alternative to conventional chemical synthesis methods.

Combining nanosilica obtained from agricultural waste and Recycled aggregate obtained from demolition waste can be a best alternative to replace natural aggregate in significant amount for desirable compressive strength enhanced by nanosilica which ultimately promote sustainability in concrete waste management while creating new opportunities for advanced material applications.

1.2 Statement of the Problem

Rapid urbanization and continuous construction activities have resulted in the accumulation of massive scale of construction and demolition waste, leading to serious challenges in debris management and scarcity of landfill sites. At the same time, the excessive use of natural aggregates has caused depletion of natural construction materials.

Additionally, improper discarding of agricultural waste such as rice husk contributes to environmental pollution and land degradation. Although recycled aggregate concrete offers a sustainable solution, its application is limited due to reduced strength and durability at higher replacement levels of recycled aggregates.

Therefore, there is a reason to develop a sustainable and efficient process that utilizes recycled aggregates and rice husk-derived nanosilica to produce high-strength recycled aggregate concrete while addressing environmental and resource conservation concerns.

1.3 Objectives of the Study

General Objective

a) To enhance the strength of recycled aggregate concrete by incorporating nanosilica derived from rice husk ash.

Specific Objective

a) To perform sol–gel extraction to synthesize nanosilica.

b) To characterize nanosilica using appropriate characterization techniques.

c) To evaluate the effect of nanosilica on the mechanical and durability properties of recycled aggregate concrete.

1.4 Scope of the Study

The scope of this study mainly rivets on improving the performance of recycled aggregate concrete (RAC) by integrating nanosilica synthesized from rice husk ash (RHA). The research emphasizes the sustainable utilization of construction and demolition waste together with agricultural waste to produce environmentally friendly concrete materials. The study investigates the possibility of substituting natural aggregate with recycled aggregate at different replacement levels and evaluates the effectiveness of nanosilica in compensating for the reduction in strength generally observed in recycled aggregate concrete.

This research includes the drawing out and synthesis of nanosilica from locally available rice husk ash using the sol–gel method. The produced nanosilica is characterized using FTIR analysis to confirm the formation of silica and evaluate its chemical properties. The study further examines the suitability of recycled aggregates collected from demolition sites by conducting aggregate impact value, water absorption, and Los Angeles abrasion tests. These tests help determine the mechanical properties and durability characteristics of recycled aggregates before their use in concrete production.

The study also aims to promote sustainable construction practices by reducing the excessive consumption of natural aggregates and minimizing environmental pollution caused by improper disposal of rice husk and construction debris. By utilizing waste materials as valuable construction resources, the research contributes to the concept of reduce, reuse, and recycle in the construction industry. Furthermore, the findings of this study may provide a foundation for future research related to the durability, microstructural properties, and large-scale application of recycled aggregate concrete incorporating naturally derived nanosilica.

1.5 Limitations of the study

a. The results of this study may not be universally applicable because the properties of recycled aggregate and rice husk ash vary depending on local materials, environmental conditions, and sources of construction waste. Therefore, the performance of RAC may differ in other regions.

b. The study does not include a detailed economic analysis of recycled aggregate concrete and nanosilica production. Costs related to collection, processing, transportation, and chemical treatment were not fully evaluated, so the overall cost-effectiveness for large-scale application remains uncertain.

c. The research was carried out under controlled laboratory conditions, which may not fully represent actual field conditions. Variations in mix preparation, curing conditions, workmanship, and environmental exposure in real construction projects may affect the performance of concrete.

d. The study mainly focused on compressive strength and basic aggregate properties. Other important properties such as durability, tensile strength, flexural strength, shrinkage, and long-term performance were not investigated in detail.

e. The characterization of nanosilica was limited to FTIR analysis only. Advanced tests such as SEM, XRD, and particle size analysis were not performed due to limited laboratory facilities and resources.

Chapter 2

Literature Review

2.1 General

The selection of appropriate building materials is one of the most significant factors governing the strength, durability, sustainability, and overall economy of any construction project. Concrete, being the most commonly used construction material globally, plays a crucial role in infrastructure development. However, its extensive use has led to increased demand for natural aggregates and cement, resulting in significant depletion of natural resources and higher environmental outcomes associated with extraction, processing, and transportation.

With rapid urbanization and infrastructural expansion, the era of construction and demolition (C&D) waste has increased considerably. The increment of debris is directly proportional to the construction of new buildings, bridges, roads, and other infrastructure facilities. In developing countries like Nepal, this issue has become more critical due to insufficient waste management systems, limited recycling facilities, and improper disposal practices. Consequently, large quantities of construction waste are dumped in open areas, leading to environmental degradation, land pollution, and obstruction of natural drainage systems.

Under the umbrella of, Recycled Aggregate Concrete (RAC) has emerged as a sustainable alternative to conventional concrete. RAC is fabricated by replacing natural aggregates with recycled aggregates obtained from crushed construction and demolition waste. This practice helps in reducing the consumption of natural aggregates and provides an effective method for managing construction waste. Although RAC may show slightly lower mechanical properties in comparison to Natural Aggregate Concrete (NAC), such as higher water absorption and lower strength, its performance can be improved through proper mix design, treatment of recycled aggregates, and partial replacement techniques. Numerous studies have demonstrated that RAC can be effectively used in non-structural and certain structural applications when properly designed.

In recent years, additional attention has been given to the use of supplementary cementitious materials (SCMs) and nanomaterials to enhance the performance of sustainable concrete. Among these, rice husk derived nanosilica has gained significant interest. Rice husk, an agricultural by-product abundantly available in rice-producing countries like Nepal, can be processed to obtain nanosilica through controlled burning and chemical or thermal treatments. This nanosilica is characterized by its high surface area, amorphous structure, and strong pozzolanic reactivity.

When incorporated into concrete, rice husk derived nanosilica reacts with calcium hydroxide released during cement hydration forming additional calcium silicate hydrate (C-S-H) gel, which becomes primary strength-contributing phase in concrete. This reaction significantly improves the microstructure of the cement matrix by filling nano-scale voids, refining pore structure, and enhancing density. As a result, improvements in compressive strength, durability, water resistance, and overall mechanical performance of concrete have been widely reported.

The combined use of RAC and rice husk derived nanosilica presents a promising approach for sustainable construction. While RAC helps in reducing environmental burden from construction waste, nanosilica enhances the weakened microstructure of recycled concrete, compensating for strength loss and durability issues. This synergy not only improves the performance of recycled concrete but also promotes the utilization of agricultural waste, thereby supporting a circular economy approach in the construction sector.

In the Nepalese context, where both construction waste and rice husk are abundantly available, the integration of RAC with rice husk derived nanosilica offers a highly sustainable and cost-effective solution. However, further experimental and field-based studies are required to optimize mix proportions, evaluate long-term performance, and establish standardized guidelines for practical application.

2.2 Previous studies

Several researchers have explored the use of recycled aggregate concrete (RAC) and rice husk derived nanosilica as sustainable alternatives in the construction industry. Their studies mainly focus on the mechanical properties, durability, structural behavior, and environmental benefits of recycled aggregate and nanosilica-incorporated concrete.

Researchers have also extensively investigated the extraction of silica and nanosilica from rice husk and rice husk ash. Rice husk, being an abundant agricultural waste product in rice-producing countries, contains a high percentage of silica which can be extracted economically and sustainably.

A detailed review on the production and characterization of silica from rice husk discussed different extraction methods such as controlled combustion, alkali extraction, acid precipitation, and sol-gel synthesis. The review reported that rice husk-derived silica exhibits high purity, large surface area, and excellent pozzolanic reactivity, making it highly suitable for cementitious materials and nanotechnology applications [1].

A durability study on recycled aggregate concrete concluded that replacement of natural aggregate up to 25% caused no significant strength loss and exhibited acceptable durability properties under moderate exposure conditions. The study recommended the use of partial substitution of natural aggregate with recycled aggregate for sustainable concrete production [2].

The structural response of beam-column connections created using recycled aggregate concrete and enhanced with micro concrete at the joint region was investigated under reversed cyclic loading. Different percentages of recycled coarse aggregate were used in the concrete mix. The results showed that replacement of natural coarse aggregate with recycled aggregate up to 30% provided satisfactory compressive strength, splitting tensile strength, and flexural strength. The study suggested that RAC can be effectively utilized in structural beam-column connections when proper strengthening techniques are adopted [3].

The feasibility of incorporating nanosilica into recycled aggregate concrete was experimentally investigated using recycled aggregate contents of 50% and 100%. The results demonstrated that nanosilica significantly upgraded compressive strength and reduced water absorption by refining the microstructure and strengthening the interfacial transition zone between recycled aggregates and cement paste [4].

The extraction and characterization of nanosilica from rice husk using thermal and chemical treatment methods were studied. The produced nanosilica showed high purity, amorphous structure, and fine particle size, making it suitable for industrial and construction applications. The research highlighted rice husk as a sustainable and economical source for nanosilica production [5].

The production methods and applications of rice husk-derived nanomaterials were researched. The use of nanosilica in concrete, environmental treatment, biomedical fields, and energy storage was discussed. The authors concluded that rice husk-derived nanomaterials are eco-friendly, cost-effective, and beneficial for sustainable development and waste utilization [6].

The successful synthesis of purified nanosilica from rice husk ash through a simple chemical extraction method was demonstrated using controlled burning, alkali extraction, and acid precipitation processes. The produced nanosilica particles ranged from 5 to 50 nm in size and exhibited uniform spherical morphology with a specific surface area exceeding 270 m^2/g. X-ray diffraction analysis confirmed the amorphous structure of the silica, while FTIR analysis identified characteristic Si–O–Si bonds. The study concluded that rice husk-derived nanosilica can serve as a sustainable and cost-effective alternative to commercially produced nanosilica for cementitious and industrial applications [7].

A simple and economical precipitation method for producing pure silica from rice husk ash was developed using acid pretreatment techniques to remove metallic impurities such as calcium, potassium, and iron. The extracted silica possessed purity greater than 95% and exhibited a highly amorphous structure essential for high reactivity. The study emphasized that rice husk ash can be transformed into a valuable industrial material through environmentally friendly processing methods [8].

The preparation and characterization of silica gel from rice husk ash were studied through alkali extraction and acidification processes. Sodium silicate obtained from rice husk ash was converted into silica gel possessing high porosity and large surface area. The study highlighted that synthesis conditions such as alkali concentration, precipitation temperature, and acid concentration significantly influence the characteristics of the final silica product [9].

The use of recycled concrete aggregate in high-strength concrete was studied by replacing natural aggregates with recycled aggregates at varying replacement levels. The findings indicated that replacement levels up to 30% did not significantly reduce compressive strength. However, beyond this limit, strength reduction became more pronounced due to the higher porosity and weaker interfacial transition zone of recycled aggregates [10].

A review on the use of recycled aggregate in concrete reported that replacement levels up to 25% can produce compressive strength comparable to conventional concrete. However, higher replacement levels reduce strength and durability because of increased water absorption and porosity. The study highlighted that recycled aggregate concrete has considerable potential as a sustainable construction material, although further research is necessary to improve the interfacial transition zone and long-term durability for large-scale structural applications [11].

Another study on the combined use of nanosilica and natural fibers in recycled aggregate concrete reported substantial improvements in both compressive and flexural strengths. Incorporation of 0.3% nanosilica increased compressive strength by 22.5% and flexural strength by 25.6%. The study highlighted the sustainability potential of combining recycled materials with nanoscale additives and natural fibers for producing high-performance concrete [12].

Overall, previous studies indicate that recycled aggregate concrete is a sustainable alternative to conventional concrete and can effectively reduce construction waste and natural resource depletion. However, RAC generally exhibits lower mechanical and durability properties because of increased porosity, old adhered mortar, and weaker interfacial transition zones. The incorporation of rice husk-derived nanosilica has shown considerable potential in overcoming these deficiencies by enhancing microstructure, reducing porosity, and increasing the formation of calcium silicate hydrate gel. Therefore, the combined utilization of recycled aggregates and rice husk-derived nanosilica presents a promising approach for developing sustainable, durable, and high-performance concrete suitable for future construction practices [4], [12].

The aggregate impact test is widely used to evaluate the toughness of aggregates by determining their resistance to sudden shock or impact loads. It provides an indication of the strength and quality of aggregates used in road and concrete construction. Lower impact values generally represent stronger and durable aggregates suitable for high-strength applications [13].

Similarly, the Los Angeles abrasion test is a standard procedure used to evaluate the hardness and resistance of aggregates against wear and grinding actions. The test simulates the mechanical degradation of aggregates during handling and service conditions, where a lower abrasion value indicates better resistance and higher durability of the material [14].

Variability in mechanical properties compared to natural aggregates were studied. The study emphasized that RCA generally shows higher porosity and lower strength due to adhered mortar, but proper processing and treatment can improve its performance. The review also suggested that RCA can be effectively used in structural and non-structural applications with appropriate quality control measures [15].

The effect of multiple recycling stages on aggregate strength was also investigated. Aggregates were categorized into first-generation, second-generation, and third-generation recycled aggregates. Their strengths were evaluated using Aggregate Crushing Value (ACV) and Aggregate Impact Value (AIV) tests. The results indicated that both ACV and AIV increased with successive recycling generations. For natural aggregates, the ACV increased by 2.5%, 4.64%, and 6.79% after the first, second, and third recycling stages respectively, while the AIV increased by 7.04%, 10.35%, and 12.47%. The study concluded that first-generation recycled aggregates possess strength properties comparable to natural aggregates and can therefore be safely used in concrete production [16].

The mechanical properties of recycled concrete aggregate, including specific gravity, water absorption, apparent specific gravity, and Los Angeles abrasion value, were experimentally evaluated and compared with natural aggregates. Concrete specimens containing 0%, 35%, 50%, and 65% recycled aggregate were prepared. The study revealed that repeated recycling and increasing age of recycled concrete adversely affected the mechanical properties of RAC. To improve the properties of RAC, ureolytic bacteria were incorporated, resulting in enhanced compressive strength. It was reported that the compressive strength of RAC produced from two-year-old recycled concrete was approximately 6% lower than that prepared from one-year-old recycled concrete. The study also emphasized the importance of maintaining a lower water-cement ratio to achieve higher compressive strength in RAC [17].

An overview of recycled aggregate concrete research conducted in China between 1996 and 2011 highlighted the rapid advancement of RAC technology and applications. The review discussed the mechanical behavior, durability, shrinkage characteristics, and structural performance of RAC. The study emphasized that although RAC generally exhibits lower mechanical properties than conventional concrete, improvements in processing techniques and admixture use can significantly enhance its performance [18].

The potential for recycled aggregate concrete to be used as a structural material was studied by preparing four concrete mixes with varying percentages of recycled coarse aggregates (0%, 25%, 50%, and 100%). Twelve reinforced concrete beam specimens with different transverse reinforcement configurations were cast and tested to failure. The study concluded that when proper durability precautions are taken, replacement of natural coarse aggregate with recycled aggregate up to 25% does not significantly affect the shear capacity of reinforced concrete beams [19].

An Extensive review on recycled concrete aggregate examined the influence of RAC on the material and structural properties of concrete. The review found that the replacement of natural aggregate with recycled aggregate generally decreases compressive strength, modulus of rupture, and elasticity due to the presence of adhered mortar and higher porosity in recycled aggregates. However, despite these reductions, the study concluded that RAC can still be considered a viable structural material when proper mix design and quality control measures are implemented [20].

The influence of combustion temperature on the structural characteristics of rice husk ash was also investigated. The study found that combustion temperatures between 600°C and 700°C produce highly reactive amorphous silica, whereas temperatures above 800°C result in crystalline silica forms such as cristobalite and tridymite, which possess lower reactivity. The study further demonstrated the successful preparation of nanostructured silica using alkali extraction and acid precipitation methods [21].

The application of rice husk-derived nanosilica in high-performance concrete demonstrated significant improvements in compressive strength, durability, and water resistance. The nanosilica acted as a pozzolanic material, reacting with calcium hydroxide released during cement hydration to form additional (C–S–H) gel. This reaction refined the pore structure and enhanced the density of the concrete matrix. The study concluded that rice husk-derived nanosilica is a promising material for sustainable and durable concrete production [22].

2.3 Research Gap

Although numerous studies have confirmed the potential of rice husk as an abundant and economical source of silica and nanosilica, and several researchers have demonstrated the positive influence of nanosilica on the mechanical and durability properties of recycled aggregate concrete (RAC), significant research gaps still remain. Most existing studies primarily focus on laboratory-scale production methods and commercially available synthetic nanosilica, while limited attention has been given to the practical utilization of naturally derived nanosilica obtained directly from agricultural waste materials such as rice husk.

Furthermore, the development of a standardized, environmentally friendly, and economically feasible method for producing high-quality nanosilica from rice husk on a large scale is still lacking.

In addition, although recycled aggregate concrete has been widely investigated as a sustainable alternative to conventional concrete, many studies report a noticeable reduction in mechanical properties when the replacement level of recycled aggregate exceeds approximately 30%. This reduction is mainly attributed to the porous nature of recycled aggregates, the presence of adhered old mortar, higher water absorption capacity, and weaker interfacial transition zones between aggregate and cement paste. As a result, the structural application of RAC at higher replacement percentages remains limited, particularly in situations where high strength and durability are required.

Another important limitation identified in previous research is that most enhancement techniques for RAC are based on synthetic or commercially manufactured nanosilica. While synthetic nanosilica has proven effective in improving compressive strength, pore refinement, and durability, its production process is often expensive, energy-intensive, and associated with environmental concerns. Comparatively fewer studies have investigated the use of naturally derived nanosilica obtained from agricultural waste products such as rice husk ash. Therefore, the sustainability and economic benefits of using rice husk-derived nanosilica in concrete have not yet been fully explored.

Moreover, limited research has been conducted on the combined effect of naturally derived nanosilica and high replacement levels of site-extracted recycled aggregate concrete. Most available studies focus either on low percentages of recycled aggregate replacement or on RAC prepared under controlled laboratory conditions. The performance of RAC containing more than 30% site-extracted recycled aggregate treated with rice husk-derived nanosilica remains largely unexplored. There is insufficient information regarding its compressive strength, workability, durability, and microstructural behavior under practical construction conditions.

Therefore, this study aims to address these research gaps by investigating the effect of rice husk-derived nanosilica on recycled aggregate concrete containing higher percentages of site-extracted recycled aggregates. The research intends to evaluate whether naturally derived nanosilica can effectively compensate for the loss in strength and durability associated with higher RAC replacement levels, thereby contributing toward sustainable, economical, and environmentally friendly concrete technology.

Chapter 3

Methodology

3.1 Study area

Chitwan district was the primary location for the study. Various demolition sites inside chitwan district were observed. Naurange, Gholbazar and bhojad area were chosen because there was a possibility of high ratio of extraction of recycled aggregate. Also the rice husk was taken from Geetanagar area for nanosilica extraction.

3.2 Research methodology

The figure 3.1 illustrates the overall research methodology adopted for the study on recycled aggregate concrete incorporated with rice husk-derived nanosilica. The process begins with the preparation of raw materials, which includes the collection and processing of rice husk ash and recycled aggregates. The prepared rice husk ash is then utilized for the production of nanosilica through suitable extraction methods.

After the production of nanosilica, recycled aggregates are used as a replacement for natural aggregates in different proportions to prepare M20 grade concrete mixes. Subsequently, nanosilica is added to the concrete mixtures to enhance the mechanical and durability properties of recycled aggregate concrete.

The prepared concrete specimens are then subjected to various laboratory tests to evaluate their performance characteristics. Based on the test results, the concrete is characterized in terms of strength and other engineering properties. Finally, the obtained data are analyzed and interpreted, followed by report writing and presentation of the research findings.

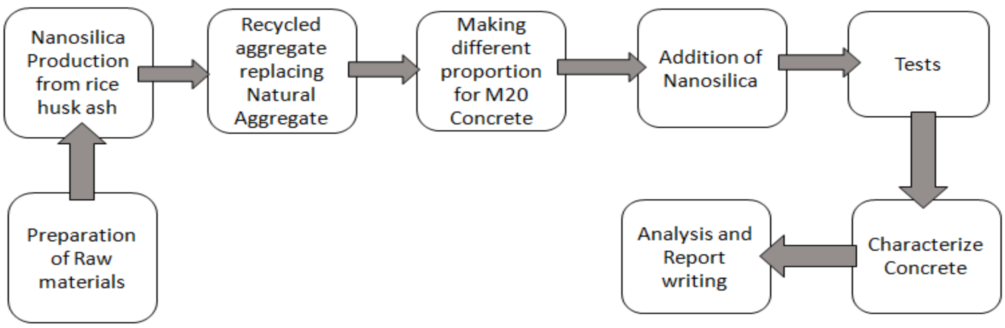

Figure 3.1: Research Methodology Flowchart

3.3 Materials and Chemicals Used

3.3.1 Materials Used

a) Cement

Ordinary Portland Cement (OPC) of Grade 43 was used as the primary binding material in this study. It is responsible for strength development in concrete through hydration reactions. When mixed with water, cement forms calcium silicate hydrate (C–S–H) gel, which provides hardness and binding between aggregates.

b) Fine Aggregate (Sand)

Natural river sand was used as fine aggregate. It fills voids between coarse aggregates, improves workability, and contributes to the overall density and strength of concrete. The sand used was clean, well-graded, and free from organic and clay impurities to ensure proper bonding.

c) Coarse Aggregate

Crushed stone aggregates were used as coarse aggregate in Natural Aggregate Concrete (NAC). For Recycled Aggregate Concrete (RAC), processed concrete waste from demolished structures was used. The recycled aggregates were cleaned, crushed, and sieved to achieve the required size distribution. This promotes sustainable construction by reducing natural resource consumption and construction waste.

d) Rice Husk Ash

Rice Husk Ash was obtained by controlled burning of rice husk collected from local rice mills. The husk was combusted at a controlled temperature to produce amorphous silica-rich ash. RHA is a valuable pozzolanic material containing a high percentage of silica, making it suitable for nanosilica extraction. It also helps in waste management and reduces environmental pollution caused by agricultural waste burning.

e) Water

Clean potable water was used for both mixing and curing of concrete specimens. The water was free from impurities such as oils, salts, and organic matter, ensuring proper cement hydration and consistent strength development.

3.3.2 Chemicals Used

1. Potassium Hydroxide (KOH)

   Potassium hydroxide solution was used in the alkaline extraction process of nanosilica from Rice Husk Ash. It reacts with silica present in RHA to form soluble sodium silicate, which is an important intermediate in nanosilica synthesis.

2. Hydrochloric Acid (HCl)

   Hydrochloric acid was used for acid precipitation of silica from sodium silicate solution. It helps in converting dissolved silica into fine nanosilica particles and also removes unwanted impurities, improving purity and quality.

3. Distilled Water

   Distilled water was used throughout the chemical processes to avoid contamination from dissolved minerals or salts. It ensures controlled chemical reactions and enhances the purity of the final nanosilica product.

3.4 Preparation of Nano Silica from Rice Husk Ash (RHA)

The nanosilica used in this study was synthesized from Rice Husk Ash (RHA) through a chemical extraction process involving alkaline dissolution followed by acid precipitation. The process was carried out in a controlled manner to obtain high-purity, fine-sized silica particles in the nano range.

i. Raw Material Collection

Rice husk collected from local rice mills of Geetanagar and is thoroughly washed and dried to remove dirt and impurities Afterwards was grinded into fine powder which was sieved to get uniform particle distribution as in figure 3.2. Then it was subjected to controlled combustion in a muffle furnace at approximately 350°C for 3 hours as in figure 3.3. This controlled burning ensured the formation of amorphous silica rather than crystalline silica. The obtained ash was then cooled naturally and sieved to remove unburnt carbon particles and coarse impurities, resulting in fine RHA powder.

Figure 3.2: Grinding of the Sample into its appropriate size

Figure 3.3: Controlled Combustion

ii. Alkaline Extraction Process

The prepared RHA was mixed with sodium hydroxide (NaOH) solution of known concentration. The mixture was heated and stirred continuously for a specific duration (2 hours) as mentioned in figure 3.4. During this process, silica present in the ash reacted with NaOH to form soluble sodium silicate solution.

This reaction can be represented as:

$$SiO_2 + 2KOH \rightarrow K_2SiO_3 + H_2O$$

After completion, the solution was filtered to remove insoluble residues, obtaining a clear sodium silicate solution.

Figure 3.4: Heating and Mixing of Rice husk ash with KOH

iii.Acid Precipitation of Silica

The potassium silicate solution was slowly treated with hydrochloric acid (HCl) under constant stirring as in figure 3.5. Acid was added drop wise to control pH and ensure uniform particle formation. This reaction caused the precipitation of silica in gel form shown in figure 3.5.

Reaction:

$$K_2SiO_3 + 2HCl \rightarrow SiO_2 \text{ (precipitated)} + 2KCl + H_2O$$

Figure 3.5: Adding HCL drop wise to get silica gel

iv. Washing and Drying:

The formed silica gel was repeatedly washed with distilled water to remove potassium chloride (KCl) and other soluble impurities. Washing was continued until neutral pH was achieved, ensuring high purity of the silica product. The purified silica gel was dried muffle furnace at approximately 100–110°C until all moisture was removed as per figure 3.6. The dried material was then ground into fine powder using a mortar, pestle, or ball mill to obtain nanosilica particles**.** The final product was a fine, white, high-surface-area nanosilica powder. It was stored in airtight containers to prevent moisture absorption and used as an additive in concrete to enhance strength, durability, and microstructure.

Figure 3.6: Drying and formation of silica

v. Characterization

Fourier Transform Infrared Spectroscopy (FTIR) characterization was carried out to analyze the functional groups and confirm the presence of silica in the synthesized nanosilica sample. The FTIR analysis was performed within the wavelength range of 4000–500 cm^{-1} and with the PerkinElmer Spectrum IR (version 10.6.2) through which the graph was obtained as in figure 3.7.

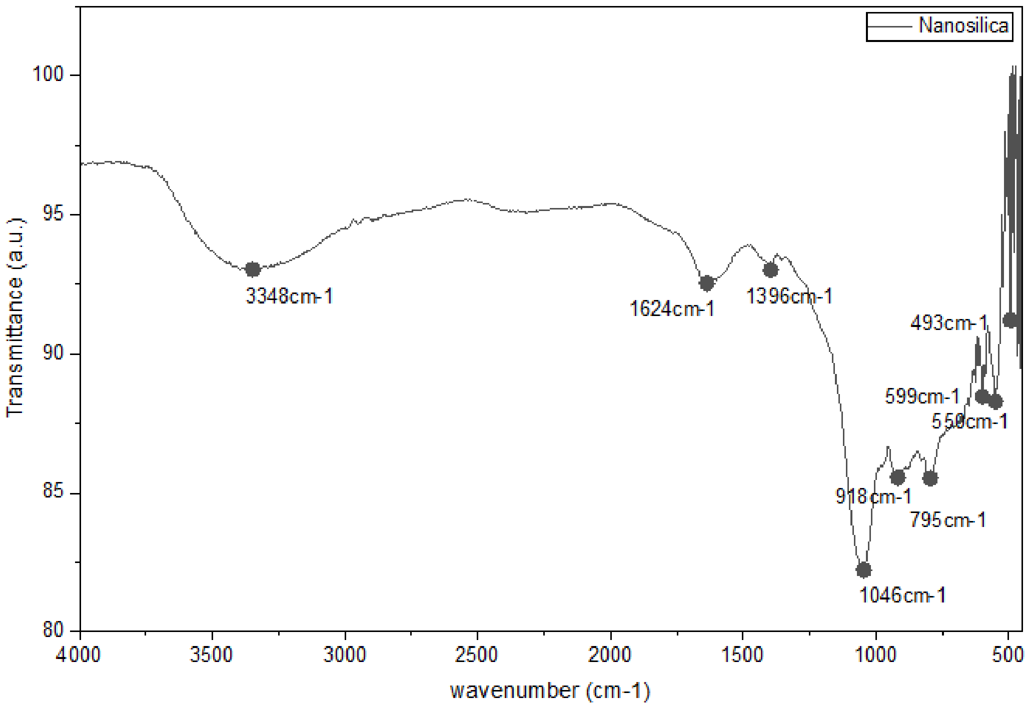

Figure 3.7: Characterization graph

3.4 Extraction and Preparation of Recycled Aggregate

1. Collection of Demolished Concrete

Demolished concrete waste was collected from nearby construction and demolition sites (figure 3.8). The collected concrete pieces were ensured to be free from excessive impurities such as wood, plastic, glass, and soil.

Figure 3.8: Demolition site

2. Segregation of Concrete Waste

The collected demolished concrete was manually sorted to separate usable concrete fragments from unwanted materials and foreign particles.

3. Manual Hammering

Manual hammering was carried out to remove adhered mortar, residue, and impurities from the surface of previously used construction concrete as illustrated on figure 3.9. This process helped in obtaining cleaner recycled aggregates suitable for concrete production.

Figure 3.9: Manual hammering

4. Sieving of Aggregates

The cleaned recycled aggregates were passed through standard sieves to retain the required aggregate size and proper grading for concrete mixing as per figure 3.10.

Figure 3.10: Seiving

5. Washing Process

The recycled aggregates were completely washed with clean water to discard dust, loose particles, and remaining surface impurities (figure 3.11).

Figure 3.11: Washing

6. Drying of Aggregates

After washing, the recycled aggregates were air-dried under normal atmospheric conditions to remove excess moisture before use (figure 3.12).

Figure 3.12: Drying

3.5 Tests on Recycled Aggregate

The prepared recycled aggregates subject to various standard physical tests to evaluate their quality and suitability for use in Recycled Aggregate Concrete (RAC). These tests were essential to understand the strength, durability, and absorption characteristics of the aggregates, which directly influence the performance of concrete.

3.5.1 Impact test

Impact test determines material response to sudden loads. It is used to evaluate toughness, strength and durability in various industries. We can classify them as per their percentage by using the table 3.1.

Table 3.1: Classification of aggregate-based on different impact value

Aggregate impact value	Classification
<20%	Exceptionally strong
10-20%	Strong
20-30%	Satisfactory for road surfacing
<35%	Weak for road surfacing

Procedure:

i. The impact testing machine should be placed directly on a level and rigid surface without using any packing or wedging, ensuring that the hammer guide columns remain perfectly vertical as illustrated in Figure 3.13.

ii. ii. The cup is securely attached to the base of the apparatus, after which the entire aggregate sample is filled into the cup and compacted using 25 strokes of the tamping rod.

iii. iii. The hammer is then lifted so that its lower face is positioned 380 mm above the aggregate surface inside the cup and allowed to drop freely. A total of 15 blows are applied to the sample, maintaining a minimum interval of one second between successive blows.

iv. iv. After completion of the impact process, the crushed aggregate is removed from the cup and sieved through a 2.36 mm IS sieve until no noticeable quantity passes within one minute. The material passing through the sieve is weighed accurately to 0.1 g and recorded as W5, while the retained portion is weighed as W4. If the combined weight (W6 = W4 + W5) differs from the original sample weight (W3) by more than 1 g, the test result is rejected and the procedure is repeated with a fresh sample. The test should be conducted twice for accuracy.

Calculation:

The proportion of fines produced to the total weight of the sample in each test shall be calculated and expressed as a percentage, and the final value should be reported to one decimal place:

Aggregate impact value= $\frac{W5}{W3}$*100%

Figure 3.13: Impact test Apparatus

3.5.2 Water Absorption Test

The water absorption test is a method used to calculate the amount of water a material can absorb under specified condition. It is normally carried out on porous materials such as concrete, bricks, tiles and wood.

Water absorption of aggregate is an important indicator of its weathering resistance and durability. It represents the percentage of water absorbed by the aggregate when it is fully immersed in water. The test for water absorption is carried out as per the procedure specified in IS 2386 (Part 3), which outlines the method for determining specific gravity and water absorption of aggregates.

Procedure:

i. For this test, approximately 2000 g of aggregate is taken and thoroughly washed with clean water to remove dust and impurities.

ii. The fine particles are removed, and the excess water is drained. The aggregates are then placed in a wire basket.

iii. The basket containing the aggregate is immersed in distilled water maintained at a temperature between 22°C and 32°C for 24 hours.

iv. After 24 hours, the basket along with the aggregates is weighed and recorded as W1.

v. The aggregates are then removed from the mesh and weighed separately and recorded as W2.

vi. The surface water is drained from the aggregates, and they are weighed again in the surface-dry condition as W3.

vii. Finally, the sample is placed in a drying oven for 24 hours. After oven drying, the aggregates are weighed and recorded as W4.

Calculation:

The water absorption of the aggregates are calculated using the standard formulae as per IS 2386 (Part 3).

Water absorption= $\frac{W3-W4}{W4}$ *100%

3.5.3 Los- Angeles's abrasion test

The Los Angele's abrasion test is a method done to determine the resistance of aggregates (such as crushed stone, gravel, etc.) to abrasion and wear. It measures the durability of the aggregates caused by repeated impacts and abrasion from steel balls within a drum as per figure 3.14.

Procedure:

i. The test sample and the abrasive charge shall be placed in the Los Angeles abrasion testing machine and the machine rotated at a speed of 20 to 33 rev/min. The abrasive charge is placed depending upon the grading the test sample mentioned in table 3.2.

ii. The total weight of the aggregate sample is taken as W1 according to the grading groups A, B, C, D, E, F, and G as specified in Table 3.3.

iii. For grading A, B, C, and D, the abrasion machine is rotated for 500 revolutions, while for grading E, F, and G, it is rotated for 1000 revolutions. The machine is operated in such a way that a uniform peripheral speed is maintained. If an angle shelf is used, the machine is rotated so that the sample is lifted and dropped on the outer surface of the angle.

iv. After completion of the specified number of revolutions, the sample is discharged from the machine and a preliminary separation is carried out using a sieve coarser than the 1.70 mm IS sieve.

v. The material passing through the 1.70 mm IS sieve is collected and recorded as W2. The material retained on the sieve is then washed, oven-dried at 105–110°C until a constant mass is achieved, and weighed accurately to the nearest gram.

Calculation:

The proportion of the weight of passing to the total sample weight in each test must be stated as a percentage, the result being recorded to the first decimal place:

Aggregate abrasion value= $\frac{W2}{W1}$*100%

Table 3.2: Abrasive charge as per the grading

Grading	Number of spheres	Weight of charge (gram)
A	12	5000±25
B	11	4584±25
C	8	3330±20
D	6	2500±15
E	12	5000±25
F	12	5000±25
G	12	5000±25

Table 3.3: Gradings of test samples

Sieve Size		Weight in gram of test sample for Grade						
Passing (mm)	Retained on (mm)	A	B	C	D	E	F	G
80	63	-	-	-	-	2500*	-	-
63	50	-	-	-	-	2500*	-	-
50	40	-	-	-	-	5000*	5000*	-
40	25	1250	-	-	-	-	5000*	5000*
25	20	1250	-	-	-	-	-	5000*
20	12.5	1250	2500	-	-	-	-	-
12.5	10	1250	2500	-	-	-	-	-
10	6.3	-	-	2500	-	-	-	-
6.3	4.75	-	-	2500	-	-	-	-
4.75	2.36	-	-	-	5000	-	-	-
*Tolerance of ±2 percent permitted.								

Figure 3.14: Abrasion apparatus

3.6 Preparation of Recycled Aggregate Concrete incorporating nanosilica

3.6.1 Material quantity calculation

The standard concrete cube specimen used for compressive strength testing has dimensions of 15 cm × 15 cm × 15 cm, giving a total volume of:

$$V = 0.15 \times 0.15 \times 0.15 = 0.003375\ m^3$$

Based on the mix ratio 1: 1.5: 3 (Cement: Fine Aggregate: Coarse Aggregate), the material quantities required for casting one cube specimen are calculated proportionally from 1 m^3 of concrete.

1. Material Quantities for One Cube
   - Cement: 1.36 kg
   - Fine Aggregate (Sand): 2.19 kg
   - Coarse Aggregate: 4.22 kg
   - Water (w/c ≈ 0.5): 0.68 L
2. Nano Silica (NS) Content

   Nano silica is used as an admixture and is calculated as a percentage of cement content:
   - 0.4% NS = 5.44 g
   - 0.8% NS = 10.88 g
   - 1.2% NS = 16.32 g
3. Recycled Aggregate (RA) Replacement

   For coarse aggregate replacement:
   - 50% RA mix:

- Natural Aggregate (NA) = 2.11 kg
- Recycled Aggregate (RA) = 2.11 kg

- 100% RA mix:
  - Natural Aggregate (NA) = 0 kg
  - Recycled Aggregate (RA) = 4.22 kg

Thus, for casting one standard concrete cube, approximately 1.36 kg of cement, 2.19 kg of fine aggregate, 4.22 kg of coarse aggregate, and 0.68 L of water are required, along with the specified dosage of nano silica depending on the mix proportion. This formulation is used consistently for all experimental mixes to ensure uniformity in testing conditions.

3.6.2 No of cubes calculation

The number of concrete cube specimens prepared for each mix proportion used in the study were present in the table 3.4. Each mix (N, A, B, C, D, E, and F) was cast into six cubes in total, consisting of three specimens for 14-day curing and three specimens for 28-day curing. This ensures that compressive strength results at each curing age are reliable and based on average values rather than a single test result.

Across all seven mixes, a consistent testing approach was followed, resulting in 21 cubes for 14-day testing and 21 cubes for 28-day testing, giving a total of 42 concrete cubes for the entire experimental program. This uniform distribution of specimens helps maintain accuracy, reduce experimental variation, and ensure fair comparison of strength results among all mix proportions.

Table 3.4: Number of cubes calculation

Mix ID	14 Days (3 cubes each)	28 Days (3 cubes each)	Total Cubes
100% NA	3	3	6
50% RA and 0.4% NS	3	3	6
50% RA and 0.8% NS	3	3	6
50% RA and 1.2% NS	3	3	6
100% RA and 0.4% NS	3	3	6
100% RA and 0.8% NS	3	3	6
100% RA and 1.2% NS	3	3	6
Total	21	21	42

3.6.3 Batching

Initially, we planned to create a cube with M20 strength with respect to the specified code, using a nominal design ratio of 1:1.5:3. After that, we decided to batch 100% NA, while replacing 50%, and 100% of RA over NA as in figure 3.15. For that we decided move forward with the ratios given in table 3.4

Table 3.5: Sample with their ratios

Sample	Ratio
N	100% NA
A	50% RA and 0.4% NS
B	50% RA and 0.8% NS
C	50% RA and 1.2% NS
D	100% RA and 0.4% NS
E	100% RA and 0.8% NS
F	100% RA and 1.2% NS

Figure 3.15: Batching

3.6.4 Mixing

The appropriate proportions of coarse aggregate and sand were first measured and dry mixed thoroughly to ensure uniform distribution of materials. After achieving a consistent dry mix, water was added gradually to maintain a water–cement (w/c) ratio of 0.5. The mixing was continued until a homogeneous and workable wet mixture was obtained as in figure 3.16. Proper care was taken to ensure uniform consistency of the mix for effective casting and preparation of concrete specimens.

Figure 3.16: Mixing

3.6.5 Slump test

The slump test is a straight forward test used to compute the workability of freshly mixed concrete. It comprises of filling a conical mold with concrete illustrated as figure 3.17, compacting it, and then removing the mold to see how much the concrete slumps or settles. The amount of slump indicates the concrete's plasticity and is a measure of its capacity to be properly placed and compacted during construction. This test helps to guarantee that the concrete mix has the desired properties for a specific construction project and is an essential step in ensuring quality concrete work.

Figure 3.17: Slump Test

Table 3.6: Slump test

Proportion	Slump value (mm)
100% NA	85
50% RA	80
100% RA	75

The table 3.5 shows the slump values (in millimeters) for various proportions of recycled aggregate concrete (RA) correlated to natural aggregate concrete (NA). It shows that as the proportion of RA increases, the slump generally decreases, showing that higher amounts of recycled material led to a less workable concrete mix. Nevertheless, the values of our proportion are workable.

3.6.6 Placing, Compaction and Curing

Placing, compaction, and curing are essential steps in preparing concrete test cubes to assess strength and quality (figure 3.18). A clean, dry mold is oiled and filled with concrete in layers, each compacted using a tamping rod to remove air voids and ensure uniformity. The surface is then leveled and covered to prevent moisture loss. After 24 hours, the cube is demolded and cured for about 28 days by water immersion, wet coverings, or in a curing chamber. Proper curing maintains moisture for hydration, enabling the concrete to gain strength and durability and achieve its design performance.

Figure 3.18: Placing and Curing of Cubes

3.7 Compressive strength test

The compressive strength test finds a material's ability to resist compression forces. While commonly used on construction materials like concrete and rock, it can also be implemented to other substances.

Table 3.7: Compressive Strength of concrete

Days	Percentage of strength
7	About 60-70% of the specified 28-day strength
14	Around 75-85% of the specified 28-day strength
28	The specified compressive strength requirement for the concrete

The test procedure to measure the compressive strength of concrete is defined by IS: 516 – 1959 and the amount of strength that should be attained in days are shown as per table 3.6.

Procedure:

a. The specimen was placed between the loading plates of the Universal Testing Machine.

b. The specimen was positioned carefully to ensure proper alignment and uniform load distribution.

c. A compressive load was applied gradually to the specimen.

d. The load was added continuously until the specimen failed.

e. The maximum load at failure was recorded in kilo Newton's (kN).

f. The compressive strength was calculated using the recorded load and specimen area.

The compressive strength was calculated using the following formula:

Compressive strength of concrete (F_c)= $\frac{P}{A}$

F_c = Compressive strength (MPa)

P = Maximum load applied (N)

A = Cross-sectional area (mm^2)

The figure 3.19 demonstrates the testing procedure used to evaluate compressive strength, ensuring consistency in load application.

Figure 3.19: Compressive strength Apparatus

Chapter 4

Results and Discussion

4.1 Results

4.1.1 FTIR Test

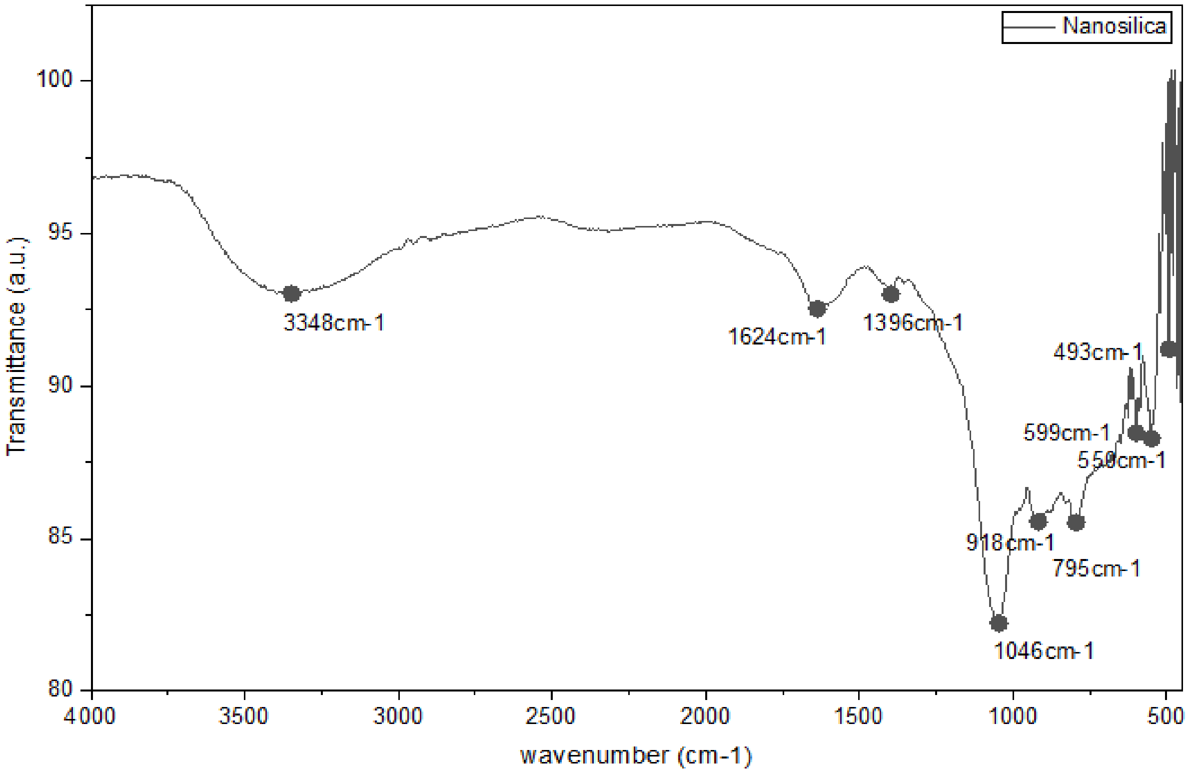

Figure 4.1: FTIR result

The FTIR spectrum of nanosilica obtained from rice husk ash confirms the successful formation of amorphous silica. The wide absorption band around 3348 cm^{-1} represents to O–H stretching vibrations, showing the presence of surface silanol (Si–OH) groups and adsorbed moisture, which is typical for nanosilica [8]. The peak at 1624 cm^{-1} is subjected to the bending vibration of H–O–H, further confirming physically adsorbed water on the silica surface. The strong and dominant peak at 1046 cm^{-1} represents the asymmetric stretching vibration of Si–O–Si [9], which is the characteristic band of silica and confirms the formation of a silica network. The band observed near 918 cm^{-1} is associated with Si–OH stretching, indicating high surface reactivity of the nanosilica [21]. Additional peaks in the range of 795–800 cm^{-1} and 450–550 cm^{-1} correspond to symmetric stretching and bending vibrations of Si–O–Si bonds, respectively [21]. Overall, the FTIR results indicate the presence of highly pure, amorphous nanosilica synthesized from rice husk ash.

The laboratory process and this FTIR graph shown on Figure 4.1 indicate that approximately 20.8% of nano silica can be extracted from rice husk ash respectively from precipitation process.

14.1.2 Impact Test

In order to know the test results, there should be certain notations.

Wt of dry sample+ cylinder= W1

Wt of measuring cylinder= W2

Wt of sample, W3= W1-W2

Wt of crushed aggregate retained on 2.36mm sieve, W4

Wt of crushed aggregate passing on 2.36mm sieve, W5

Total weight, W6=W4+W5

Aggregate impact value (AIV) = W5/W3*100%

The below Table 4.1 displays the overall impact value of various 100% NAC samples, which is 9.8%, 10.39%, and 10.05% for samples 1, 2, and 3, respectively. From this, the average effect value of 100% NAC is 10.08%.

Table 4.1: Aggregate impact value of 100% NA

AGGREGATE IMPACT VALUE			
Sample: 100% NA	Sample 1	Sample 2	Sample 3
W_1	1.030	1.028	1.876
W_2	0.676	0.676	1.524
W_3	0.354	0.352	0.352
W_4	0.310	0.318	0.308
W_5	0.044	0.038	0.044
W_6	0.354	0.354	0.352
Aggregate impact value (AIV)	9.8	10.39	10.05
Average impact value = 10.08%			

Table 4.2 below displays the total effect value of several 50% RAC samples, which is 11.35%, 12.35%, and 13.20%, respectively. Through which the average impact value of 50% RAC can be obtained that is 12.3%.

Table 4.2: Aggregate impact value of 50% RA

AGGREGATE IMPACT VALUE			
Sample: 50% RA	Sample 1	Sample 2	Sample 3
W_1	1.882	1.032	0.994
W_2	1.524	0.676	0.676
W_3	0.358	0.356	0.318
W_4	0.310	0.312	0.276
W_5	0.084	0.044	0.042
W_6	0.358	0.356	0.318
Aggregate impact value (AIV)	11.35	12.35	13.20
Average impact value =12.3%			

Table 4.3 below displays the total effect value for each sample of 100% RAC, which is 19.10%, 16.65%, and 17.05%, respectively. Therefore, the average impact value for 100% RAC is obtained as 17.6%.

Table 4.3: Aggregate impact value of 100% RA

AGGREGATE IMPACT VALUE			
Sample: 100% RA	Sample 1	Sample 2	Sample 3
W_1	0.990	0.998	0.988
W_2	0.676	0.676	0.676
W_3	0.314	0.322	0.312
W_4	0.254	0.268	0.268
W_5	0.06	0.054	0.044
W_6	0.314	0.322	0.312
Aggregate impact value (AIV)	19.10	16.65	17.05
Average impact value= 17.6%			

According to the Table 4.4, 100% RA has the highest AIV (17.6%), while 100% NA has the lowest (10.8%). The impact value increases with increasing RA content [13],[15], showing a direct relationship. Since all values are below 20%, the aggregates are considered very tough and suitable. However, due to the significant difference of about 6.8% between 100% RA and 100% NA, 50% RA (12.3%) [16],[18] is a better alternative as it shows only a small increase while incorporating recycled aggregate as per figure 4.2.

Table 4.4: Average impact values of different proportions of RA and NA

Percentage (%)	Average Impact value (%)
100% NA	10.8
50% RA	12.3
100% RA	17.6

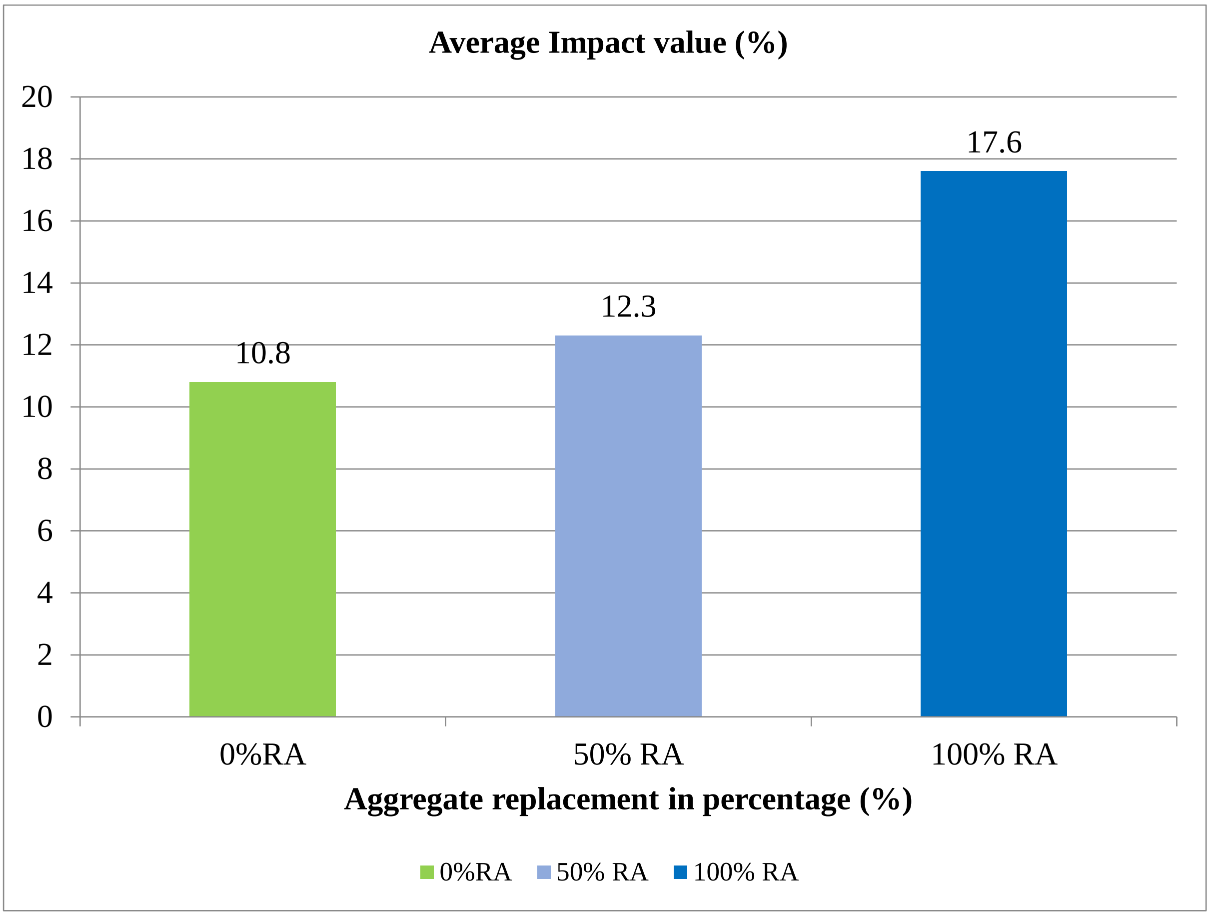

Figure 4.2: Graph of Average Impact Value

4.1.3 Water absorption test

For water absorption test we require following masses which are represented as,

Weight of Sat. Aggregate + basket with water (W_1)

Weight of basket with water (W_2)

Weight of Sat. Agg in water (W_3)

Weight of Oven dried aggregate in air (W_4)

Water absorption= $\frac{W3-W4}{W4}$ *100%

The Table 4.5 shows that Water absorption value keep on increasing with the increment of RA which shows that the value of water absorption is directly proportional to the amount of RA taken [15],[19],[23]. The highest of them is the 100% RA (4.5%) which signifies that with the remaining residues of the RA aggregate has increased its water absorption capacity [18] [23]. The smallest is the 0%RA which is 2.5% and with lo difference is the 50%RA that is 3.2%. Seeing the difference from figure 4.3 we can say that 50% RA can be an option.

Table 4.5: Different Water absorption values of different proportion

Sample	100%NA	50%RA	100%RA
W_1	3.765	3.766	3.767
W_2	1.706	1.697	1.742
W_3	2.049	2.069	2.099
W_4	1.998	2.002	2.010
Water absorption (%)	2.5	3.2	4.5

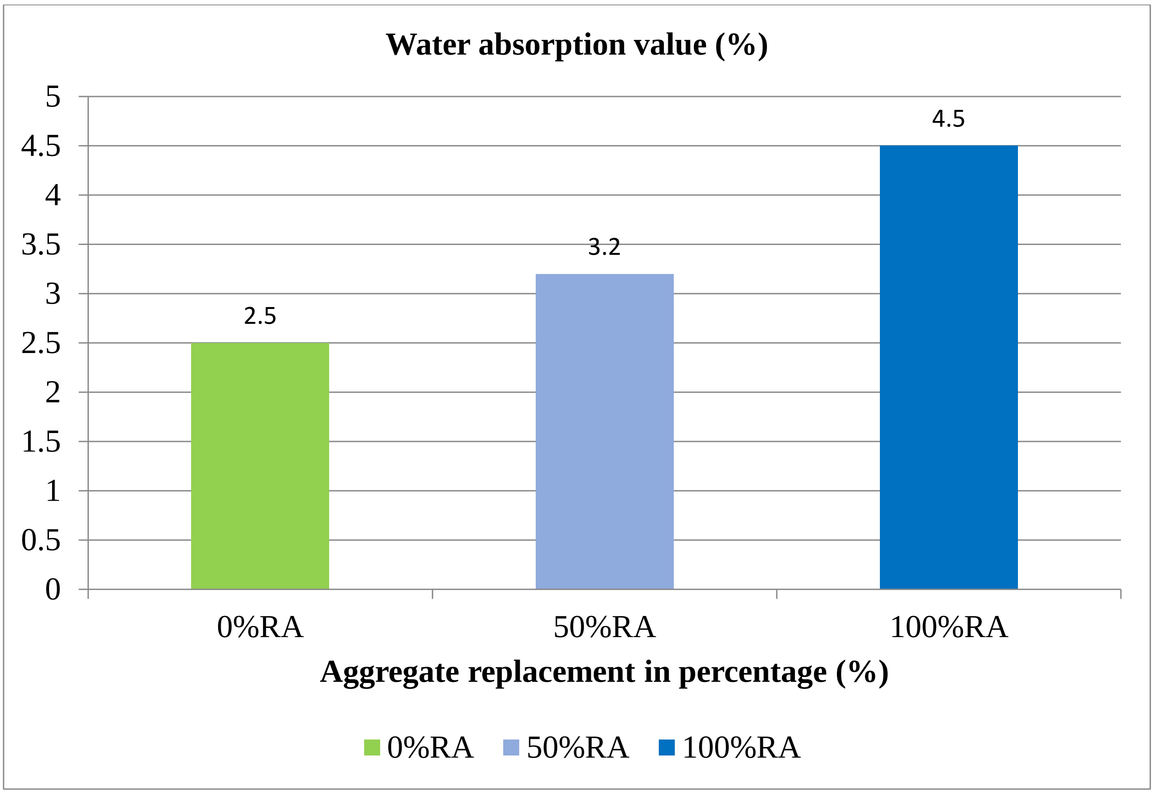

Figure 4.3: Graph of Water absorption value

4.1.4 Los- Angeles's abrasion test

Table 4.6 below shows the los- Angeles's abrasion test conducted on 100% natural aggregate. The table gives the value of los Angeles's abrasion as 23.3% where 3.779 kg of sample was retained and 1.221 kg was passed on 1.70 mm IS sieve.

Table 4.6: Los Angeles's Abrasion Value for 100% NA

Retained on IS Sieve	Total Weight (gm)	Retained	Passed	Percentage (%)
12.5 mm	1250	3.779	1.221	23.3
20 mm	1250			
25 mm	1250			
40 mm	1250			

Table 4.7 below reveals the los- angeles’s abrasion test conducted on replacement of natural aggregate with 50% recycled aggregate. The table gives the value of los angeles’s abrasion as 25.6% where 3.695 kg of sample was retained and 1.309 kg was passed on 1.70 mm IS sieve.

Table 4.7: Los Angeles's Abrasion Value for 50% RA

Retained on IS Sieve	Total Weight (gm)	Retained	Passed	Percentage (%)
12.5 mm	1250	3.679	1.331	25.6
20 mm	1250			
25 mm	1253			
40 mm	1257			

Table 4.8 above reveals the los- angeles’s abrasion test conducted on replacement of natural aggregate with 100% recycled aggregate. The table presents the value of los angeles’s abrasion as 28.2% where 3.679 kg of sample was retained and 1.331 kg was passed on 1.70 mm IS sieve.

Table 4.8: Los Angeles's Abrasion Value for 100% RA

Retained on IS Sieve	Total Weight (gm)	Retained	Passed	Percentage (%)
12.5 mm	1250	3.503	1.499	28.2
20 mm	1251			
25 mm	1250			
40 mm	1251			

As per the table 4.9 the highest value of Los Angeles value is for 100% RA which is 28.2% and the lowest is the 0% RA which is 23.3% 50%RA being in the middle which is 25.6%. This (Figure 4.4) also shows that with the increment of RA content the abrasion value also increases. However as the value is less than 30% aggregate is suitable for construction has it been more than 30% it would have been only favorable to use on pavement [14],[15].

Table 4.9: Los Angeles's Abrasion Value

Aggregate replacement in percentage (%)	Los Angeles's Abrasion Value (%)
100% NA	23.3
50% RA	25.6
100% RA	28.2

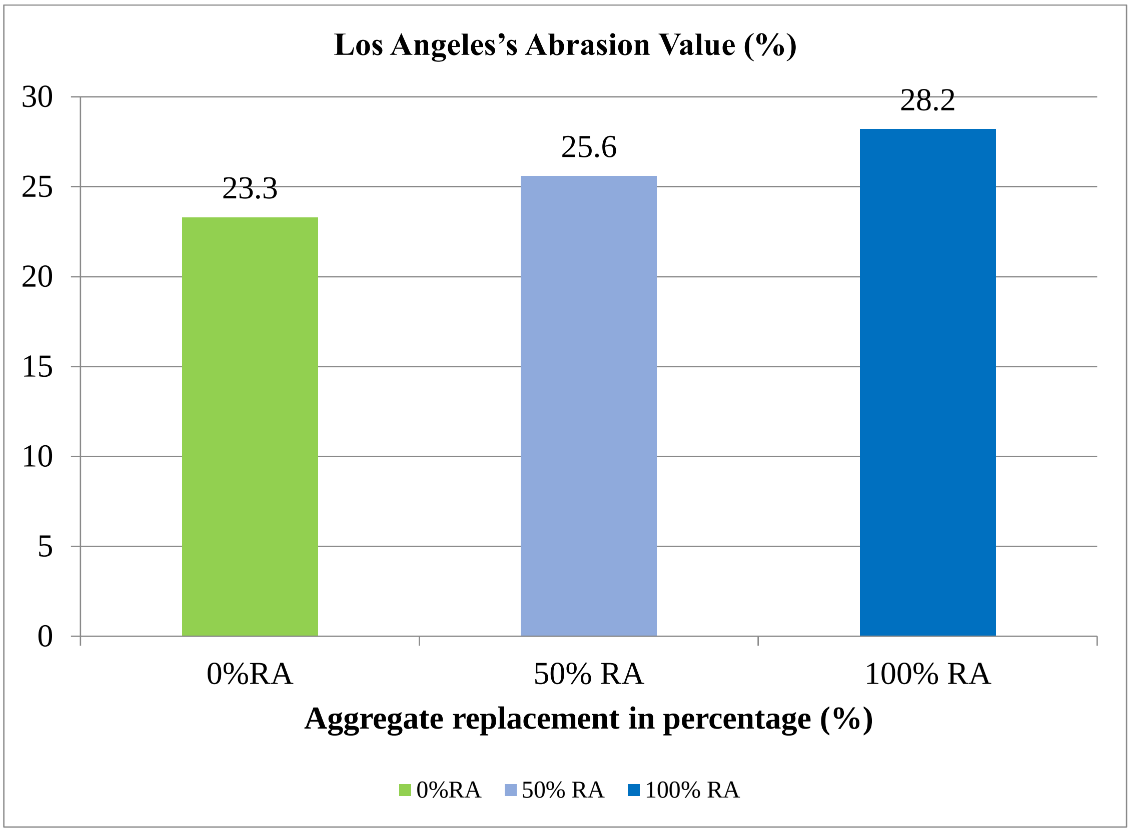

Figure 4.4: Graph of Abrasion Value

4.1.5 Compressive Strength test

Table 4.10 shows the compressive strength of concrete cube specimens at 14 days for different mixes (N, A, B, C, D, E, and F). The control mix (N) achieved an average strength of 19.14 N/mm², with values ranging from 18.90 to 19.33 N/mm², indicating consistent performance. Mixes A and B showed slightly lower average strengths of 18.32 N/mm² and 18.51 N/mm² respectively, suggesting a minor reduction compared to the control. Mix C exhibited the highest strength among all mixes, with values between 19.89 and 21.70 N/mm² and an average of 20.8 N/mm², indicating improved performance. In contrast, mixes D, E, and F showed significantly lower strengths, with average values of 14.24 N/mm², 15.4 N/mm², and 15.86 N/mm² respectively. Overall, the results indicate that compressive strength varies with mix composition, where moderate replacement improves strength, but higher replacement levels lead to a noticeable reduction at 14 days.

Table 4.10: Compressive strength of 14 days

Compressive Strength Test			
14 Days			
Sample	Load (KN)	Compressive Strength (N/mm2)	Average
N1	434.93	19.33	19.14
N2	431.55	19.18	
N3	425.25	18.90	
A1	409.50	18.2	18.32
A2	400.05	17.78	
A3	426.83	18.97	
B1	421.43	18.73	18.51
B2	422.78	18.79	
B3	405.00	18.00	
C1	447.53	19.89	20.8
C2	488.25	21.70	
C3	469.80	20.88	
D1	332.10	14.76	14.24
D2	303.75	13.5	
D3	326.25	14.5	
E1	352.80	15.68	15.4
E2	355.95	15.82	
E3	334.35	14.86	
F1	353.03	15.69	15.86
F2	359.78	15.99	
F3	355.05	15.78	

Table 4.11 presents the compressive strength results of concrete cube specimens at 28 days for different mixes (N, A, B, C, D, E, and F). The control mix (N) achieved strengths ranging from 21.29 to 22.72 N/mm², with an average of 22.2 N/mm², indicating good strength development over time. Mix A showed slightly lower values between 19.25 and 20.8 N/mm², with an average

of 20.2 N/mm², while Mix B performed closer to the control with strengths ranging from 21.39 to 21.56 N/mm² and an average of 21.48 N/mm². Mix C exhibited the highest compressive strength among all mixes, with values between 22.3 and 22.7 N/mm² and an average of 23.5 N/mm², indicating superior performance. On the other hand, Mixes D, E, and F showed comparatively lower strengths; Mix D ranged from 16.26 to 18.68 N/mm² (average 17.78 N/mm²), Mix E from 18.1 to 18.72 N/mm² (average 18.36 N/mm²), and Mix F from 19.8 to 20.37 N/mm² (average 20.02 N/mm²). Overall, the results indicate that compressive strength increases from 14 to 28 days for all mixes, with Mix C showing the best performance, while higher replacement levels in mixes like D, E, and F lead to reduced strength compared to the control.

Table: 4.11: Compressive Strength of 28 days

Compressive Strength Test			
28 Days			
Sample	Load (KN)	Compressive Strength (N/mm2)	Average
N1	479.03	21.29	22.2
N2	508.05	22.58	
N3	511.20	22.72	
A1	433.13	19.25	20.2
A2	468.00	20.8	
A3	462.15	20.54	
B1	485.10	21.56	21.48
B2	481.28	21.39	
B3	483.30	21.48	
C1	510.75	23.57	23.5
C2	508.73	23.89	
C3	501.75	22.99	
D1	420.30	18.68	17.78
D2	400.05	17.78	
D3	365.85	16.26	
E1	407.25	18.1	18.36
E2	421.20	18.72	
E3	411.98	18.31	

F1	458.33	20.37	20.02
F2	447.75	19.9	
F3	445.50	19.8	

By seeing its result in 14 and 28 days as per Table 4.12, the proportion with 0%RA+0%NS has given strength of 19.14 N/mm² and 22.20 N/mm² in 14 and 28 days respectively. While the strength slightly decreases with increment of RA but involving higher NS content which is 1.2% strength increases which was even higher than normal aggregate and 23.5 N/mm² in 14 and 28 days, however reaching the RA at 100% and even involving higher NS, the strength was significantly lower than the control mix but on reaching NS 1.2% the strength shows that it is quite workable ie 15.86 N/mm² and 20.02 N/mm² for 14 and 28days respectively. The results and figure 4.5 indicate that NS significantly and effectively enhances the strength of Recycled aggregate concrete [10],[17],[19] which also suggest us that the optimum combination is 50%RA+1.2%NS.

Table 4.12: Average Compressive Strength values for different proportions

Proportion	Compressive Strength (14days) (N/mm²)	Compressive Strength (28days) (N/mm²)
100% NA	19.14	22.20
50% RA and 0.4% NS	18.32	20.20
50% RA and 0.8% NS	18.51	21.48
50% RA and 1.2% NS	20.8	23.5
100% RA and 0.4% NS	14.24	17.78
100% RA and 0.8% NS	15.40	18.36
100% RA and 1.2% NS	15.86	20.02

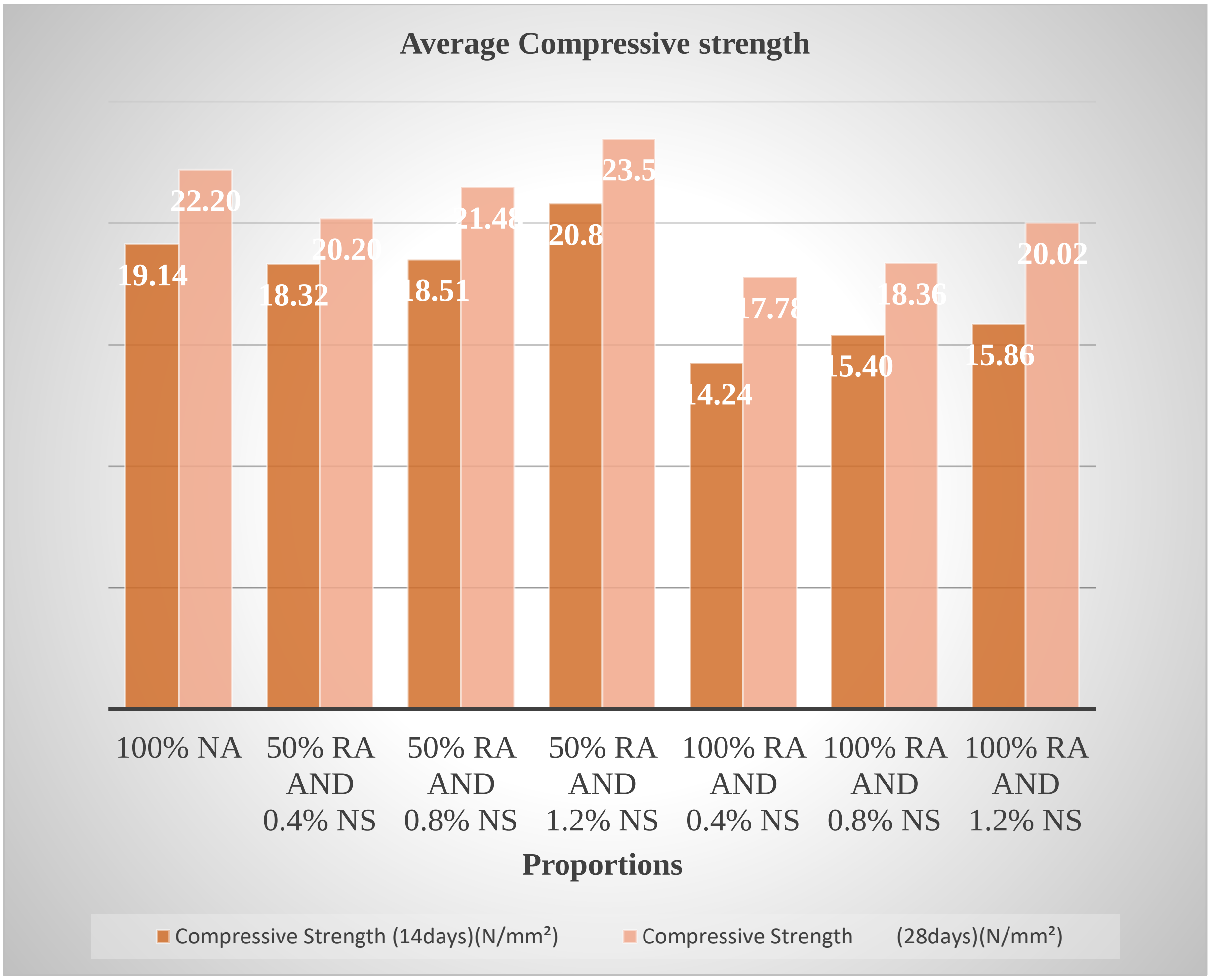

Figure 4.5: Graph of different proportion average compressive strength

4.1.6 Mean, Standard Deviation

Table 4.13: Standard Deviation table of 28 days

Mix ID	Mean (N/mm^2)	Std. Deviation (N/mm^2)
100% NA	22.20	0.79
50% RA and 0.4% NS	20.20	0.83
50% RA and 0.8% NS	21.48	0.09
50% RA and 1.2% NS	23.5	0.21
100% RA and 0.4% NS	17.78	1.22
100% RA and 0.8% NS	18.36	0.32
100% RA and 1.2% NS	20.02	0.30

This table 4.13 presents the mean compressive strength and standard deviation for different concrete mix IDs (N, A, B, C, D, E, and F). The mean values indicate the average compressive strength achieved by each mix, while the standard deviation shows the level of variation or consistency within the test results.

From the table, Mix C (23.5 N/mm²) shows the highest mean strength, slightly higher than the control mix N (22.20 N/mm²), indicating improved performance. Mix B (21.48 N/mm²) also shows relatively good strength with the lowest standard deviation (0.09), meaning its results are highly consistent and reliable. On the other hand, Mix D (17.57 N/mm²) has the lowest mean strength and the highest standard deviation (1.22), indicating weaker performance and greater variability in results. Mixes A, E, and F show moderate strength values with relatively small deviations, suggesting stable but slightly reduced performance compared to the control mix. Overall, the table highlights that certain mixes (especially B and C) perform efficiently with good consistency, while Mix D shows poor strength and high variability.

4.1.7 Comparative Analysis

The percentage change in compressive strength was calculated using the equation

$$\%\Delta = \frac{Fm - Fc}{Fc} \times 100$$

where,

Fm is the compressive strength of the modified mix

Fc is the control mix strength.

This method is used to compare all mixes with the control specimen (N) by showing how much each mix increases or decreases in strength. A positive value indicates improved performance, while a negative value shows a reduction in compressive strength compared to the control.

Table 4.14: Change in compressive strength

Mix ID	% Change in Compressive Strength
100% NA	0%
50% RA and 0.4% NS	−3.24%
50% RA and 0.8% NS	+5.86%
50% RA and 1.2% NS	−19.91%
100% RA and 0.4% NS	−17.30%
100% RA and 0.8% NS	−9.82%

This table 4.14 presents the percentage change in compressive strength of RA–NS modified concrete mixes compared to the control specimen (100% NA). Positive values indicate an increase in strength, while negative values indicate a reduction relative to the control.

The results show that 50%RA + 0.8% NS (+5.86%) achieves the highest increase in compressive strength, indicating the most effective mix proportion among all modified samples. This suggests that an optimum combination of recycled aggregate and nano silica improves the concrete's internal structure and strength performance. The mix 50%RA + 0.4% NS (−3.24%) shows a very small reduction, meaning its performance is close to the control and remains relatively stable. Other mixes such as 100%RA + 0.8% NS (−9.82%) and 100%RA + 0.4% NS (−17.30%) show moderate to significant reductions in strength, indicating weaker performance due to higher recycled aggregate content and lower optimization of nano silica.
The mix 50%RA + 1.2% NS (−19.91%) shows the greatest reduction in compressive strength, making it the least effective combination among all tested mixes.
Overall, the results clearly indicate that the control mix provides the baseline performance, while a moderate replacement of RA with an optimal NS content (0.8%) enhances strength. In contrast, excessive replacement or imbalance in nano silica content leads to a decline in compressive strength.

4.2 Discussion and validation

The table 4.13 validates the experimental results with previous studies. It shows that nanosilica can be effectively extracted from rice husk ash using the water bath method, with a yield of 20.8%, consistent with earlier research. Recycled aggregates show slightly higher impact and abrasion values than natural aggregates but remain within acceptable limits, confirming their suitability for construction. The compressive strength results indicate that nanosilica significantly improves recycled aggregate concrete performance, with both 50% and 100% recycled aggregate mixes showing satisfactory strength. Overall, the findings align well with literature, confirming that nanosilica enhances RAC properties and enables higher utilization of recycled aggregates.

Table 4.15: Validation with respect to literature

Aspect	Experimental Result	Interpretation	Supporting References
Nanosilica extraction from RHA	Yield: 20.8% (water bath method)	Effective silica recovery from agricultural waste using alkaline extraction	[8] Kalapathy et al. (2000), [21] Liou (2004), [1] Md. Tariqul Islam et al. (2024), [22] Nguyen et al. (2019)

Recycled aggregate impact value	RA: 17.6%, NA: 10.8%	RA has lower toughness due to adhered mortar but still acceptable (<20%)	[15] McNeil & Kang (2013), [18] Xiao et al. (2012), [16] Sultana et al. (2021), [13] ScienceDirect
Abrasion value	RA: 28.2%, NA: 23.3%	Higher wear in RA due to porosity but within permissible limit (<30%)	[15] McNeil & Kang (2013), [18] Xiao et al. (2012), [14] LA Abrasion Test reference
50% RA + 1.2% NS compressive strength	23.5 N/mm² > Control (22.2 N/mm²)	Strength improvement due to nanosilica densification and ITZ enhancement	[4] Younis & Mustafa (2018), [12] Haruehansapong et al. (2024), [19] Etxeberria et al. (2006), [17] Singh & Singh (2023)
100% RA + 1.2% NS compressive strength	20 N/mm² (satisfactory)	Full replacement feasible with nanosilica compensation	[12] Haruehansapong et al. (2024), [19] Etxeberria et al. (2006), [11] Lamichhane et al. (2024), [15] McNeil & Kang (2013)
Effect of parent concrete condition	Strength influenced by micro-cracking, carbonation, weathering	Quality more important than age of concrete	[15] McNeil & Kang (2013), [18] Xiao et al. (2012), [10] Limbachiya et al. (2000), [16] Sultana et al. (2021)

Chapter 5

Conclusions and Recommendations

5.1 Conclusion

The present study successfully demonstrated the extraction of nanosilica from Rice Husk Ash (RHA), evaluation of recycled aggregate properties, and improvement of recycled aggregate concrete (RAC) using nanosilica. It was observed that nanosilica can be effectively extracted in a considerable amount using the water bath-assisted alkaline method, achieving a yield of 20.8 [8], [1], [5].

The results showed that recycled aggregates exhibit behavior comparable to natural aggregates, although with slightly higher impact and abrasion values. The impact value of recycled aggregate (17.6%) was higher than natural aggregate (10.8%), and the abrasion value (28.2%) was also higher than that of natural aggregate (23.3%). However, both values remained within acceptable limits, confirming that the aggregates are suitable for construction applications [15],[18].

The study also highlighted that the performance of recycled aggregate is influenced by the condition of the parent concrete. In some cases, long-term exposure leads to carbonation, micro-cracking, and weathering, which increases porosity and reduces aggregate quality [15],[11].

The compressive strength results clearly demonstrated the positive effect of nanosilica on recycled aggregate concrete. The mix containing 50% RA + 1.2% nanosilica achieved 23.5 N/mm^2, which was higher than normal concrete (22.2 N/mm^2), indicating significant strength improvement due to nanosilica addition. Even the 100% RA + 1.2% nanosilica mix achieved 20 N/mm^2, which is considered satisfactory for structural applications. This confirms that nanosilica enhances the microstructure by filling voids and improving the interfacial transition zone (ITZ) [4],[12],[21].

The satisfactory performance of 100% recycled aggregate concrete is particularly important, as it shows that full replacement of natural aggregates is possible when nanosilica is used indicating that nanomaterials significantly improve the durability and mechanical behavior of recycled aggregate concrete [12],[19],[10]. The presence of nanosilica compensates for the weaknesses of recycled aggregates such as higher porosity and adhered mortar, leading to improved density and strength.

Overall, the study confirms that the combination of recycled aggregates and nanosilica provides a sustainable solution for modern construction. It promotes effective utilization of construction and demolition waste and agricultural waste (rice husk), thereby reducing environmental pollution. This supports the principles of reduce, reuse, and recycle, contributing to sustainable and eco-friendly concrete technology [6],[11],[12].

5.2 Recommendations

Based on the findings of this study, several recommendations can be made to improve the practical application of recycled aggregate concrete (RAC) and nanosilica in construction practices. These suggestions aim to enhance sustainability, performance, and economic feasibility in future research and field applications.

i. Encourage the use of RAC as an environmentally friendly replacement for natural aggregate in the manufacturing of concrete by the Nepalese construction industry along with other nations who are developing.

ii. Analyze costs over the course of the whole project to see whether using RAC in construction makes financial sense. Determine if the initial expenses related to making and utilizing RAC are balanced by long-term benefits such as reduced waste disposal costs and a longer supply of aggregate materials.

iii. Conduct further research to determine the most effective proportions of recycled aggregate concrete (RAC) to natural aggregate concrete (NAC) to achieve the desired concrete properties while maximizing the utilization of recycled materials.

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Appendices

Appendix A: Figures of Laboratory work

Figure: preparation of Rice husk ash


WEIGH
Explorer










06
TOXIC GAS

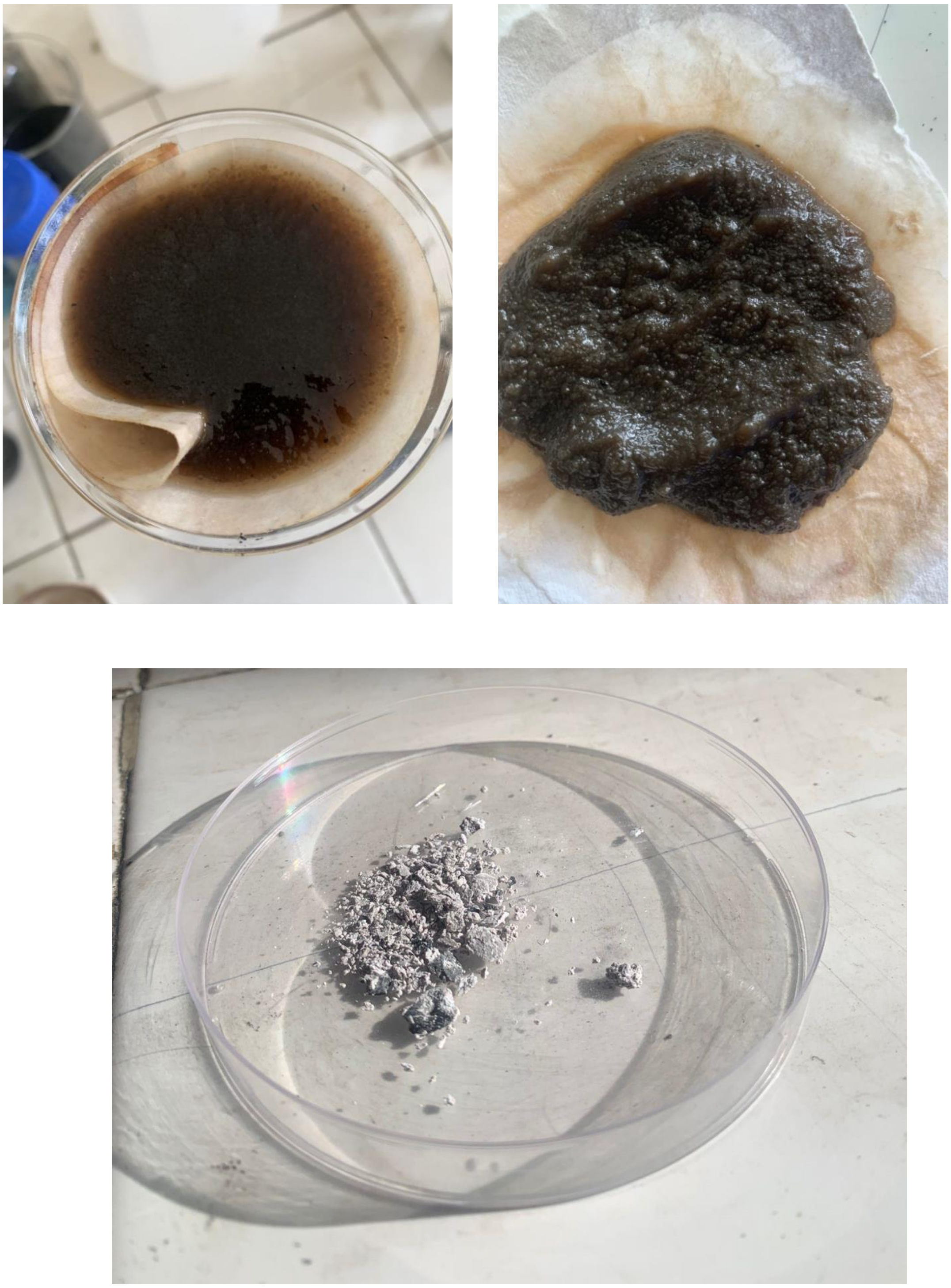

Figure: Extraction of nanosilica from rice husk ash


50 RA
0.8% NS


SBSW


SHRI BALAJI SCIENTIFIC WORKS
NEW DELHI
MODEL NO. SBSW DUTM/1000 KN
SBSW INSTRUMENTS
COMPUTERISED UTM 100

Figure: Compressive strength test

Appendix B: Approval Letter of Paper

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EVEREST ENGINEERING COLLEGE

(Pokhara University Affiliation)

G.P.O. Box: 13289, Sanepa-2, Lalitpur

Reg No. 13208/56/057

Ref. No.

Date: 30 April 2026

To Whom It May Concern

This is to certify that a research paper entitled "Enhancing the Strength of Recycled Aggregate Concrete Incorporating Nanosilica Synthesized from Risk Husk Ash", authored by Sangina Lamichhane, Shreeyash Acharya, Rishikesh Yadav, Dr. Gokarna Bahadur Motra and Khem Raj Shrestha was accepted for oral presentation, based on the abstract submitted for the presentation, at the International Conference on Civil Engineering Innovations and Sustainable Development (CEISD-2026), held on 26 April 2026, organized by Everest Engineering College. The authors made the presentation at the Conference.

The authors have submitted a full-length paper of the same title for consideration for publication in a double-blind peer-reviewed journal Everest Advances in Science and Technology (EAST), with ISSN 3102-0410 (print) and ISSN 3102-0429 (online). The paper has been sent to the reviewer(s) for review comments. Based on the review comments (accepted with minor corrections) the paper has been accepted for publication. All accepted papers will be published in EAST after plagiarism checking, and uploaded in Nepal Journals Online (NepJol) platform with DOI number.

Thank you.

Sincerely

Prof. Dr. Hari Krishna Shrestha
Principal, Everest Engineering College
Chief Editor, Everest Advances in Science and Technology (EAST)

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PAPER NAME

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