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Performance Evaluation of M20 Concrete with Rice Husk-Derivatives

BY

RISHIKESH YADAV

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DECLARATION

I hereby declare that the Thesis entitled "Performance Evaluation of M20 Concrete with RH-derviatives" submitted to the Institute of Engineering, Tribhuvan University, in partial fulfillment of the requirements for the award of the degree of Master of Science in Materials 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.

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. Dr. Prof Khem Raj Shrestha, this Thesis is submitted by Rishikesh Yadav, (Roll No.: 080MSMSE014), entitled "Performance Evaluation of M20 Concrete with RH-derivatives" 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.

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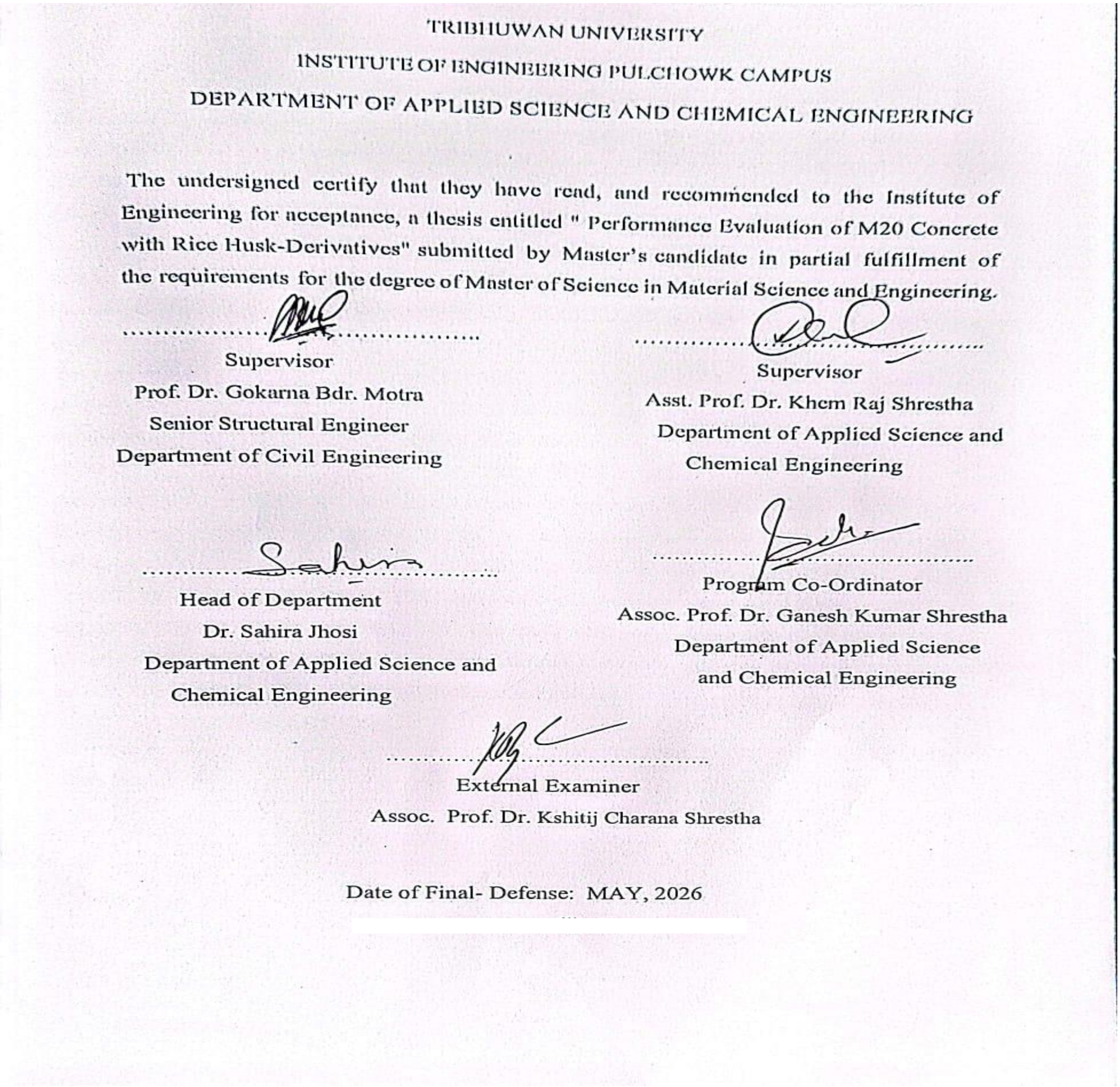
CERTIFICATION AND LETTER OF APPROVAL



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ABSTRACT

One of the most common building materials is concrete because it is strong, durable and versatile. The experimental study of M20 grade of concrete mix using rice husk and its derivatives such as rice husk biochar (RHB) and rice husk ash (RHA) as partial cement substitutes is a sustainable approach that can be used to limit the agricultural waste and environmental footprint of the construction without affecting the mechanical properties. In the context of Nepal, rice producing generates considerable amounts of agricultural-wastes, notably rice husk. This study inspects the performance of M20 grade concrete incorporating rice husk and its derivatives, such as rice husk ash (RHA) and rice husk biochar (RHB), as partial replacement of cement by weight. A replacement level of 5% for each material was selected to evaluate its effect on the workability and mechanical properties. The slump test analysis revealed that a minimal decline in workability due to the porous nature and water absorption capacity of the materials. The mechanical strength (compressive) results at 28days exhibited the incremental improvement for mixes containing 5% RHA (28.1MPa) and 5% RHB (26.9 MPa) compared to the control mix (26.4 MPa), while a minimal reduction was noticed for the combined mix as 15% in total replacement of cement by RH-derivatives (23.7MPa). The development in the strength is assigned to the pozzolanic reaction of amorphous silica present in RHA, which assist to the formation of additional calcium silicate hydrate (C-S-H) gel. Fourier Transfer Infrared Spectroscopy (FTIR) analysis confirmed the presence of Si-O-Si bonds, pointing out silica contribution during hydration. The study clarifies that the rice husk -derivatives can be effectively utilized as supplementary cementitious materials (SCMs), promoting the sustainable construction and efficient agricultural-waste management.

Keywords: rice husk, rice husk ash, rice husk biochar, sustainable concrete, compressive strength, slump test, FTIR.

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LIST OF SYMBOLS

Symbol	Description	Unit
fck	Characteristic compressive strength of concrete	MPa
fcu	Compressive strength of cube	MPa
fcm	Mean compressive strength of concrete	MPa
fck,cube	Characteristic compressive strength of 150 mm cube	MPa
w	Water content in concrete	kg/m^3
c	Cement content	kg/m^3
s	Fine aggregate (sand) content	kg/m^3
g	Coarse aggregate content	kg/m^3
W/C	Water–cement ratio	–
Vc	Volume of cement	m^3
Vw	Volume of water	m^3
Vs	Volume of sand	m^3
Vg	Volume of coarse aggregate	m^3
ρ	Density of concrete	kg/m^3
P	Percentage replacement of cement by RH, RHA, or RHB	%
Slump	Workability of fresh concrete	mm
RH	Rice Husk	–
RHA	Rice Husk Ash	–
RHB	Rice Husk Biochar	–
μ	Mean value of test results	–
σ	Standard deviation of test results	–
V	Volume of concrete	m^3
n	Number of specimens	–
$C_S{-}H$	Calcium Silicate Hydrate	–
CH	Calcium Hydroxide / Portlandite	–
2θ	Bragg angle for XRD analysis	degrees
λ	Wavelength of X-ray in XRD	nm
A	Absorbance (FTIR)	–
ν	Wavenumber (FTIR)	cm^{-1}

Notes

1. Symbols related to mix proportions (c, w, s, g, Vc, Vw, Vs, Vg) are used in IS 10262:2019 mix design calculations.
2. Symbols related to material characterization (C−S−H, CH, 2θ, λ, A, ν,) are used in XRD and FTIR analysis.
3. Symbols related to mechanical testing (fck, fcu, Slump, μ, σ) are used in fresh and hardened concrete tests.

LIST OF ACRONYMS AND ABBREVIATIONS

Acronym / Abbreviation	Full Form	Description / Use
RH	Rice Husk	Raw agricultural residue used as partial cement replacement
RHA	Rice Husk Ash	Burnt and processed rice husk used as pozzolanic material
RHB	Rice Husk Biochar	Thermochemically processed rice husk used as cementitious additive
M20	Mix Design Grade 20	Concrete with characteristic compressive strength of 20 MPa
OPC 43	Ordinary Portland Cement 43 Grade	Cement used for M20 concrete mixes
C-S-H	Calcium Silicate Hydrate	Main hydration product responsible for concrete strength
CH	Calcium Hydroxide	Also known as Portlandite; by-product of cement hydration
FTIR	Fourier Transform Infrared Spectroscopy	Used to characterize functional groups in materials
XRD	X-ray Diffraction	Used to identify crystalline phases in concrete/materials
IS	Indian Standard	Reference code for material testing and concrete mix design
W/C	Water–Cement Ratio	Ratio of water to cement used in mix design
PPC	Pozzolana Portland Cement	Cement blended with pozzolanic material
SP	Superplasticizer	Chemical admixture used to improve workability (not used in this study)

kg/m^3	Kilogram per Cubic Meter	Unit of material quantity for concrete mix
mm	Millimeter	Unit of measurement for cube dimension or slump
MPa	Megapascal	Unit of compressive strength of concrete
n	Number of Specimens	Used in statistical calculation for tests
μ	Mean / Average	Statistical representation of test results
σ	Standard Deviation	Statistical dispersion in experimental results

Notes: All acronyms are used consistently throughout Chapters 1–7

CHAPTER ONE: INTRODUCTION

1.1 Background

Concrete is the most widely used construction material in the world due to its versatility, strength, durability, and relatively low cost (Neville et al., 2011). It is extensively used in the construction of buildings, bridges, pavements, dams, and other infrastructure. Concrete is primarily composed of cement, fine aggregate, coarse aggregate, and water. Among these components, cement acts as the binding material that holds the aggregates together and provides the necessary strength and durability to the concrete structure (Mehta & Monteiro et al., 2014).

However, the production of cement is associated with significant environmental concerns. Cement manufacturing is an energy-intensive process and is responsible for a considerable amount of global carbon dioxide (CO_2) emissions. It is estimated that cement production contributes approximately 7–8% of the total global CO_2 emissions. The increasing demand for cement due to rapid urbanization and infrastructure development has further intensified the environmental impact associated with cement production (Amran et al., 2021; Thomas et al., 2013). As a result, there is growing interest in identifying alternative or supplementary materials that can partially replace cement in concrete without compromising its performance (Papadakis & Tsimas et al., 2013).

Figure 1 Rice husk-based material for sustainable construction

This issue is addressed by the utilization of agricultural and industrial by-products as supplementary cementitious materials. These materials not only reduce the consumption of cement but also help in managing waste materials that would otherwise pose environmental problems. Among the various agricultural wastes, rice husk has gained significant attention due to its abundant availability and favorable chemical properties (Chandrasekhar et al., 2012).

The figure 1, presents the visual representation of the raw materials used in the study, highlighting both conventional and sustainable components of concrete production. It includes rice husk, rice husk biochar and rice husk ash as agricultural by-products, along with standard construction materials such as Hongshi cement 43-grade, 20mm nominal coarse aggregate and river sand as fine aggregate and water.

Rice husk is shown in figure 1 as a lightweight, fibrous agricultural residue obtained from rice milling, which is abundantly available in countries like Nepal. When subjected to controlled burning, it produces rice husk ash, a fine grey powder rice in amorphous silica, known for its pozzolanic properties that enhances the strength and durability of the concrete. Similarly, rice husk biochar, produced through pyrolysis under limited oxygen conditions, appears as porous black material that can improve internal curing and microstructure due to its high surface area.

The figure 1, also illustrate conventional material used in concrete production. Hongshi 43-grade cement acts as the primary binding material. The 20mm coarse aggregate provides mechanical strength and load-bearing capacity, while river sand serves as fine aggregate, contributing to workability and particle packing. Water, shown in a trough, is essential for cement hydration and achieving the desired consistency of the mix.

Overall, the figure 1, supports the background of the study by emphasizing the integration of locally sourced available agricultural waste materials with the traditional concrete ingredients. This approach not only addressed environmental concerns related to waste disposal but also explores sustainable alternatives for enhancing concrete performance.

1.1.1 Rice Husk

The outer protective covering of rice grains is husk, removed during the milling process. It constitutes about 20% by the weight of harvested rice. In countries (Nepal) where rice production is high, a huge amount is generated every year as an agricultural by-product (Habeeb & Mahmud et al., 2010). The disposal prevents environmental challenges, as it is often burned in open fields or dumped in landfills, leading to air pollution and environmental degradation (Sharma & khan et al.,2017). However, rice husk contains a enough proportion of silica and carbon, makes it a valuable resource for producing useful materials for construction and other industrial applications (Chandrasekhar et al., 2012).

1.1.2 Rice husk Ash and Rice husk Biochar

Rice husk can be converted into different derivatives through thermal treatment processes. Two important derivatives are Rice Husk Ash (RHA) and Rice Husk Biochar (RHB). Rice husk ash is known for its high amorphous silica content, exhibits strong pozzolanic properties (Ganesan et al., 2011). Due to its pozzolanic properties, RHA can react with calcium hydroxide released during the hydration of cement to form additional calcium silicate hydrate, which contributes to improved strength and durability of concrete (Habeeb et al., 2010; Zhang et al., 2010). Givi et al., 2010, ash contains about 80-85% silica and high specific surface area, makes it an effective pozzolanic material.

Figure 2: RH and Its derivatives used in concrete for sustainable concrete mix

According to Givi et al. (2010), husk contains about 80-85% pozzolanic silica. Chemical properties of a typical ash are presented in table 2. In addition, RHA is used as partial replacement of Portland cement in lime pozzolana mixes. The pozzolanic reactions start when the dicalcium silicate and tricalcium silicate come in contact with water during hydration process of cement as shown in Equations as:

$2(3CaO\text{-}SiO2) + 6H2O \longrightarrow 3CaO.2SiO2.3H2O + 3Ca\,(OH)2$ …………………Equation 1
$2(2CaO\text{-}SiO2) + 4H2O \longrightarrow 3CaO.2SiO2.3H2O + 3Ca\,(OH)2$ …………………Equation 2
$Ca\,(OH)2 + H2O + Al2O3 \longrightarrow Al2O3.Ca(OH)2.H2O$ ……………………………Equation 3
$SiO2 + Ca\,(OH)2 + H2O \longrightarrow CaO.SiO2.H2O$ ……………………………………Equation 4

From the equations (1,2, 3 and 4), these reactions result in calcium silicate hydrate (C S-H) and calcium hydroxide. The excess calcium hydroxide reacts with alumina and water to form calcium aluminate hydrate as shown in Equation 3. Both C-S-H and C-A-H are responsible for the production of gel. The presence of excess calcium hydroxide is harmful to strength. An addition of pozzolanic material such as ash in concrete causes a reaction between silica and the excess calcium hydroxide that produces more C-S-H gel as shown in Equation 4. This gel fills the pores of the concrete and reduces capillary leading to more strong and durable concrete. Givi et al. (2010) also elaborates the properties of ash modified concrete, concluded that the inclusion of ash in concrete showed improved mechanical properties of concrete.

The pozzolanic reactions occurring in cementitious system improve the microstructure of concrete by reducing pore spaces and capillary voids, leading to enhanced mechanical properties and durability (Safiuddin & hearn et al., 2010). Studies have demonstrated that the incorporation of ash improves strength, permeability resistance, and durability of concrete (Prusty & Patro et al., 2015; Kumar & Singh et al., 2018)

Similarly, rice husk biochar is produced through pyrolysis under limited oxygen conditions. Biochar is a carbon-rich porous material with high surface area and unique microstructural charcteristics (Uthaman et al., 2018). When incorporated into cement-based materials, biochar improves water retention capacity, internal curing efficiency and hydration behavior within the concrete (Yin et al., 2017). The porous nature of biochar can also impart to improved microstructural development and durability performance of concrete (Tuan & Ye, et al., 2014).

Rice husk biochar, on the other hand, is produced through pyrolysis, which is the thermal decomposition of organic materials in the absence or limited presence of oxygen. Biochar is a carbon-rich, porous material that has a high surface area and unique microstructural characteristics. When incorporated into cement-based materials, biochar can influence the internal structure, water retention capacity, and durability of concrete. The porous structure of biochar may also contribute to internal curing, improve hydration efficiency and potentially enhance the durability performance of concrete. Studied shown the properties of ash to predict the performance of ash as pozzolan. Literature regarding ash-modified concrete was examined to get an summary of the performance properties and chemical behavior behind the improved properties of RHA-modified concrete.

The incorporation of rice husk derivatives into concrete has attracted considerable research interest in recent years due to their potential to improve mechanical properties while promoting sustainable construction practices (Amran et al., 2021). These materials can help reduce the environmental footprint like carbon dioxide emission of cement production, minimize agricultural waste disposal problems, and contribute to the development of eco-friendly and sustainable construction technologies (Singh et al., 2016). Among different grades of concrete used in construction, M20 grade concrete is one of the most commonly used grades for structural and non-structural functionality like residential buildings, pavements, and small-scale infrastructure. Evaluating the performance of M20 grade of concrete with the incorporation of rice husk- derivatives is therefore important in order to determine their suitability for practical construction applications.

In addition to mechanical performance, understanding the chemical and mineralogical characteristics of materials used in concrete is essential for evaluating their behavior and interaction within the cement matrix. Advanced characterization techniques such as Fourier Transform Infrared Spectroscopy (FTIR) and X-Ray Diffraction (XRD) provide valuable information about the chemical composition and mineral phases present in materials (Ramezanianpour et al., 2014). These techniques can be used to analyze rice husk derivatives as well as hardened concrete samples to better understand the microstructural changes that occur when such materials are incorporated into concrete.

Therefore, in this study, the performance of M20 concrete incorporating rice husk derivatives will be evaluated through experimental investigation. Fresh concrete properties will be assessed using the slump test, while hardened concrete performance will be evaluated through compressive strength testing of cube specimens at different curing ages. Additionally, material characterization techniques such as FTIR will be employed to analyze rice husk derivatives and powdered samples obtained from crushed concrete cubes after compressive strength testing. The findings of this study will contribute to understanding the potential use of rice husk-derivatives as sustainable materials in concrete production.

1.2 Problem of statement

The construction industry is one of the largest consumers of natural resources and energy. Cement, which is a primary component of concrete, requires significant energy for its production and contributes substantially to greenhouse gas emissions and environmental degradation (Thomas et al., 2013). With the increasing demand for infrastructure development, the consumption of cement continues to rise, leading to greater environmental concerns.

Simultaneously, agricultural residues such as rice husk are generated in large quantities worldwide annually, creating improper disposal and environmental management challenges. Rice husk, including open burning and uncontrolled dumping, results in environmental pollution and waste management issues (Sharma & Khan et al., 2017). Although rice husk derivatives such as rice husk ash and rice husk biochar possess beneficial properties that may enhance concrete performance, their effective utilization in conventional concrete mixes requires further investigation (Barbhuiya et al., 2025).

Previous studies have indicated that rice husk ash can act as a pozzolanic material and improve certain properties of concrete. Similarly, biochar has shown potential for modifying the microstructure of cementitious materials. However, there is still limited experimental information regarding the combined influence of rice husk derivatives on the performance of commonly used concrete grades such as M20 concrete.

Furthermore, while rice husk biochar has shown potential for enhancing microstructural properties and internal curing behavior, experimental data regarding its influence on fresh and hardened properties of concrete remain insufficient (Yin et al., 2017). Therefore, further investigation is necessary to evaluate the effect o rice husk derivatives on the workability, strength and mineralogical characteristics of concrete.

1.3 Objectives of the Study

The main objective of this research is to evaluate the performance of M20 grade concrete incorporating rice husk derivatives.

The specific objectives of the study are:

a) To determine the workability of fresh concrete using the slump test,

b) To determine the compressive strength of concrete cubes of standard and replacement mix at curing ages of 7, 14, and 28 days,

c) To investigate the chemical characteristics of rice husk and its derivatives using Fourier Transform Infrared Spectroscopy (FTIR) to ensure the pozzolanic properties,

d) To evaluate the influence of rice husk derivatives on the overall performance of M20 grade concrete,

1.4 Scope of the Study

The study aligns on the evaluation of M20 grade of concrete incorporating rice husk derivatives under laboratory conditions. The scope of the study includes the preparation and testing of concrete specimens as well as the characterization of raw materials and hardened concrete samples. The incorporation of agricultural waste materials such as rice husk-derivatives is intended to investigate their suitability as sustainable supplementary materials in concrete production (Amran et al., 2021).

Fresh concrete properties will be evaluated using slump test, assess the workability of the concrete mix with standard testing procedures (Neville, et al., 2011). For hardened concrete testing, cube specimens with dimensions of 150 mm × 150 mm × 150 mm will be cast and cured for specified durations. The strength of concrete cubes will be obtained at curing period of 7 , 14, and 28-days using a compression testing machine, most important mechanical properties of concrete (Mehta & Monteiro et al., 2014).

In addition to mechanical testing, the study includes material characterization will be carried out to analyze the chemical properties of rice husk and its derivatives. Fourier Transform Infrared Spectroscopy (FTIR) will be used to study the functional groups present in rice husk and its derivatives, particularly to verify the pozzolanic nature of rice husk ash (Chandrasekhar et al., 2012).

After compressive strength testing, powdered samples will be collected from crushed concrete cubes. These powdered samples will be further analyzed using FTIR and X-Ray Diffraction (XRD) techniques in order to investigate the chemical and mineralogical characteristics of the hardened concrete matrix (Ramexanianpour et al., 2014).

The scope of the study is limited to evaluation of the workability, compressive strength and chemical characterization of concrete incorporating rice husk- derivatives. Other important properties such as flexural strength, shrinkage, tensile strength, creep, permeability, and long-term durability are not included within the scope of this study.

1.5 Relevancy of the study

The utilization of agricultural waste materials in construction has gained significant importance due to increasing environmental concerns and the growing demand for sustainable construction materials (Sharma & khan et al., 2017). Rice husk is one of the most abundantly available agricultural by-products in rice-producing countries and is often disposed of through open burning or dumping, leading to environmental pollution and waste management problems (Habeeb & Mahmud et al., 2010) The incorporation of rice husk- derivatives: ash and biochar in concrete can provide both environmental and engineering benefits. The use of rice husk ash as a supplementary cementitious material can reduced cement consumption and lower carbon dioxide emissions associated with cement production (Thomas et al., 2013).

The use of agricultural waste materials in construction has gained considerable importance in recent years due to the increasing emphasis on sustainable development and environmental protection. Rice husk is one of the most abundant agricultural by-products and is often underutilized despite its potential for value-added applications.

Utilizing rice husk derivatives in concrete can help address multiple environmental challenges simultaneously reduces the demand for cement, decrease carbon emissions associated with cement production, and provide an effective method for managing agricultural waste. Furthermore, incorporating rice husk derivatives into concrete may enhance certain properties of the material, contributing to improved performance and durability.

This study is relevant to the development of sustainable construction materials and may provide useful insights into the potential use of rice husk derivatives in conventional concrete mixes. The findings of this study may contribute to promoting environmentally friendly construction practices and encouraging the utilization of agricultural waste in civil engineering applications (Barbhuriya et al., 2025).

1.6 Feasibility of the study Within the Scope and Time Frame

The experimental work required for this research is feasible within the available laboratory facilities, resources, and time frame. The materials required for preparing concrete, including cement, aggregates, water, and rice husk derivatives, are readily available. The collection and preparation of rice husk – derivatives can be performed using simple and accessible processing methods (Chandrasekhar et al., 2012)

The experimental program primarily involves slump testing of fresh concrete and compressive strength testing of cube specimens, which are standard laboratory procedures commonly conducted in civil engineering laboratories (Neville et al., 2011). The number of specimens required is manageable, as only 150 mm cube specimens will be prepared and tested for curing period of 7, 14, and 28- days.

In addition, material characterization will be performed using FTIR and XRD analysis, which are established techniques for studying the chemical and mineralogical properties of materials. These analyses will provide additional insights into the interaction between rice husk derivatives and the cement matrix (Ramezanianpour et al., 2014).

Since the study focuses on a limited number of experimental tests and characterization techniques, it can be completed within the designated project duration.

Therefore, the research is considered practical and achievable within the available resources and time constraints.

1.7 Limitations of the study

The study is limited to M20 grade concrete only; therefore, the results may not be directly applicable to other concrete grades used in different structural applications.

a) Only rice husk and its derivatives, namely rice husk ash and biochar, are considered in this research. Other supplementary materials such as fly ash, silica fume and ground granulated blast furnace slag are not investigated in this study (Papadakis & Tsimas, et sl., 2013).
b) Evaluation is restricted to workability (Slump test) and compressive strength only. Other important mechanical properties such as split tensile strength, flexural strength and modulus of elasticity are not investigated (Mehta & Monteiro et al., 2014).
c) The Study focuses only on short-term strength development at curing ages of 7, 14, and 28

days. Long-term performance and durability characteristics of concrete are not considered.

d) FTIR analysis in this research is limited to chemical characterization of materials. Detailed microstructural investigations such as Scanning Electron Microscopy (SEM) analysis are not included due to limited scope and resources.

e) The study is conducted under controlled laboratory conditions, what may not fully represent field conditions and environmental exposure during practical construction applications.

f) Economic analysis, cost-benefit evaluation and large-scale practical implementation aspects are not considered in this study.

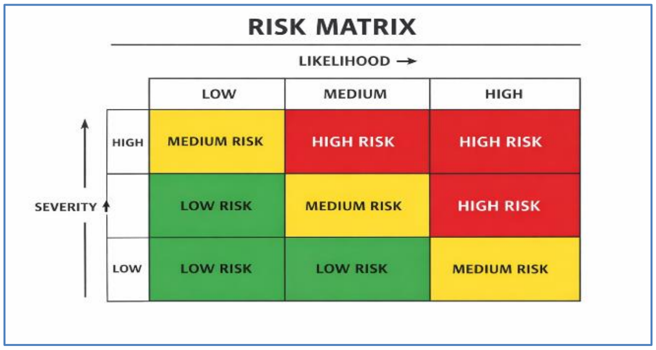
g) Durability-related properties such as permeability, shrinkage, creep, sulphate resistance, and resistance to aggressive environmental exposure are not included in this research (Kumar & Singh et al., 2018).

h) The important durability such as permeability, shrinkage, creep and resistance to the environmental exposure are not included.

i) Only Cube specimens (150mm × 150 mm× 150 mm) are used for compressive strength testing; behavior of other specimen shape and sizes is not considered.

1.8 Risk Matrix Interpretation of study

From figure 3, the risk matrix for this study reflects that, due to its limited scope and controlled laboratory conditions, most of activities fall within low to medium risk categories, while only few are in high-risk categories. Since, the study is restricted to workability, compressive strength and FTIR analysis for RH and its-Derivatives characterization only, the range of hazardous operations is minimized. Routine process such as mixing, casting, curing, and slump testing fall under low risk due to their severity and controlled likelihood.



RISK MATRIX

LIKELIHOOD →

SEVERITY ↑

	LOW	MEDIUM	HIGH
HIGH	MEDIUM RISK	HIGH RISK	HIGH RISK
	LOW RISK	MEDIUM RISK	HIGH RISK
LOW	LOW RISK	LOW RISK	MEDIUM RISK

Figure 3**:** Risk Matrix (Source: ISO 45001, 2018; ASTM C39/C39M-23, 2023)

From the figure 3, the activities like material handling, and sample preparation for FTIR fall under medium risk because of dust exposure and moderate handling hazards. The compression testing of concrete cubes represents the primary high-risk activity due to possibility of sudden specimen failure and equipment-related hazards.

Overall, the limitations of this study- such as exclusion of advanced durability tests, long term performance evaluation, and field applications- helps to confine the risks to a manageable level within a laboratory environment. Therefore, the experimental program can be safely conducted by following standard laboratory safety guidelines and risk mitigation measures (ISO 45001, 2018; ASTM C39/C39M-23, 2023).

CHAPTER TWO: LITERATURE REVIEW

2.1 Rice Husk and Its Derivatives in Cement-Based Materials

The growing demand for sustainable construction materials has encouraged researchers to explore alternative resources that can partially replace conventional cement in concrete. Among various agricultural by-products, rice husk has attracted considerable attention due to its abundant availability and high silica content. Rice husk is the outer protective layer of rice grains that is removed during the milling process. It accounts for approximately 20–22% of the total weight of harvested rice and is generated in large quantities in rice-producing countries. Improper disposal of rice husk through open burning or dumping often leads to environmental pollution and waste management challenges.

Rice husk contains a high proportion of silica along with organic compounds such as cellulose and lignin. Because of its chemical composition, husk can be turned into valuable derivatives through thermal treatment processes. Two of the most commonly studied derivatives are Rice Husk Ash (RHA) and Rice Husk Biochar (RHB). These materials have been widely investigated as supplementary materials in cementitious systems due to their potential to improve concrete properties while reducing environmental impact (Mehta, 1992).

Ash is produced through the controlled burning of rice husk at high temperature typically ranging between 600°C - 800°C. During this process, the organic components of rice husk are burned off, leaving behind a silica-rich ash. The silica present in rice husk ash is primarily in amorphous form, which makes it highly reactive and suitable for use as a pozzolanic material in cement-based systems. When incorporated into concrete, rice husk ash reacts with calcium hydroxide produced during the hydration of cement to form additional calcium silicate hydrate (C–S–H) gel, which contributes to the development of strength and durability in concrete (Ganesan et al., 2008).

In recent years, researchers have also investigated biochar derived from rice husk as an additive in cementitious materials. Biochar is produced through pyrolysis, which is a thermal decomposition process carried out in the absence or limited presence of oxygen. The resulting material is a carbon-rich, porous structure with high surface area and adsorption capacity. Due to its unique physical and chemical characteristics, biochar has the potential to influence the hydration process, microstructure, and durability of cement-based materials (Gupta and Kua, 2017).

The incorporation of rice husk derivatives into concrete has gained significant interest as part of sustainable construction practices.

These materials not only reduce the consumption of cement but also provide an effective method for utilizing agricultural waste that would otherwise contribute to environmental pollution. Furthermore, the use of rice husk derivatives in concrete can improve certain properties such as compressive strength, durability, and resistance to chemical attack when used in appropriate proportions (Chandrasekhar et al., 2018).

The reaction mechanisms involved in cement systems containing rice husk derivatives are complex and involve interactions between cement hydration products and the supplementary materials. Similar to other pozzolanic materials, rice husk ash reacts with calcium hydroxide released during cement hydration, forming additional cementitious compounds that refine the pore structure of the concrete matrix. This process results in a denser microstructure and improved mechanical performance of concrete.

Although various studies have reported improvements in concrete properties with the incorporation rice husk- derivatives, effectiveness largely depends on several factors such as burning temperature, particle size, replacement percentage, and curing conditions. Improper processing of rice husk ash may result in crystalline silica formation, which reduces its pozzolanic activity. Similarly, excessive incorporation of biochar may increase the porosity of concrete, which can negatively affect mechanical strength.

In addition to mechanical performance, researchers have also investigated the microstructural characteristics of cement-based materials containing rice husk derivatives. Advanced characterization techniques such as Fourier Transform Infrared Spectroscopy (FTIR) and X-Ray Diffraction (XRD) are commonly used to analyze the chemical composition and mineralogical phases present in these materials. FTIR analysis helps identify functional groups and chemical bonds within the material, while XRD analysis provides information about crystalline phases such as calcium hydroxide, quartz, and calcium silicate hydrate present in the hardened concrete matrix (Scrivener et al., 2016).

Although the macroscopic properties of concrete containing rice husk derivatives may appear similar to those of conventional concrete, their microstructure, hydration behavior, and durability characteristics can vary significantly depending on the type and amount of derivative used. Therefore, further experimental studies are necessary to evaluate the performance of concrete incorporating rice husk derivatives under different conditions and to better understand their interaction with cement hydration products.

The utilization of rice husk derivatives in concrete represents a promising approach toward developing supplementary cementitious materials, reducing cement consumption and utilizing agricultural waste, and contribute to environmentally friendly construction practices. Continued research in this area is essential to optimize the use of rice husk derivatives in concrete and to fully understand their effects on mechanical and microstructural properties.

2.2 Materials to Be Incorporated in Concrete

2.2.1 Raw Rice Husk (RH)

Raw rice husk is the outer protective layer of rice grains, accounting for approximately 20–22% of the total weight of harvested rice. It is primarily composed of cellulose, lignin, and 15–20% silica (Mehta, 1992). Raw husk directly incorporated into concrete as a partial replacement for fine aggregate or cement. Its primary effect is as a filler, enhancing packing density of the concrete matrix. However, low pozzolanic reactivity, raw RH contributes less to chemical strength gain compared to processed derivatives.

Previous studies report that RH can slightly reduce workability due to its irregular particle shape and porosity. Incorporation of RH up to 5–10% by weight of cement has been shown to improve matrix density and provide environmental benefits by utilizing agricultural waste (Chandrasekhar et al., 2018).

Production and Use:

a) RH is generally washed, dried, and sieved before incorporation.
b) Some studies incorporate raw RH directly as a partial cement or sand replacement (Mehta, 1992).
c) Unprocessed RH has a lower pozzolanic activity but can provide filler effects.

2.2.2 Rice Husk Ash

Rice husk is massive agricultural waste by- product around the world. Nepal produces 18 billion tons of rice every year. When rice is harvested, husk is removed from the grain at a processing center.

Husks approximately 20% of the grain only and are not easily composted or useful as animal feed. However, when it combusted at high temperatures, give a 20% yield of ash by weight of total husk. Ash has a high content of amorphous silica, makes it an ideal pozzolan. According to ASTM C618, a pozzolan is a material in which the combination of silicon dioxide, aluminum oxide and iron oxide are not less than 70%. The amorphous SiO_2 content with porous structure of the ash depends on the temperature and duration of combustion (Tuan 2011). Ash is obtained through the controlled combustion of husk at standard temperature 600–800°C. The combustion process removes the organic content, produces ash which is rich in amorphous silica, exhibits high pozzolanic reactivity (Ganesan et al., 2008). Ash reacts with calcium hydroxide released during cement hydration to form additional calcium silicate hydrate gel, improves compressive strength, reduces porosity, and enhances durability (Chai et al., 2025). Studies found that replacing 10–20% of cement by weight with ash is optimal for M20 concrete, providing a balance between strength improvement and workability (Chandrasekhar et al., 2018). Excessive replacement (>25%) showed increase water demand and reduce workability. Ash contains about 80-85% silica, highly reactive (Kishore, et al. 2011). Another study showed content of silica to be about 90-95% (Gursel, et al. 2016). Table shows different composition analyses of RHA from other studies.

Table 1: Oxide composition of RHA from the literature

	(Shanmugava-divu, et al. 2014)	(Kartini, et al. 2014)	(Hesami, et al. 2013)	(Givi, et al. 2013)
oxide	Mass Percent (%)			
CaO	2.04	-NA-	1.15	1.30
SiO_2	78.40	96.70	86.02	87.86
Al_2O_3	1.04	1.01	0.36	0.68
Fe_2O_3	0.30	0.05	0.16	0.93
MgO	0.80	0.19	0.36	0.35

RHA is porous in nature with high surface. Because of its high surface area, mixes with RHA require more superplasticizer than standard mixes (Zareei, et al. 2017). If a superplasticizer is not being used, then water demand increases with RHA addition, the porous structure of ash allows to absorb the water (Shanmugavadivu, et al. 2014). The particle size of RHA is also a main factor that affects water demand and hydration rates. Different studies report different mean sizes for RHA particles : 7.3 μm was reported by (Tuan 2011), 25.83 μm (Kartini, et al. 2010). Another study found that grinding to an average particle size of 10 μm showed some crushing of the cellular structure of RHA, but the effects were minor when compared to the increased reactivity due to smaller particle size (Gursel, et al. 2016).

Role of RHA in Alkali-silica reaction (ASR)

Alkali-silica reaction in concrete is a type of alkali-aggregate reaction, occurs due to the chemical reactions of alkali oxides and silica. Generally, alkali oxides are a composition of cement and silica compounds that come from the reactive aggregate used in the concrete. The reaction between silica and alkali oxides results in ASR gel, expands in the presence of moisture, creating cracks in concrete. The entire process is shown in Equation 5 and 6.

$$\text{Alkali hydroxide (from cement)} + \text{Silica (from aggregate and RHA)} \longrightarrow \text{Alkali-silica gel}$$

Equation 5

$$\text{Alkali} - \text{Silica gel} + \text{Moisture} \longrightarrow \text{Concrete Expansion and cracking}$$

Equation 6

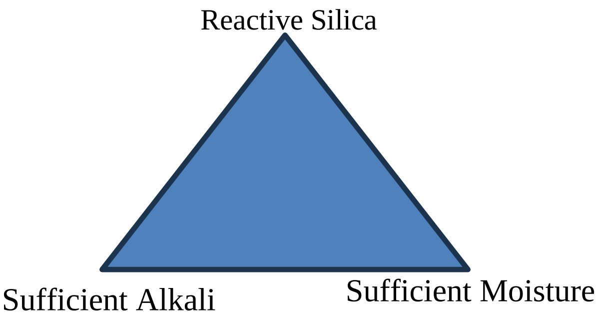


Figure 4: Necessary components for ASR reaction (Akhnoukh et al., 2016)

From figure 4, Akhnoukh et al. (2016) reported early concrete distress in pavement and barriers due to ASR in Arkansas, investigated for possible mitigations of such distresses by using local aggregates. According to these authors, the necessary components for ASR reaction are shown in Figure 4. The key factors leading to the pavement cracking were the use of the local reactive aggregates, preparation of concrete without any supplementary cementitious material and the presence of high moisture content in the air. It was found that the usage of 15% ash as a partial replacement of cement in concrete reduced the ASR expansion by 50% more than the Control sample. Moreover, the use of the 10% ash in concrete was found to be optimum in mitigating the ASR expansion.

Abbas et al. (2017) studied the use of RHA in mortar at four different percentages: 10%, 20%, 30% and 40% by weight to mitigate ASR in concrete. The mortar mixes were prepared with alkali-silica reactive aggregate; sand from Dolomite-limestone rock and OPC according to the ASTM C1260 method. Three mortar bars were made for each ash dosage and readings were taken up to 28 days.

Water Absorption and Porosity

The porosity is most important factor to consider for evaluating the durability of concrete matrix. Studies have linked increased strength and reduced corrosion to lower porosity. Hesami (2013) recommends a direct relationship between porosity and permeability, compressive and tensile strengths are reduced while permeability and porosity are increased. The results shows that partial replacement of cement by weight with RHA, effectively reduces porosity only to a certain amount 8% -10% depending on the water to cement ratio; after which the porosity increases because the high specific surface area of ash. However, studies reported after 28-days of curing, concrete with only OPC was 3 - 7 times more permeable than concrete containing superplasticizer and with replacement of OPC by 20% ash and 30% ash respectively (Kartini, et al. 2010). This study suggested that due to its finer particles and pozzolanic reaction, ash created gel to fill the larger voids in the hydrated cement, thus reducing the mean pore radius.

2.2.3 Rice Husk Biochar (RHB)

Rice husk biochar is produced through pyrolysis of RH in limited oxygen conditions, resulting in a carbon-rich, porous material with a high surface area (Gupta & Kua, 2017). The pore structure of biochar allows to retain water and release it gradually during hydration, providing internal curing, promoting better strength development and reduces micro-cracks in concrete. Literatures reported that optimal biochar content about 3–10% by weight of cement, improve compressive strength, shrinkage resistance, and durability of concrete. However, excessive may increase porosity, reducing mechanical performance (Tan et al., 2021).

2.2.4 Combined Incorporation (RH + RHA + RHB)

Several recent studies have investigated combining RH, RHA, and RHB in concrete to exploit their synergistic effects. The combination leverages:

a) RH as a filler improving matrix packing.
b) RHA providing pozzolanic strength gain.
c) RHB contributing to internal curing and long-term durability.

Research by Tan et al. (2021) demonstrated that concrete mixes incorporating 10–15% RHA, 5% RHB, and 5% RH showed improved compressive strength, reduced porosity, and better workability compared to mixes containing individual derivatives. The study concluded that combined incorporation can optimize mechanical and durability performance if the proportions are carefully selected.

2.3 Mechanical Properties of Concrete with Rice Husk and Its Derivatives

The mechanical properties of concrete incorporating rice husk-derivatives have been extensively investigated concerning workability (slump) and strength performance (compressive, tensile, and flexural tests).

2.3.1 Slump and Workability

Workability is crucial for fresh concrete placement and compaction. Slump tests measure consistency and workability, wherein higher slump values indicate better flowability. Incorporation of rice husk ash generally reduces workability due to the high surface area and internal porosity of RHA, increasing water demand. Nduka et al. (2022) observed a reduction in slump as RHA content increased in high-performance concrete mixes, indicating that RHA's fine particles absorb more water from the mix.

Similarly, other researchers have reported that as RHA percentage increases, slump values decline due to the ash's high surface texture and stronger internal friction, requiring more water or admixtures to maintain workability levels comparable to control concrete.

Biochar incorporation also affects slump values, typically reducing workability due to its porous and irregular structure, which absorbs mix water and impedes flow. Literature indicates that low-level biochar addition (e.g., 1–3%) slightly reduces slump but can be managed with superplasticizers, while higher contents (>5%) significantly reduce slump.

2.3.2 Compressive Strength

Compressive strength is a primary metric for evaluating the performance of concrete mixes with RH derivatives. Incorporation of RHA has generally shown positive effects on compressive strength up to an optimum level. The mechanical improvement is attributed to the pozzolanic reaction of amorphous silica in RHA with calcium hydroxide, forming additional calcium silicate hydrate (C–S–H) gel, which densifies the cement matrix and improves strength.

For instance, concrete mixes with 5–20% RHA replacement showed compressive strength increases ranging from 2.4% to 18.7% at 28 days compared to control mixes, indicating that RHA enhances strength development as curing age increases.

A study using machine learning to predict compressive strength further confirmed that RHA incorporation up to 30% can improve concrete strength compared to control, with optimal performance near 10–15% replacement, after which strength begins to decrease.

Biochar has shown similar trends in mechanical performance. Low-level biochar replacement (1–3% by weight) can increase 28-day compressive strength by 10–40% due to improved hydration kinetics and microstructural compaction. However, strength declines at higher dosages (>5%), as excessive biochar increases porosity and weakens the matrix.

Studies combining rice husk derivatives with other additives (such as carbon nanotubes) have demonstrated further improvements in compressive strength and durability characteristics, indicating synergistic potential when multiple components are combined.

Compressive Strength of Cement and Concrete Structures with RHA

Partial cement replacement by ash shows enhance in the strength of various concrete mixes. The optimum amount of ash, differs among various studies and ultimately depends on several different factors: aggregate used, water to cement ratio and curing time. When using a water to cement ratio of 0.53 for cement mortars and concrete, up to 30% of the cement can be replaced with ash, negatively affects compressive strength (Ganesan, et al. 2008). The highest compressive strength recorded in this study for mortar was at 15% replacement with ash by weight of cement and for concrete at 20% ash replacement (Ganesan, et al. 2008). Compressive strength of concrete with replacement levels: 4%, 8% and 12%, water to cement ratio of 0.27 were tested and results obtained showed 8% to have the highest compressive strength about 17.5MPa compared to 14 MPa with 0% ash (Hesami, et al. 2014). Tuan (2011) studied the effects of ash on ultra-high -performance concrete, requires a compressive strength at least 150MPa. He found 20% replacement by weight have the higher compressive strength at 91 days while 10% replacement showed higher compressive strength at earlier ages up to 28 days. This was evaluated to ash absorbing mixing water and delaying cement hydration.

Zareei et al. (2017) tested compressive strength of concrete with 25% replacement of OPC with ash after 7 and 28 days of curing period, found that increase of 6.9% and 6.8% in compressive strength respectively compared to concrete with only OPC (Zareei, et al. 2017). It was also reported in this study that 28 days of curing was sufficient time for development of strength but durability is not being evaluated.

2.3.3 Durability and Microstructure

Rice husk ash (RHA) improves the durability of concrete by refining its pore structure and reducing permeability, which helps limit the ingress of harmful substances. Biochar contributes by reducing cracks and enhancing internal curing, allowing the concrete to retain moisture more effectively during hydration. Rice husk, on the other hand, acts mainly as filler material, improving the overall compaction of the concrete matrix. Furthermore, FTIR analysis from prior studies reveal enhanced formation of C-S-H gel along with reduced Calcium hydroxide peaks in the concrete mixes incorporating RHA and RHB indicating improved properties.

2.4 Experiments and Tests in Previous Studies on Concrete with Rice Husk and Its Derivatives

This section reviews the testing methods and experimental outcomes from previous research relating to concrete mixes containing rice husk and its derivatives.

2.4.1 Fresh Concrete Testing

The slump test is widely used to assess fresh concrete workability. According to Nduka et al. (2022), high-performance concrete with increasing RHA content exhibited lower slump values, reflecting reduced workability due to RHA’s high fineness and absorption.

Additional research noted that both RHA and biochar decrease slump, but this can be counteracted with water-reducing admixtures or adjusted mix proportions to maintain acceptable workability for practical casting.

2.4.2 Hardened Concrete Testing

Compressive strength testing on 150 mm cubes is the benchmark for hardened concrete performance. Numerous studies adhere to the standard schedule of 7, 14, and 28 - days of curing period.
Chandrasekhar et al. (2018) reported a linear increase in compressive strength in RHA concrete up to 15% replacement. Gupta & Kua., (2017) observed that biochar-modified concrete showed improved compressive strength at low replacement levels, with a peak at 5% RHB. Combined RHA + RHB mixes demonstrated compressive strengths comparable or superior to control mixes at 28 days when optimally proportioned.

Other researchers also evaluated additional tests such as split tensile strength and flexural strength, which further support compressive strength findings by demonstrating improved mechanical interlocking and bonding in RHA and biochar modified concrete.

2.4.3 Combined Materials Testing

Some recent studies reviewed combined replacements such as RHA with nano-silica or other fillers to investigate interactive effects on compressive strength and microstructure. These analyses confirm improvements in strength and durability properties when RHA is integrated with additional mineral additives.

2.5 Microstructural Analysis using FTIR and XRD

Understanding the chemical and mineralogical transformations in concrete incorporating rice husk derivatives is essential for correlating mechanical performance with microstructure. FTIR (Fourier Transform Infrared Spectroscopy) and XRD (X-Ray Diffraction) are indispensable tools for characterizing such change

2.5.1 FTIR Analysis

FTIR identifies functional groups and bonds present in materials. In concrete containing RHA, FTIR spectra typically show enhanced peaks associated with Si–O–Si and Si–O–Al stretching, indicating increased formation of C–S–H and other hydration products. Changes in hydroxyl and carbonate-related bands can also reveal reduced calcium hydroxide content due to pozzolanic activity. These observations correlate with strength enhancement in RHA concrete mixes.

Similarly, FTIR can detect subtle chemical differences in biochar-containing concrete, showing changes in organic carbon functional groups and interaction with hydration products, which influence microstructure evolution.

2.5.2 XRD Analysis

XRD is used to identify crystalline phases formed during cement hydration and modification by supplementary materials. In rice husk ash concrete, XRD patterns often demonstrate a reduction in portlandite (CH) peaks and an increase in C–S–H and amorphous silica phases, indicating pozzolanic reactions.

For biochar-incorporated concrete, XRD analyses can reveal similar trends, with variations in intensities of hydrated and un-hydrated phase peaks. Enhanced peaks of C–S–H and reduced portlandite suggest better mechanical performance at low replacement levels.

Together, FTIR and XRD provide complementary insight: FTIR reveals structural bonds and functional groups, while XRD identifies crystalline phases. Integrating these methods enables a holistic microstructural interpretation of how RH derivatives influence hydration products and densification of concrete matrices.

2.5 Research Gap

Despite significant advancements in the study of rice husk (RH) and its derivatives—rice husk ash (RHA) and rice husk biochar (RHB)—several critical gaps remain that limit comprehensive understanding of their potential in concrete applications:

a) Limited Studies on Combined Use: Most research focuses on individual incorporation of either RH, RHA, or RHB. Few studies investigate the synergistic effects of combining all three materials (RH + RHA + RHB) in concrete, leaving a knowledge gap regarding optimal mix proportions and their influence on mechanical and microstructural performance (Tan et al., 2021; Chai et al., 2025).

b) Standardized M20 Concrete Testing: Although RHA and RHB have been tested in various concrete grades, there is limited data on M20 concrete mixes, particularly under controlled curing periods of 7, 14, and 28 days. Most studies either focus on high-strength or low-grade concrete, making direct comparisons difficult (Nduka et al., 2022; Gupta & Kua, 2017).

c) Fresh Concrete Properties Correlation: While several studies report compressive strength and durability, the relationship between fresh concrete properties (slump/workability) and hardened mechanical performance in RH derivative concrete remains underexplored. Understanding this correlation is essential for practical casting and field implementation.

d) Comprehensive Microstructural Characterization: Microstructural studies often focus on either FTIR or XRD, but rarely combine both analyses on the concrete powder obtained after compressive testing. A combined study would allow direct correlation between chemical/molecular transformations and mechanical performance, providing more robust insights into how RH derivatives influence hydration and matrix densification (Chandrasekhar et al., 2018; Nduka et al., 2022).

e) Optimization of Replacement Levels: Most literature evaluates individual replacement levels of RH derivatives without investigating incremental or mixed replacement strategies, such as combining low percentages of RH with moderate RHA and RHB. Optimizing these proportions could maximize compressive strength, durability, and sustainability simultaneously.

f) Environmental and Sustainability Analysis: While RH derivatives are known to reduce cement consumption and CO_2 emissions, quantitative studies linking material usage with environmental impact, durability, and lifecycle performance in M20 concrete are scarce.

Summary:

These gaps highlight the need for a systematic study that integrates fresh concrete testing (slump), hardened concrete evaluation (compressive strength), and microstructural characterization (FTIR), considering individual and combined incorporation of RH, RHA, and RHB.
Addressing these gaps will provide a holistic understanding of the materials' performance and guide optimized, sustainable concrete production.

CHAPTER THREE: RESEARCH METHODOLOGY

3.1 Research Methodology

The methodology flowchart represents a systematic experimental process that starts from research planning, moves through material preparation and concrete production, includes testing and decision-making for specimen quality, and ends with data analysis and reporting to evaluate the effectiveness of rice husk–based cement replacement is shown in figure 5 as:

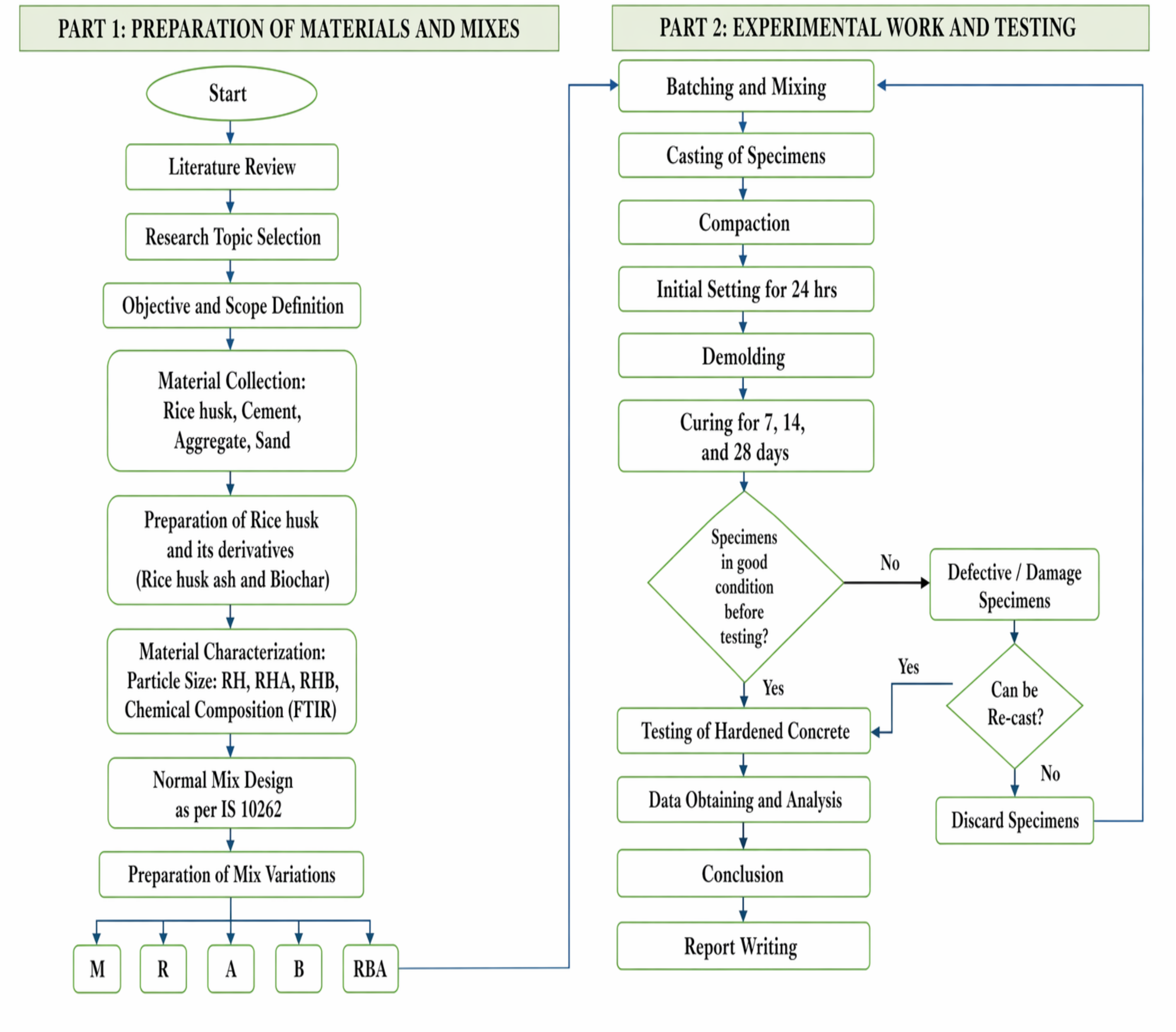


Figure 5: Flowchart of methodology

3.2 Research Activities

3.2.1 Objectives, Scope and Literature review

This section is explained in chapter 1 and 2 respectively.

3.2.2 Material Collection

Material collection involves procuring all required raw materials—rice husk locally sourced from suryabinayak, Bhakatpur, Nepal, cement (OPC from Hongshi Shivam Cement Pvt Ltd), fine aggregate (sand) sourced from River sand from Malekhu, Dadhing, coarse aggregate, and water—from reliable sources (Tap Water), ensuring they meet standard specifications, and properly storing them to maintain their quality before use in experimentation.

3.2.3 Preparation of Rice husk and Its derivatives

Preparation of rice husk- derivatives (traditional process at casting site) involves locally processing collected rice husk into usable forms—burning it under controlled conditions to produce rice husk ash (RHA) and preparing biochar (RHB) using limited-oxygen heating—followed by cooling, grinding, and sieving to obtain uniform, fine materials suitable for partial cement replacement.

1. Collection and Cleaning of Rice Husk (RH)

   Rice husk is first collected from local rice mills. After collection, impurities such as dust, soil, stones, and other organic matter are removed manually or by using sieving process to ensure cleanliness of the material. If required, the cleaned rice husk is then washed with clean water to further eliminate any remaining fine impurities. Following this, the husk is air dried under sunlight for a24-48 hours to remove moisture and further dried in oven for 24 hours for completely moisture removable. Finally, it is prepared for subsequent use and also used for preparation of RHA and RHB as shown in figure 6.

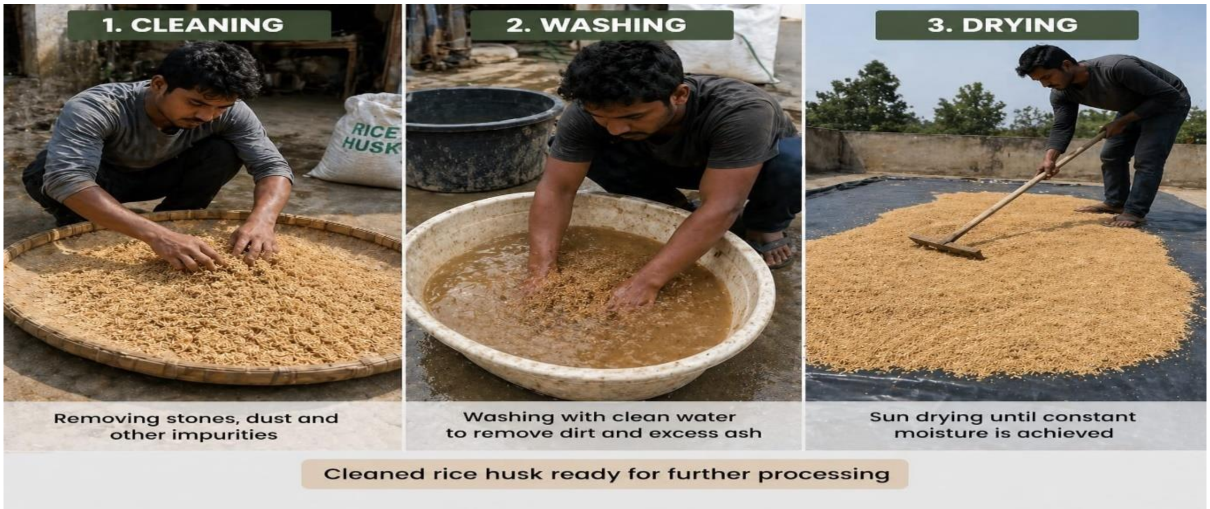


Figure 6: Preparation of cleaned rice husk

2. Preparation of Rice Husk Ash (RHA) – Traditional Burning Method

From figure 7, RHA is an agricultural by-product (Bie et al., 2015; Givi et al., 2010). It is the outer layer of rice hull that is produced from the rice husking process. It is reported that about 30% of the paddy grains is converted into husk (Givi et al., 2010). About 20% of husk by weight is transformed into ash during the burning process of husk (Givi et al. 2010; Rashid et al., 2010). Ash is very light in weight, easily carried out by the wind and water when it is in the dry state. In addition, RHA is very hard to coagulate, leads to air and water pollution and cannot be degraded naturally due to the presence of siliceous compositions (Zerbino et al., 2011).

Figure 7 : Rice husk burning in open air

From figure 8, ash results in a disposal problem for rice millers. Recycling and reusing of waste material like ash, lead towards a greener world and it has high potential of a pozzolan due to its high silica content. Several researchers studied the physical properties and chemical composition of ash, recommended that RHA can be used as a partial replacement of cement (Bie al., 2015, Givi et al., 2010; Khan et al., 2012; Rashid et al., 2010; Zerbino et al., 2011). Givi et al. (2010) also discussed the advantages of the RHA incorporation in concrete, reported that the use of ash in concrete could improve mechanical properties of concrete such as compressive, tensile, and flexural strength. Further, study reported that modified concrete reduced the permeability of water and shrinkage due to being a denser concrete. Moreover, RHA produced durable concrete, reduced deleterious expansion due to the alkali silica reaction, increased resistance to chemical attacks.

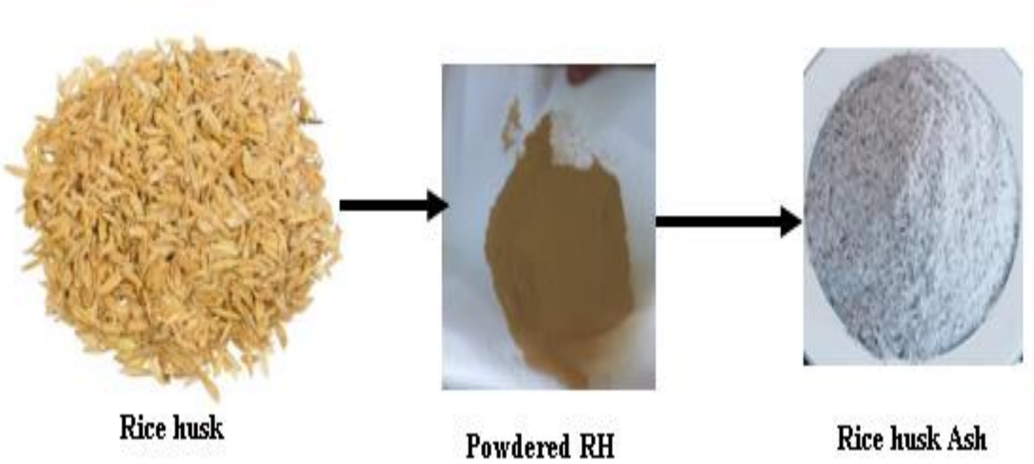


Figure 8: Rice husk transferred to Rice husk Ash

Procedure:

a. Setup for Burning

i) Prepare an open field or metal drum/kiln at the casting site.

ii) Place a perforated base or bricks to allow air circulation.

iii) Ensure safety measures (distance from structures, fire control).

b. Controlled Burning

i) Ignite the dried rice husk.

ii) Maintain controlled combustion (avoid excessive flames).

iii) Cover partially with a metal sheet or soil to limit oxygen.

iv) Target temperature range: ~600–700°C (approximate in traditional method).

v) Allow slow burning for 4–6 hours.

c. Cooling

After complete burning, allow ash to cool naturally (do not quench with water).

d. Grinding and Sieving

i) Grind the ash manually (mortar/pestle or grinder).

ii) Sieve through 75 µm sieve to obtain fine RHA as cement particles.

iii) Store in airtight containers to avoid moisture absorption.

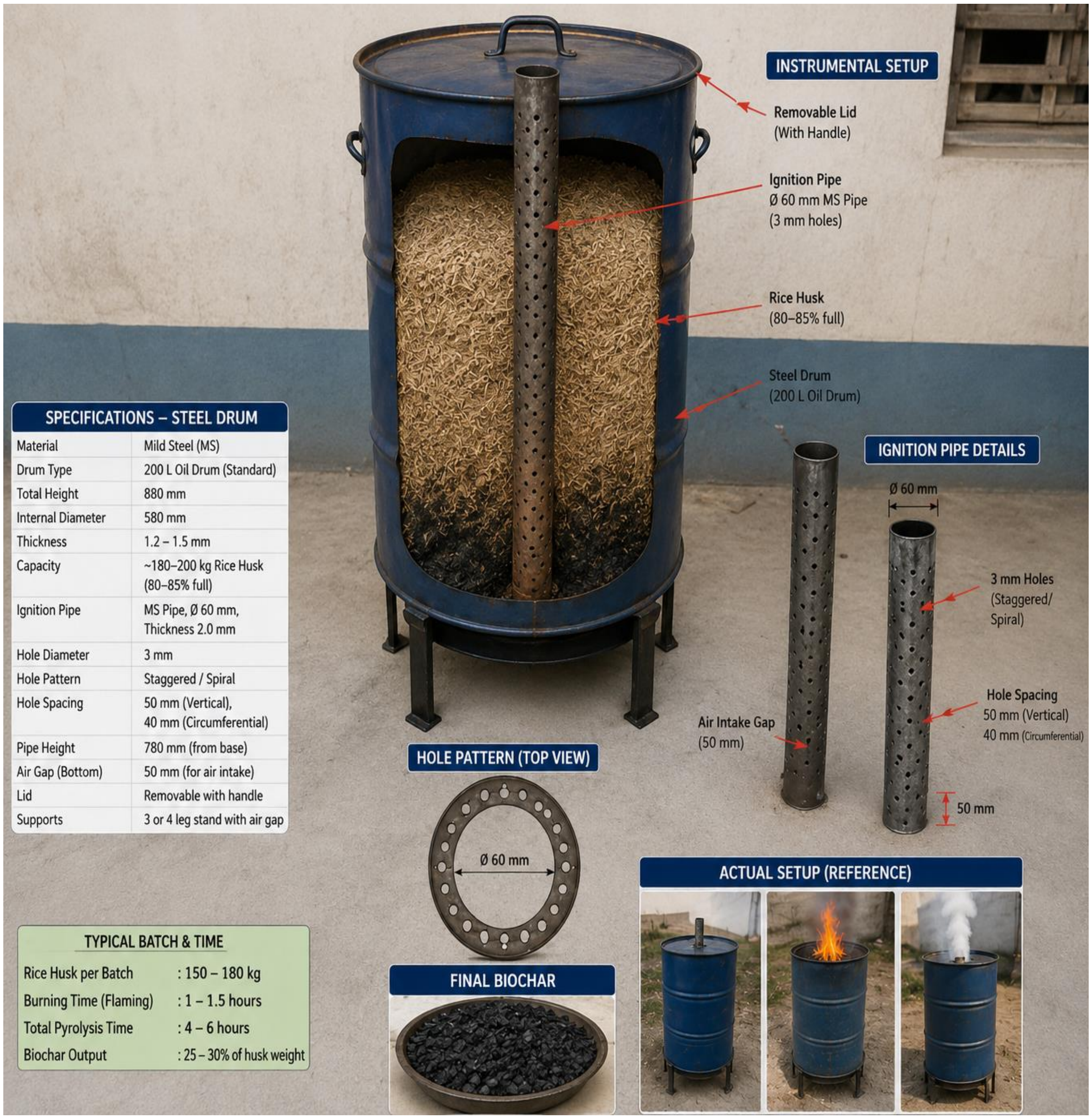
3. Preparation of Rice Husk Biochar (RHB) – Traditional Pyrolysis

a. Setup

i) Use a closed metal drum with small holes (limited oxygen condition).

ii) Fill the drum with dried rice husk.

Figure 9 illustrates the experimental setup used for producing RHB through the pyrolysis process using a steel drum ignition system. The setup consists of a standard 200L mild steel drum with a height 0f 880mm and an internal diameter of 580mm. The drum is filled with rice husk up to 80-90% of its capacity. A perforated ignition pipe of 60mm diameter and 780mm height is placed vertically at the center of the drum to initiate controlled burning. The pipe contains 3mm staggered holes with spacing of 50mm vertically and 40mm circumferentially to allow uniform heat distribution and airflow during pyrolysis. An air intake gap of 50mm is provided at the bottom of the drum to support controlled combustion. The setup also includes a removable lid with handle to maintain limited oxygen conditions required for pyrolysis. The system typically processes 150-180 kg of rice husk per batch with total pyrolysis duration of about 4 to 6 hours, producing approximately 25 to 305 biochar yield by rice husk weight.



SPECIFICATIONS – STEEL DRUM

Material	Mild Steel (MS)
Drum Type	200 L Oil Drum (Standard)
Total Height	880 mm
Internal Diameter	580 mm
Thickness	1.2 – 1.5 mm
Capacity	~180–200 kg Rice Husk (80–85% full)
Ignition Pipe	MS Pipe, Ø 60 mm, Thickness 2.0 mm
Hole Diameter	3 mm
Hole Pattern	Staggered / Spiral
Hole Spacing	50 mm (Vertical), 40 mm (Circumferential)
Pipe Height	780 mm (from base)
Air Gap (Bottom)	50 mm (for air intake)
Lid	Removable with handle
Supports	3 or 4 leg stand with air gap

TYPICAL BATCH & TIME

Rice Husk per Batch : 150 – 180 kg
Burning Time (Flaming) : 1 – 1.5 hours
Total Pyrolysis Time : 4 – 6 hours
Biochar Output : 25 – 30% of husk weight

Figure 9: Instrumental Setup and specification from instrumental setup

b. Pyrolysis Process

The Pyrolysis is a thermochemical process used to concert RH into RHB by heating the material under limited or absence of oxygen conditions. During this, the organic components of RH such as cellulose, hemicellulose and lignin undergo thermal decomposition, resulting in the formation of biochar, bio-oil and gaseous products (Chandrasekhar et al., 2012)

The production of RHB generally occurs at temperature ranging from 300^0 C to 700^0C depending on the desired properties of the final products. Lower pyrolysis temperature mainly produced higher char yield, while higher temperature enhances porosity and carbon content of the biochar (Uthaman et all., 2018). The controlled heating process prevents complete combustion and allows the formation of a stable carbon-rich materials with high surface area and porous microstructure.

Rice husk biochar possesses unique physical and chemical properties that make it suitable for cementitious applications. The porous structure of RHB improves water absorption and internal curing behavior within concrete, while its high carbon content contributes to improved microstructural development (Yin et al., 2017). Additionally, the large surface area of RHB can enhance the bonding between cement paste and aggregate, thereby influencing the mechanical and durability properties of concrete.

The pyrolysis process also contributes to sustainable waste management by converting agricultural waste into value-added construction materials. Compared to open burning RH, pyrolysis significantly reduced environmental pollution and greenhouse gas emissions (Sharma & Khan et al., 2017). Therefore, the utilization of RHB in concrete production supports environmentally friendly and sustainable construction practices.

Steps:

i) Ignite from the bottom and partially seal the drum.

ii) Maintain limited oxygen supply to avoid complete combustion.

iii) Approximate temperature: 400–500°C.

iv) Continue heating for 3–5 hours.

Figure 10: Pyrolysis process (Ignition from bottom of drum)

c. Cooling

- i) Seal the drum completely after heating.
- ii) Allow slow cooling inside the drum (prevents ash formation).

d. Crushing and Sieving

- i) Remove the biochar.
- ii) Crush into fine particles.
- iii) Sieve to required size (generally <75 µm or as per mix).

4. Storage

- i) Store RH, RHA, and RHB separately in dry, airtight containers.
- ii) Label properly for identification (RH, RHA, RHB).
- iii) Protect from moisture and contamination.

Figure 11: Biochar obtained from drum

3.2.3 Material Characterization Techniques

Material Characterization Procedures:

a) Purpose

Material characterization ensures that each material used in the concrete mix meets quality and performance standards. It identifies physical and chemical properties that affect concrete strength, durability, and workability.

b) Materials to Characterize

Rice Husk (RH), Rice Husk Ash (RHA), Rice Husk Biochar (RHB), Cement, Aggregate (Coarse and Fine), Sand, Water

3.2.3.1 Characterization Methods

a. Particle Size Analysis

Objective: Determine the fineness or gradation of RH, RHA, RHB, and aggregates and sand.
Procedure:

a) A set of sieves was arranged in descending order (top to bottom): 4.75 mm, 2.36 mm, 1.18 mm, 600 µm, 300 µm, 150 µm, and 75 µm with a pan at the bottom.

b) The dried sample (Sample 1) was placed on the top sieve and subjected to mechanical shaking for 10–15 minutes.

c) After sieving, the material retained on each sieve was carefully collected and weighed.

d) The same procedure was repeated for Sample 2 under identical conditions.

% Retained = (Weight retained / Total weight) × 100

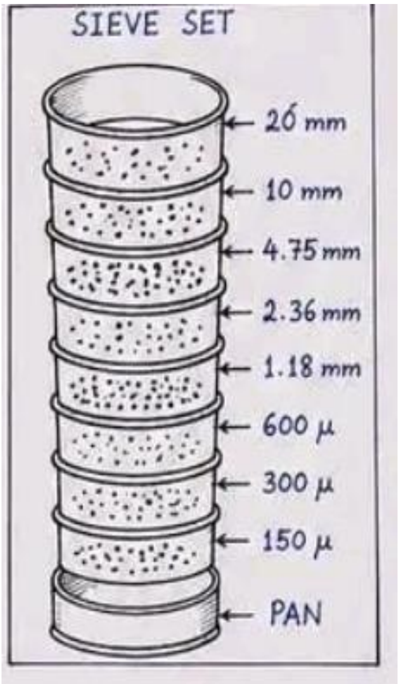


Figure 12: Sieve test setup

Cumulative % Retained = Sum of % retained

% Passing = 100 − Cumulative % Retained

e) Gradation curves were plotted for both samples (% passing vs sieve size on semi-log graph).

f) The fineness modulus (FM) for each sample was calculated.

b. Los Angeles (L.A.) Abrasion Test

The L.A. Abrasion Test determines the hardness, toughness, and resistance to wear of coarse aggregates. It simulates the abrasion and impact experienced by aggregates in roads, pavements, and concrete.

Figure 13: Los Angeles' machine test (coarse aggregate)

Sample Preparation:

a) A standard sample of aggregate (usually 5000 g for coarse aggregates) is prepared according to IS 2386 (Part IV).

b) Aggregate is sieved to ensure proper size grading (typically 20–25 mm).

c) The aggregate sample is placed in the L.A. Abrasion machine drum along with 12 steel balls (for impact).

d) The drum rotates at 30–33 rpm for 500 revolutions (or specified).

e) After rotation, the aggregate is sieved through a 1.7 mm sieve.

f) Fine particles passing the sieve are collected and weighed.

g) L.A. Abrasion Value (%) $= \frac{\text{Weight of fines passing 1.7 mm sieve}}{\text{Total weight of sample}} \times 100\ \%$

Table 2 Typical Ranges for L.A. (as per IS code

Aggregate Type	L.A. Abrasion (%)
Very hard rock	15–20
Medium hard	20–30

Soft rock	30–40

The table 2 presents the L.A. value for different types of aggregates according to IS 2386 (Part IV): 1963. Very hard rock aggregates show abrasion value of 15-20%, indicating excellent resistance to wear and impact. Medium hard aggregates have values between 20-30%, representing moderate toughness suitable for general concrete works. Soft rock aggregates exhibit abrasion values of 30-40%, indicating better aggregate lower durability and resistance to abrasion. Lower L.A. abrasion values indicates better aggregate quality and higher suitability for durable concrete construction.

c. Aggregate crushing value by using CM Method

a) Take aggregate passing 12.5mm and retained on 10mm sieve.

b) Weighs the sample taken (W1)

c) Fill the cylinder in 3 layers, each compacted ($\sim 25\ blows$)

d) Insert plunger and place in compression Testing Machine.

e) Apply load gradually (40 tones in 10minutes)

f) Remove sample and sieve through 2.36mm sieve

g) Record weight of fines as W2.

h) Aggregate crushing value is calculated by,

$$\text{ACV} = \frac{W2}{W1} \times 100\%$$

Note: ACV values less than 20% is acceptable.

d. Chemical Composition Analysis

Objective: Identify chemical constituents that influence cementitious behavior.

Procedure:

a) Use Fourier Transform Infrared Spectroscopy (FTIR) to detect functional groups in RHA and RHB.

b) Compare results with standards to ensure pozzolanic potential.

e. Specific Gravity of Sand

Objective: Determine density relative to water for mix design calculations by using Pycnometer method.

Figure 14: Pycnometer (Specific gravity test for fine aggregate)

Figure 14, shows the pycnometer apparatus used for determining the specific gravity of fine aggregate. The setup includes the pycnometer bottle, fine aggregate sample, water and weighing arrangement used during test procedure.

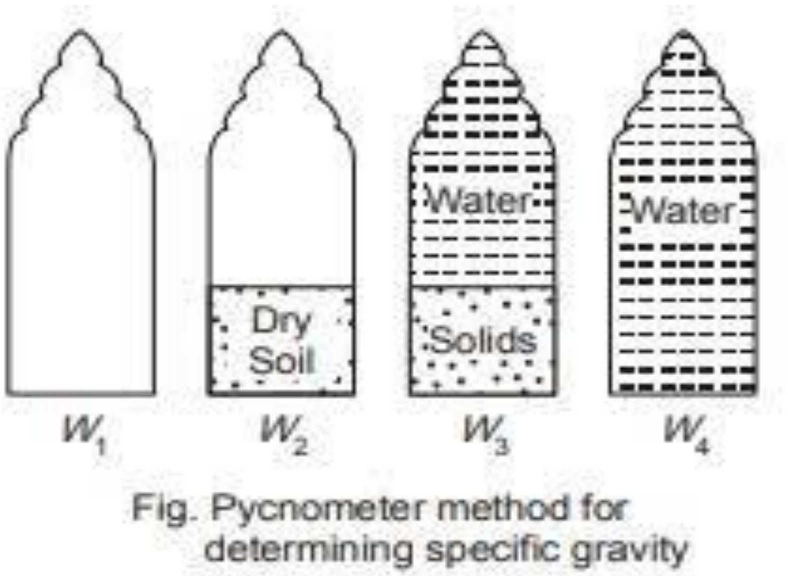


Figure 15: Pycnometer method for determining specific gravity

Figure 15, illustrates the pycnometer test method for determining the specific gravity of fine aggregate. The test is performed by measuring the weight of the pycnometer with dry aggregate, water and saturated sample to calculate the specific gravity as per IS code 2386 (Part III): 1963.

Procedure

a) Weigh Empty Pycnometer as W1,
   i. Clean and dry the pycnometer.
   ii. Record its empty weight: W1

b) Add sand Sample
   i. Place a known mass of dry powder sample into the pycnometer.
c) Record the weight of pycnometer + powder: W2
   i. Calculate sample weight: Wsample = W2−W1.
d) Add Water to the pycnometer with sand.
   i. Fill the pycnometer with distilled water until the calibration mark (meniscus) is reached.
   ii. Use gentle tapping or soft stirring to remove trapped air bubbles.
e) Weigh Filled Pycnometer: W3
   i. Wipe the outside to remove any water droplets.
   ii. Measure the weight of the pycnometer with water and powder: W3.
f) Weigh Pycnometer with Water Only: W4
   i. Fill the clean pycnometer with water only, up to the mark.
   ii. Weigh: W4.
g) Finally, Calculation of Density is done.

True density of the sample (ρ) is given by:

$$\frac{w_{sample}}{(W_2 - W_1 + w_4 - w_3)/\ \rho_{water}}$$

Where:

ρ_{water}= density of water at test temperature (g/cm³, ~0.998 g/cm³ at 25°C)
Wsample=W2−W1
W4−W3 accounts for the volume of water displaced by the powder.

h) Specific Gravity (G) is calculated by

$$\mathrm{G} = \frac{w_2 - w_1}{(W_2 - W_1) - (w_4 - w_3)}$$

f. Moisture Content

Objective: Identify water present in materials affecting mix water calculation.

Procedure: Oven-dry samples at 105°C for 24 hours and record weight loss.

RH must be free from soil and impurities before analysis.

a) RHA and RHB should be ground to a uniform fine size to ensure proper pozzolanic reaction.

b) All tests should follow ASTM or ISO standards (e.g., ASTM C618 for pozzolans).

iii. Data obtained from material characterization is used to optimize mix design and predict concrete performance.

iv. Ensures that RH, RHA, and RHB can effectively replace part of cement in concrete.

3.2.4 Mix design and Experimental activities

The study aimed to evaluate the effects of rice husk (RH) and its derivatives—rice husk ash (RHA) and rice husk biochar (RHB)—on M20 grade concrete. The experimental work was conducted in the Civil Engineering Laboratory following standard procedures. The program involved:

a) Collection and preparation of materials: OPC 43 grade cement, fine and coarse aggregates, RH, RHA, and RHB.

b) Preparation of rice husk derivatives: RHA via controlled burning and RHB via pyrolysis.

c) Concrete mix design for M20 grade as per IS 10262:2019.

d) Partial replacement of cement with RH derivatives at predetermined percentages.

e) Workability assessment using slump test.

f) Casting of 150 mm × 150 mm × 150 mm concrete cubes.

g) Curing for 7, 14, and 28 days.

h) Compressive strength testing of hardened cubes using a CTM.

i) Microstructural analysis of materials and hardened concrete powder using FTIR and XRD.

j) Analysis and comparison of results to evaluate the influence of RH, RHA, and RHB in hardened concrete.

3.3 Mix Proportion design

3.3.1 Concrete Mix Combinations

The table 3 shows different concrete mixes with rice husk-based replacements. M is the control mix with 0% replacements. R, A, and B each use 5% replacement of RH, RHA, RHB respectively. RBA combines all 3 materials (RH+RHA+RHB) each at 5% replacement, to form a hybrid mix for comparison with the controlled mix.

Table 3 Concrete Mix ID with replacement material and its %

Mix ID	Replacement Material	Replacement %
M	Control Mix	0%
R	RH	5%
A	RHA	5%
B	RHB	5%
RBA	RH + RHA + RHB	5% + 5% + 5%

3.3.2 Mix Proportion for M20 Concrete

The table 4, shows the material quantities required for 1 cum of M20 concrete mix. It represents the standard variation for M20 grade of concrete used as a reference in the study.

Table 4 **:**Quantity (kg / Cum) for M20 Concrete

Ingredients of concrete	Quantity (kg/m³)
Cement	383
Fine Aggregate	672
Coarse Aggregate	1196
Water	191
W/C Ratio	0.50

3.3.3 Modified Mixes with RH Derivatives

The table 5, shows the material quantities for modified M20 concrete cubes using RH-derivatives based replacements. The control mix (M) contains only cement with 0% replacements. In mixes R, A and B, 5% cement is replaced individually by RH-derivatives respectively, while water remains constant at 191 kg/m^3. In RBA mix, all 3 materials (RH+RHA+RHB) are combined, each at 5% replacement, reducing cement to 325.55 kg/m^3. Overall, it shows the partial cement replacement using RH-derivatives while keeping water content constant.

Table 5**:** Quantity for modified Cube with RH-Derivatives mix

Mix ID	Cement (kg/m³)	RH (kg/m³)	RHA (kg/m³)	RHB (kg/m³)	Water (kg/m³)
M	383	0	0	0	191
R	363.85	19.15	0	0	191
A	363.85	0	19.15	0	191
B	363.85	0	0	19.15	191
RBA	325.55	19.15	19.15	19.15	191

3.3.4 Number of Specimens

Cubes per mix per curing age; average used for analysis.

The table 6, shows the number of concrete specimens prepared and tested for each mix. Each mix (M, R, A, B and RBA) has 3 samples for 7, 14 and 28 days-curing, making 9 samples per mix. Overall, a total of 45 specimens were casted and tested across all curing periods for the study.

Table 6**:** Number of sample specimens for casting and testing

Mix ID	Curing Period and Testing Period			
	7 Days	**14 Days**	**28 Days**	**Total**
M	3	3	3	9
R	3	3	3	9
A	3	3	3	9
B	3	3	3	9
RBA	3	3	3	9
Total	15	15	15	45

3.4 Mix Design Calculation (IS 10262:2019)

The mix design for M20 grade concrete was carried out according to IS 10262:2019 guidelines.

Target Mean Strength $f_{ck}' = f_{ck} + 1.65S$

Where:

Characteristic compressive strength = **20 MPa**
Standard deviation = **4 MPa**

$$f_{ck}' = 20 + (1.65 \times 4) = 26.6 \text{ MPa}$$

Selection of Water Cement Ratio

For M20 concrete: Water–cement ratio = 0.50

From IS guidelines: Water content = 191 kg/m³

Cement Content

$$\text{Cement} = \frac{water}{w/c} = \frac{191}{0.5} = 382\text{kg/m3}$$

Aggregate Proportion**:** Typical proportion for M20:

Fine aggregate = 672 kg/m³

Coarse aggregate = 1196 kg/m³

The table 7, shows the final proportioning for 1 cum of concrete. It includes 383 kg cement, 672 kg fine aggregate, 1196kg coarse aggregate and 191 kg water, which defines the standard concrete mix used as the base for the study.

Table 7 **:** Final Mix Proportion (1 m^3 volume)

Material	Quantity (kg/m³)
Cement	382
Fine Aggregate	672
Coarse Aggregate	1196
Water	191

3.5 Replacement Mix Calculation

5% Replacement of Cement: 5% of cement=0.05×3825=19.1kg

Thus: Cement = 382 – 19.1 = 362.9 kg   Replacement material = 19.1 kg

Combined Replacement (RH + RHA + RHB): Each = 5%
Total replacement=15% = 0.15×382==57.3kg

Remaining cement: 382−57.3=324.7kg

3.6 Material Calculation for 150 mm Cube Specimens

Volume of cube: V = 0.15×0.15×0.15 = 0.003375m3

Total cubes = 45

Total Volume=45×0.003375=0.1519 m^3

Considering 10% extra for wastage

Total volume required =0.167 m^3

The table 8 shows the materials required for casting 0.167 cum (1 specimens-cube volume basis). It includes 63.8kg cement, 112.2 kg fine aggregate, 199.7kg coarse aggregate and 31.9kg water, which are scaled-down quantities from the standard 1 cum mix for specimen preparation.

Table 8**:** Material Required for 0.167 m^3 Concrete

Material	Quantity
Cement	63.8 kg

Fine Aggregate	112.2 kg
Coarse Aggregate	199.7 kg
Water	31.9 kg

3.7 Batching, Mixing, Casting, De-molding and curing

a. Batching:

All materials, including cement, aggregates, water, and additives, were weighed accurately according to the mix design to ensure consistency in all batches. Precise batching is essential to maintain uniformity and reproducibility of test results as shown in figure 16.

Figure 16: Batching (Weighing)

b. Mixing:

The materials were mixed thoroughly in a mechanical mixer to achieve a homogeneous concrete or mortar mix. Adequate mixing ensures uniform distribution of cement paste around aggregates, which is critical for both workability and strength.

c. Casting:

The freshly prepared mix was placed into standard molds (cube molds) and compacted properly using a tamping rod or vibrating table to remove air voids. Proper casting ensures accurate density and prevents weak zones in the specimen. The casting is shown in figure 17.

Figure 17: Casting

d. De-molding:

After the initial setting period (typically 24 hours), the specimens were carefully removed from the molds to avoid damage. De-molding allows the samples to retain their shape for subsequent curing and testing.

e. Curing:

The de-molded specimens were immersed in water or kept in a moist environment for the required curing period (3, 7, 28 days) to allow hydration of cement. Proper curing ensures maximum strength development and durability of the concrete.

Figure 18: Curing 7, 14, 28 days

3.8 Testing of concrete cube

3.8.1 Laboratory Testing Standards

The table 9 shows the lists of IS codes used for laboratory testing and concrete procedures. It ensures that all experiments are conducted as per guidelines.

Table 9 :Laboratory testing Standards and IS codes

Test / Procedure	IS Code
Plain & Reinforced Concrete – Code of Practice	IS 456:2000
Concrete Mix Design	IS 10262:2019
Sampling and Analysis of Concrete	IS 1199:2018
Compressive Strength Test	IS 516:2018
OPC 43 Grade Cement Specification	IS 8112:2013
Aggregate Specification	IS 383:2016
Cement Testing Methods	IS 4031

Additional tests: FTIR for microstructural characterization.

Aggregate Tests: Sieve analysis, crushing, abrasion.

Sand Tests: Sieve, density (pycnometer).

Cement Tests: Setting time, soundness, compressive strength, consistency.

3.8.2 Fresh Concrete Testing

A. Slump Test

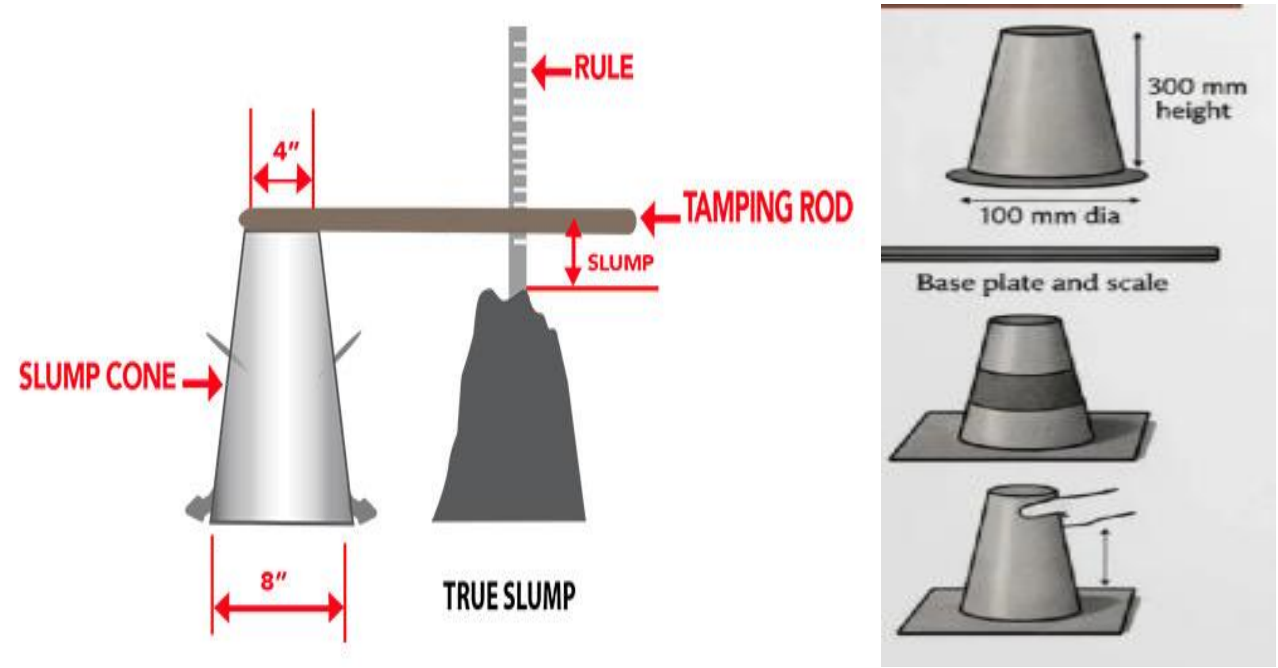


Figure 19: Slump cone- setup to measure slump value

The figure 19 shows the slump cone test setup, which is used to measure the workability of fresh concrete. This test helps to assess whether the concrete has proper workability for construction use or not.

Purpose

The slump test provides an indication of the workability and consistency of the concrete mix. The test was carried out in accordance with IS 1199:2018.

Apparatus

- Slump cone (top diameter 100 mm, bottom diameter 200 mm, height 300 mm)
- Tamping rod (16 mm diameter, 600 mm length)
- Base plate
- Measuring scale

Procedure

1. The slump cone was placed on a smooth non-absorbent surface and held firmly.
2. The freshly mixed concrete was filled in three equal layers.
3. Each layer was compacted using 25 strokes of the tamping rod.
4. The top surface was leveled with the rod.
5. The cone was lifted vertically upward slowly.
6. The subsidence of concrete was measured immediately using a scale.

Observation

The difference between the original height of the cone and the height of the concrete after subsidence is recorded as the slump value.

3.8.3 Hardened Concrete Testing

A. Compressive Strength Test

The compressive strength test was performed to evaluate the load-carrying capacity of hardened concrete cubes. The test was conducted according to IS 516:2018 using UTM machine as shown in figure 20.

Figure 20: Cube specimen under compressive testing UTM Machine

Specimen Size: Concrete cubes of 150 mm × 150 mm × 150 mm were used is shown in figure 21.

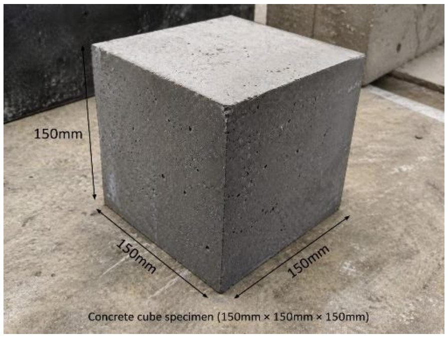


Figure 21: Concrete Cube Specimen

Procedure

a) The cube specimens were removed from the curing tank after **7, 14, and 28 days**.

b) The specimens were cleaned and excess water was wiped off.

c) The cube was placed centrally on the **compression testing machine (CTM)**.

d) The load was applied **gradually and continuously without shock**.

e) The maximum load at failure was recorded.

Compressive Strength Calculation

The compressive strength of concrete was calculated using the following equation:

$$F_c = \frac{p}{A}$$

Where:

f_c = Compressive strength (MPa)

P= Maximum applied load (N)

A = Cross-sectional area of cube (mm^2)

For a 150 mm cube**:** $A=150\times150=22500\ mm^2$

CHAPTER FOUR: RESULTS AND DISCUSSION

4.1 Introduction

This chapter presents the **experimental results obtained from fresh and hardened concrete tests** conducted on M20 grade concrete incorporating rice husk (RH), rice husk ash (RHA), and rice husk biochar (RHB) as partial replacements of cement. The performance of concrete was evaluated based on:

a) Workability using slump test for fresh concrete mix,
b) Compressive strength at 7, 14, and 28 days for hardened concrete specimens,
c) Microstructural characterization using FTIR of RH-Derivatives,

The results obtained from modified mixes were compared with the **control concrete mix** to evaluate the influence of rice husk derivatives on concrete properties.

4.2 Cement Testing Results

The physical and mechanical properties of the cement used in this study were obtained from the cement testing certificate provided by Hongshi Shivam Cement Pvt. Ltd.

The certificate includes key parameters such as normal consistency, setting times, soundness, and compressive strength at 3, 7, and 28 days, which are essential for evaluating the quality and suitability of the cement for concrete and mortar applications. These parameters ensure compliance with the relevant IS standards and provide baseline values for mix design and performance analysis in the present research.

The table 10, shows the physical properties and performance of cement tested as per NS 572:2076 (43 grade standard) and compares them with the required specifications. The results indicate that the cement satisfies all standard requirements. The normal consistency is 26.9%, which is suitable for achieving proper water demand. The initial setting time is 220 minutes, which is higher than the minimum requirement $(\geq 45 minutes),$ ensuring adequate working time. The final setting time is 280minutes, well within the allowable limit (≤ 600).

In terms of durability, the soundness value is 0.5mm, which is far below the maximum limit of 10mm, indicating good volume stability.

The compressive strength results also show higher performance than required: 3 days: 30.7 MPa (≥23 MPa); 7 days: 39.0 MPa (≥33 MPa) and 28 days: 54.7 MPa (≥43 MPa). Overall, the cement meets and exceeds all physical and strength requirements, confirming it is suitable for structural concrete applications.

Table 10 Physical Requirement of cement

Property	Requirement as per NS 572:2076 (43 grade)	Testing Result
Normal Consistency (%)	-	26.9
Initial Setting Time (Min)	≥ 45	220
Final Setting Time (Min)	≤ 600	280
Soundness (Le Chatelier)- mm	≤ 10.0	0.5
Compressive Strength – 3 days- MPa	≥ 23.0	30.7
Compressive Strength – 7 days- MPa	≥ 33.0	39.0
Compressive Strength – 28 days- MPa	43.58	54.7

4.3 Aggregate Testing Results

4.3.1 Los- Angles' Abrasion Test for aggregate

The following data of L.A. abrasion testing is obtained and the LA Abrasion value is calculated by the following formula as

$$\text{L.A. Abrasion Value (\%)} = \frac{\text{Weight of fines passing 1.7 mm sieve}}{\text{Total weight of sample}} \times 100\%$$

Table 11**::** Observation and Calculation table for L.A. ACV

Sample ID	Aggregate Size (mm)	Weight Before Test (g)	Weight of Fines Passing 1.7 mm Sieve (g)	L.A. Abrasion Value (%)	Remarks
AG-01	20–25	5000	750	15.0	Good resistance
AG-02	20–25	5000	900	18.0	Medium resistance
AG-03	20–25	5000	1200	24.0	Slightly soft

AG-04	20–25	5000	1500	30.0	Soft rock

From the above calculation table 11, AG-1 with 15% L.A. abrasion value is the most suitable for the concrete as it indicates higher strength and better resistance to crushing / impact as per IS 2386 (Part 4).

4.3.2 Aggregate crushing test by Crushing Machine

Sample 1

Original Sample weight (W1) = 300g

Weight of fine sand after passing through 2.36 sieve (W2) = 22g

ACV = $\frac{W2}{W1} \times 100\% = \frac{20}{300} \times 100\%$ = 7.33 %

Sample 2

Original Sample weight (W1) = 300g

Weight of fine sand after passing through 2.36 sieve (W2) = 23.5 g

ACV = $\frac{W2}{W1} \times 100\% = \frac{23.5}{300} \times 100\%$ = 7.83 %

Average ACV = 7.58 %

The aggregate crushing value of the taken sample is found to be 7.58% is well below the permissible limit. Hence, the aggregate is very strong and highly suitable for high- quality concrete works as per IS code 2386 (Part 4).

4.4 Sand Testing Results

4.4.1 Specific gravity using Pycnometer Method:

Sample 1

Table 12: Observation table for the Specific gravity of sample 1

Step	Description	Weight (gram)	Symbol
1	Weigh empty pycnometer	540 g	W1
2	Weigh pycnometer + dry sample	740 g	W2
3	Weigh pycnometer + water (fill to mark)	1095 g	W3
4	Weigh pycnometer + sample + water (fill to mark)	1220 g	W4

Specific Gravity (G) = $\frac{w_2-w_1}{(W_2-W_1)-(w_4-w_3)} = \frac{740-540}{(740-540)-(1220-1095)}$ = 2.667

Sample 2

Table 13 : Observation table for the Specific gravity of sample 1

Step	Description	Weight (g)	Symbol
1	Weigh empty pycnometer	540 g	W1
2	Weigh pycnometer + dry sample	740 g	W2
3	Weigh pycnometer + water (fill to mark)	10 94g	W3
4	Weigh pycnometer + sample + water (fill to mark)	1218 g	W4

Specific Gravity (G):

$$G= \frac{w_2-w_1}{(W_2-W_1)-(w_4-w_3)} = \frac{830-630}{(830-630)-(1218-1094)} = 2.632$$

Average Specific gravity = 2.649

From the calculation and the range from IS code 2386 (Part 3), the specific gravity of the taken sand (fine aggregate) obtained is 2.649, which lies within the permissible range as per code. Hence the sample is suitable for use in concrete.

Ranges:

The table 14, shows the specific gravity values of different types of sand used in concrete. It indicates that the natural river sand has specific gravity ranges of 2.55-2.70, crushed sand ranges from 2.50-2.75 and clean quartz sand ranges from 2.60-2.65. overall, it helps in understanding the density characteristics of fine aggregates used in concrete.

Table 14**:** Specific gravity of different types of sand

Types of sand	Specific gravity
Natural river Sand	2.55 -2.70
Crushed Sand	2.50 -2.75
Clean quartz sand	2.60-2.65

4.4.1 Sieve Analysis for sand Sample

Total Weight of Sample (S1 and S2) = 1000 g

Table 15**:** Sieve analysis data and calculation for fine sand (S1 and S2 sample)

Sample 1 (S1)				
Sieve Size (mm)	**Wt. (g)**	**% Ret.**	**Cum. % Ret.**	**% Pass**
4.75	0	0.0	0.0	100.0
2.36	20	2.0	2.0	98.0
1.18	90	9.0	11.0	89.0
0.600	220	22.0	33.0	67.0
0.300	300	30.0	63.0	37.0
0.150	250	25.0	88.0	12.0
0.075	90	9.0	97.0	3.0
Pan	30	3.0	100.0	0.0
Total	1000	100		

Sample 2 (S2)				
Sieve Size (mm)	**Wt. (g)**	**% Ret.**	**Cum. % Ret.**	**% Pass**
4.75	0	0.0	0.0	100.0
2.36	25	2.5	2.5	97.5
1.18	85	8.5	11.0	89.0
0.600	210	21.0	32.0	68.0
0.300	310	31.0	63.0	37.0
0.150	245	24.5	87.5	12.5

0.075	95	9.5	97.0	3.0
Pan	30	3.0	100.0	0.0
Total	1000	100		

From table 15, the sieve analysis results of fine sand (S1 and S2) samples used to determine particle size distribution. Both the samples show similar gradation. Most sand is retained between 0.600mm and 0.150mm sieves, indicating a dominance of medium to fine particles. Very little material passes the 0.075mm sieve, shows low silt content. Overall, both S1 and S2 samples have nearly identical grading and indicates a well-graded fine sand suitable for concrete production.

Table 16**:** Grain size distribution parameters of fine sand

C_u	15.29
C_c	2.95
Fineness Modulus	1.96

Table 16, shows that the sand was found to have a fineness modulus is 1.96, fine sand according to IS 383 standards (Zone III). The uniformity coefficient (Cu) of 4.0 indicates a moderately well-graded material, while the coefficient of curvature (Cc) of 1.8 confirms a continuous and well-distributed gradation.

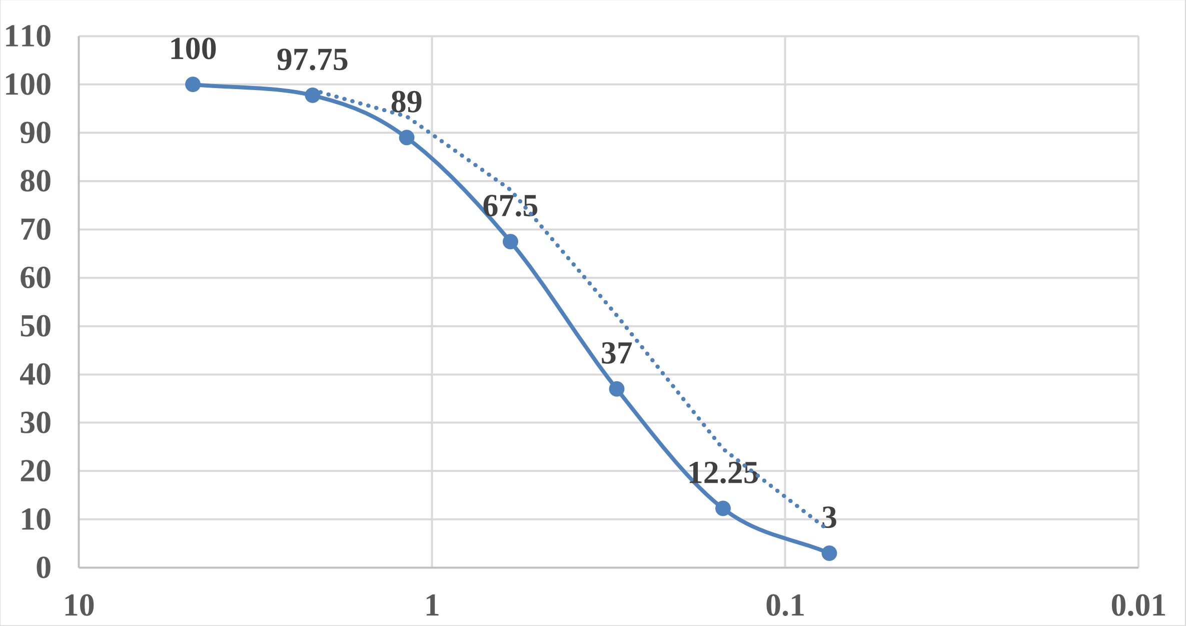


Figure 22: Particle size distribution curves for fine sand samples (S1 and S2) showing similar gradation and uniformity of source material

Figure 22, illustrates that both (S1 and S2) samples follow nearly identical particle size distribution trends. The curves show a smooth and closely overlapping pattern, indicating that both samples have consistent grading characteristics. Most particles fall within the medium to fine size ranges, confirming a well graded and uniform sand source. The similarity between the two curves also suggests that the collected sand samples are homogeneous in nature, ensuring reliable and consistent performance in concrete production.

4.5 Fresh Concrete Workability (Slump Test)

Table 17: Slump Test Results

Mix ID	Mix Description	Slump (mm)
M	Control Concrete	25
R	5% RH	23
A	5% RHA	14
B	5% RHB	17
RBA	RH+RHA+RHB	16

The table17, shows the slump test results of different concrete mixes, indicating their workability. The control mix (M) has slump of 25mm, showing the highest workability. When 5% RH is used (R mix), the slump decreases to 23mm. the mixes with RHA (A) and RHB (B) shows further reduction in workability, with slumps of 14mm and 17mm respectively. The RBA mix (combined RH+RHA+RHB) gives a slump of 16mm. overall, the results show that increasing rice husk-based replacement reduces the concrete workability, with the control mix having highest slump and modified mixes showing stiffer consistency.

From the above, we can conclude the following,

a) Workability slightly decreased due to higher surface area of RHA and porous RHB.
b) RHA mix showed lowest slump, consistent with prior studies.
c) All mixes remained within acceptable limits for normal concrete.

4.6 Compressive Strength

The compressive strength of concrete is defined as the ability of concrete to withstand axial compressive loads. It is one of the most important properties of concrete and is used to assess its quality and performance.

Concrete cube specimens of standard size (150mm cube) were tested under compression testing machine after specified curing period (7, 14 and 28 days). The load was applied gradually until failure occurred. The load at failure was recorded for each specimen.

Failure pattern of cube was also observed, that typically showed diagonal cracks or crushing, indicating proper load application and uniform distribution.

The final compressive strength is reported as the average of three specimens for each mix proportion and curing period (7, 14 and 28 days).

Table 18**:** 7- days Strength observation and calculation

7 -DAYS COMPRESSIVE TESTING RESULTS			
MIX ID	**Failure Load (P) KN**	**Compressive strength (f) N/mm^2**	**Average Compressive strength N/mm^2**
M1	326.5	14.511	14.449
M2	325.2	14.453	
M3	323.6	14.382	
R1	258.2	11.476	11.436
R2	257.6	11.449	
R3	256.1	11.382	
A1	299.1	13.293	13.228
A2	297.4	13.218	
A3	296.4	13.173	
B1	274.3	12.191	12.210
B2	277.5	12.333	
B3	272.4	12.107	
RBA1	169.5	7.533	7.425

RBA2	163.4	7.262	
RBA3	168.3	7.480	

From the table 18, we can conclude that:

a) The control mix (M) achieved the highest average compressive strength (14.449 N/mm²), indicating good early strength development.

b) The reference mix (R) showed significantly lower strength (11.436 N/mm²), about 20–21% reduction compared to M.

c) Mix A (13.228 N/mm²) performed better than R but slightly lower than M, showing moderate strength improvement.

d) Mix B (12.210 N/mm²) showed intermediate performance, higher than R but lower than A and M.

e) The RBA mix exhibited the lowest strength (7.425 N/mm²), indicating a major reduction (~48–50% lower than M), likely due to weaker bonding or higher porosity.

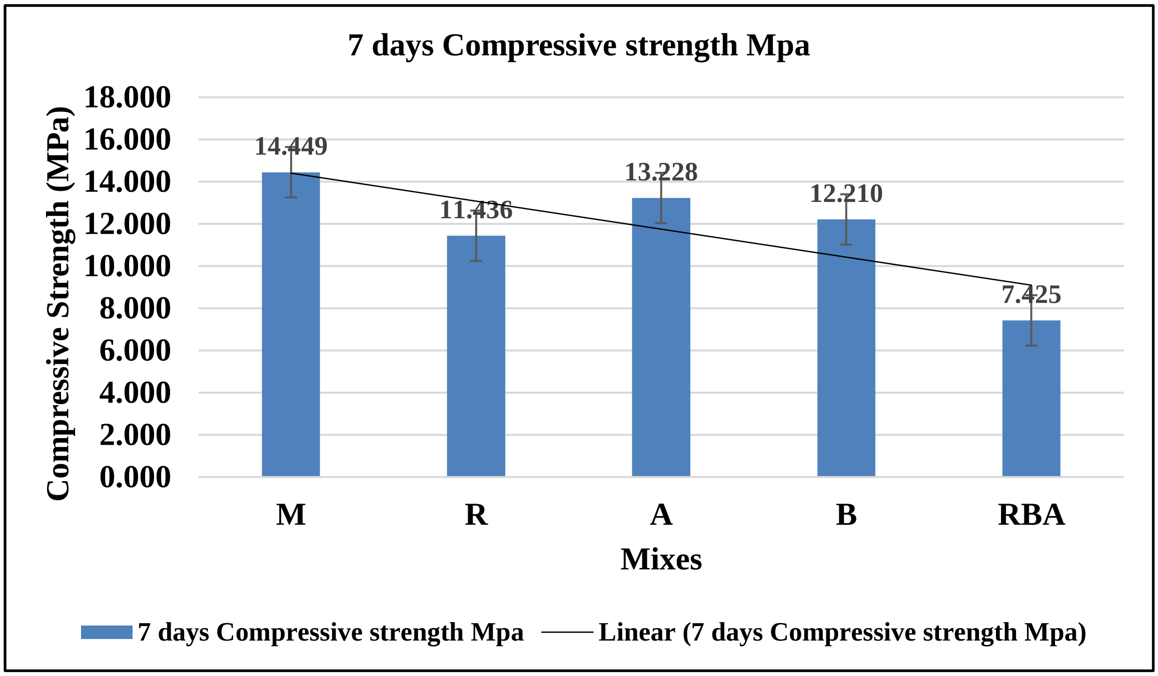


Figure 23: Graph showing 7 days compressive strength of hardened specimens

From figure 21, we withdraw the following results as:

a) RHA enhanced early strength through pozzolanic reactions.

b) RH and combined mixes slightly lower due to slower reactions.

Percentage Deviation in Compressive Strength

Table 19 7-Day Strength Deviation

Mix ID	Strength (MPa)	Deviation from M (MPa)	% Change vs M
M	14.449	0	0.00%
R	11.436	-3.013	-20.86%
A	13.228	-1.221	-8.44%
B	12.210	-2.239	-15.50%
RBA	7.425	-7.024	-48.61%

Table 19, shows the 7-Day Strength Behavior, at early curing age, all modified mixes show a reduction in strength compared to control mix (M). The highest reduction is observed in RBA mix (−48.61%**,** indicating slower early hydration and weaker initial binding. Mix R also shows a notable drop (−20.86%), while A performs comparatively better with only −8.44% reduction.

Table 20: 14- days Strength observation and calculation

14-DAYS COMPRESSIVE TESTING RESULTS			
MIX ID	**Failure Load (P) KN**	**Compressive strength (f) N/mm^2**	**Average Compressive strength N/mm^2**
M4	426.6	18.960	18.947
M5	426.9	18.973	
M6	425.4	18.907	
R4	296.7	13.187	13.243
R5	299.3	13.302	
R6	297.9	13.240	
A4	384.3	17.080	17.135
A5	387.1	17.204	
A6	385.2	17.120	
B4	323.5	14.378	14.456
B5	327.1	14.538	
B6	325.2	14.453	
RBA4	197.9	8.796	8.761
RBA5	196.1	8.716	

RBA6	197.4	8.773	

From the table 20, we can conclude that:

a) The control mix (M) achieved the highest average strength (18.947 N/mm²), showing strong strength gain at 14 days.

b) Mix A (17.135 N/mm²) performed close to M, indicating good improvement and effective strength development.

c) Mix B (14.456 N/mm²) showed moderate strength, lower than A but significantly higher than R and RBA.

d) The RBA mix (8.761 N/mm²) showed nearly similar but slightly lower strength than R, indicating minimal improvement.

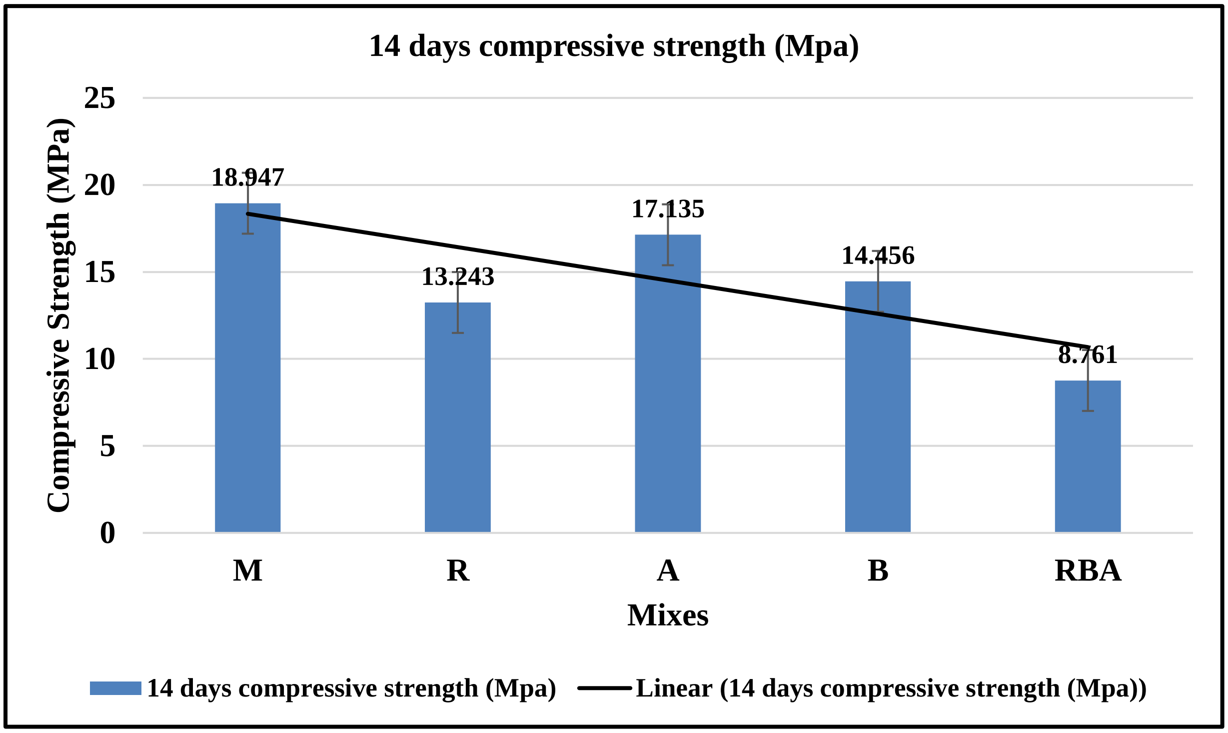


Figure 24: Graph showing 14days compressive strength of hardened specimens

From the figure 22, we can say that:

a) Strength development increased for all mixes.

b) RHA had highest strength; RHB improved slightly over RH.

Table 21: 14-Day Strength Deviation

Mix ID	Strength (MPa)	Deviation from M (MPa)	% Change vs M
M	18.947	0	0.00%
R	8.799	-10.148	-53.54%
A	17.135	-1.812	-9.56%
B	14.456	-4.491	-23.70%
RBA	8.761	-10.186	-53.75%

Table 21 shows that 14-Day Strength Behavior, at 14 days, strength development continues but still remains lower than control for most mixes. R and RBA mixes show severe reduction (>53%)**,** indicating delayed strength gain. Mix A shows relatively stable behavior with only −9.56% reduction, suggesting better pozzolanic reaction activation compared to others.

Table 22: 28- days Strength observation and calculation

28-DAYS COMPRESSIVE TESTING RESULTS			
MIX ID	**Failure Load (P) KN**	**Compressive strength (f) N/mm^2**	**Average Compressive strength N/mm^2**
M7	594	26.4	26.407
M8	596.5	26.511	
M9	592.0	26.311	
R7	558.0	24.800	24.874
R8	561.0	24.933	
R9	560.0	24.889	
A7	630.0	28.00	28.089
A8	634.0	28.178	
A9	632.0	28.089	
B7	605.0	26.889	26.911
B8	607.5	27.00	

B9	604.0	26.844	
RBA7	532.0	23.644	23.644
RBA8	534.0	23.733	
RBA9	530.0	23.556	

From the table 22, we can conclude that:

a) Mix A achieved the highest compressive strength (28.1 N/mm²), indicating the best performance among all mixes.

b) Mix B (26.9 N/mm²) and M (26.4 N/mm²) showed comparable strength, with B slightly higher than M.

c) Mix R (24.9 N/mm²) exhibited lower strength compared to M, A, and B.

d) The RBA mix recorded the lowest strength (23.7 N/mm²), indicating reduced performance.

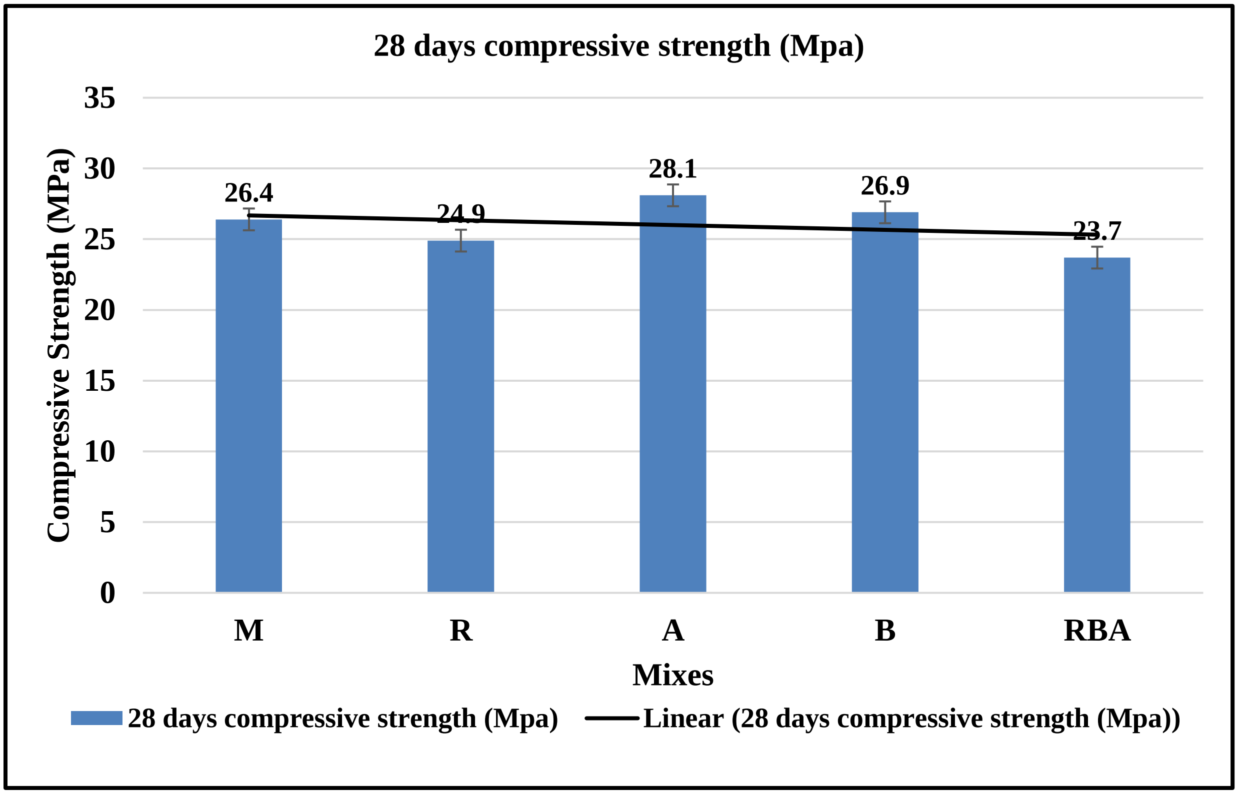


Figure 25: Graph showing 28 days compressive strength of hardened concrete

From figure 23, we can conclude that:

a) RHA mix achieved highest compressive strength due to additional C-S-H gel formation.
b) Combined replacement showed lower strength due to 15% total replacement binding material (cement) by weight.

Table 23: 28-Day Strength Deviation

Mix ID	Strength (MPa)	Deviation from M (MPa)	% Change vs M
M	26.4	0	0.00%
R	24.9	-1.5	-5.68%
A	28.1	+1.7	+6.44%
B	26.9	+0.5	+1.89%
RBA	23.7	-2.7	-10.23%

Table 23 shows that 28-Day Strength Behavior, at 28 days, long-term strength improvement becomes more visible. Mix A surpasses control with +6.44% gain, showing effective pozzolanic contribution. Mix B also slightly exceeds control (+1.89%). However, RBA still shows a reduction (−10.23%), and R remains slightly lower (−5.68%), indicating incomplete strength recovery in some combinations.

Table 24**:** 7, 14 and 28 -Day Average Compressive Strength

Mix ID	Compressive Strength (MPa)		
	7days	14 days	28 days
M	14.449	18.947	26.4
R	11.436	13.243	24.9
A	13.228	17.135	28.1
B	12.210	14.456	26.9
RBA	7.425	8.761	23.7

Table 21, shows that the compressive strength results show that all modified mixes (R, A, B, and RBA) are compared with the control mix (M) across 7, 14, and 28 days of curing. At early ages (7 and 14 days), all modified mixes generally exhibit lower strength than the control mix, indicating slower initial hydration and strength development. However, at 28 days, some improvement is observed, especially in Mix A and Mix B, which show strength values close to or slightly higher than the control mix. Mix A performs the best among the modified mixes with 28.1 MPa, even exceeding the control mix (26.4 MPa), showing good long-term strength gain. Mix R shows a significant drop at 14 days but recovers partially at 28 days, while Mix RBA consistently shows the lowest strength at all curing ages, indicating the weakest performance overall.

Finally, the strength development for the control mix to replacement mix as:

Strength Trend: RHA > RHB > Control > RH > combined mix

4.7 Microstructural Analysis

4.7.1 FTIR Results of material characterization

a. FTIR analysis of raw rice husk

Figure 26, shown the FTIR spectrum of raw - husk, showing the major functional groups present in the material. The broad absorption band at around 3317 cm^{-1} corresponds to the stretching vibration of hydroxyl groups, indicates presence of cellulose, hemicellulose, absorbed moisture and lignin. The peak near 2932 Cm^{-1}, indicate to C-H stretching vibrations of aliphatic compounds, confirmed the existence of organic constituents in the biomass material.

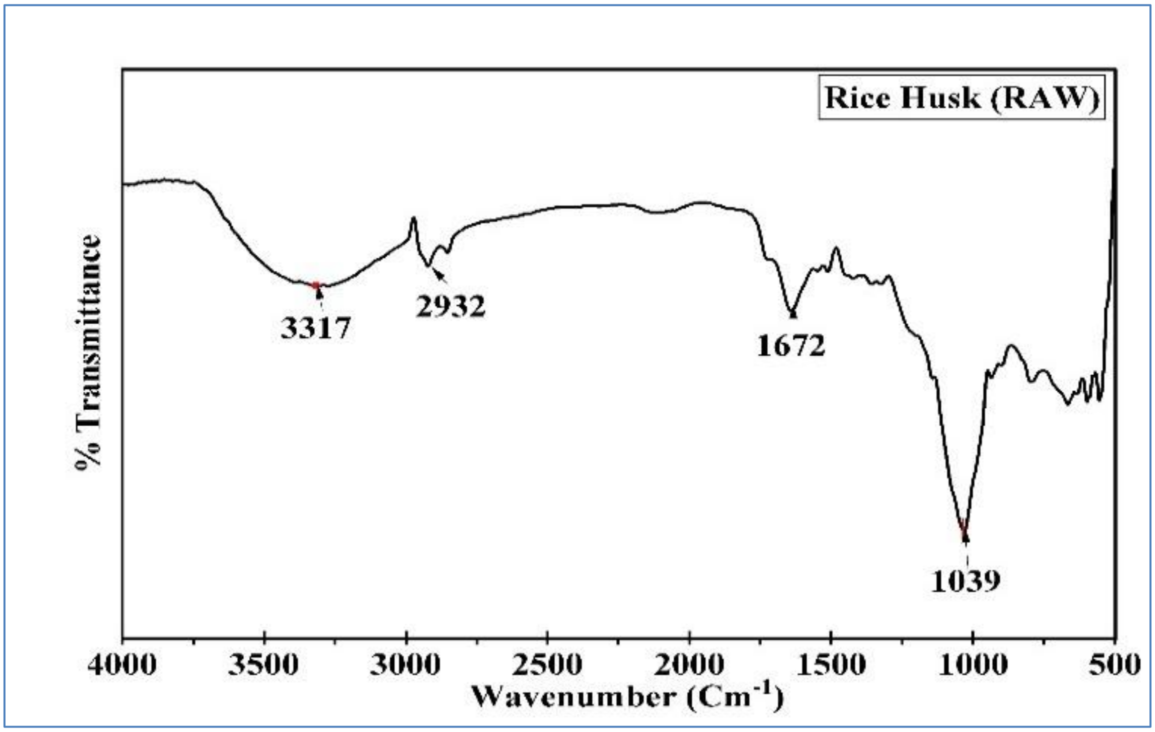


Figure 26: FTIR analysis of Raw Rice husk

A clear peak at approximately 1672 cm^{-1}, indicates C=O stretching vibrations associated with carbonyl groups mainly originating from lignin and hemicellulose components. The strong and sharp peak seen near 1039 cm^{-1}, indicates Si-O-Si and Si-O stretching vibrations, shows the presence of silica compounds in the husk. This peak confirms husk contains significant siliceous materials, which is important for pozzolanic and cementitious applications.

Overall, the FTIR results verified the presence of hydroxyl, carbonyl, aliphatic and siliceous functional group in raw rice husk. This confirms rice husk is composed of both organic biomass constituents and silica-rich inorganic compounds, making it suitable precursor materials for producing ash and other value-added construction materials.

b. FTIR analysis of rice husk biochar

Figure 27 illustrates the FTIR spectrum of the rice husk biochar, showing the major functional groups formed after the pyrolysis process. The broad absorption band observed at around 3636 cm^{-1} corresponds to stretching vibration of hydroxyl groups, indicating the presence of residual moisture, phenolic compounds, and surface hydroxyl functionalities in the biochar structure.

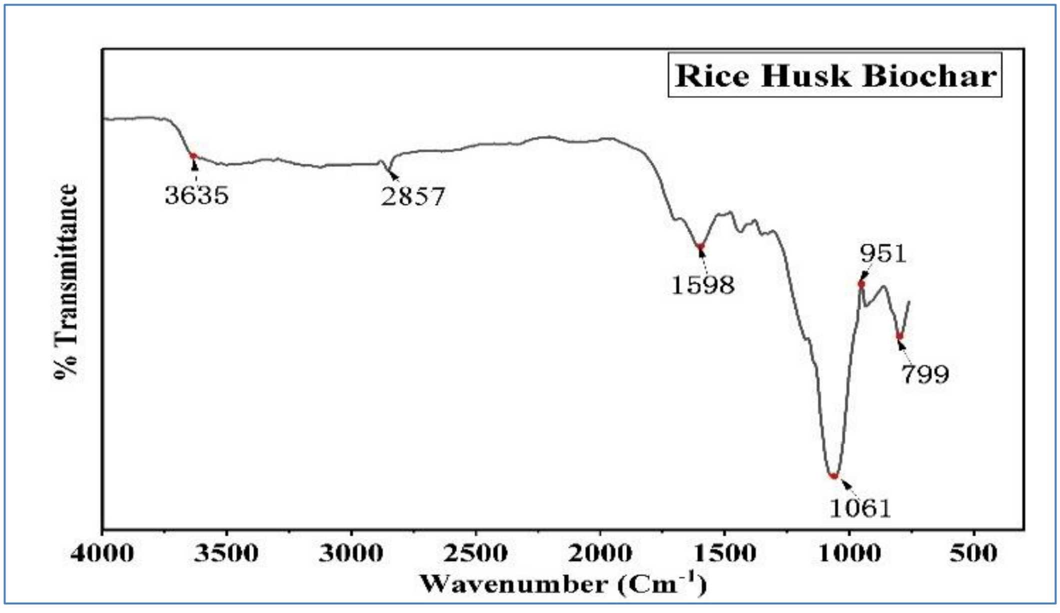


Figure 27: FTIR *analysis* of Rice husk Biochar

The peak located near 2857 cm^{-1}, indicates C-H stretching vibration of aliphatic hydrocarbon.

Compared to raw rice husk, the reduced intensity of this peak suggests decomposition of volatile organic compounds during carbonization. The absorption peak at 1598 cm^{-1}, represents C=C stretching vibrations associated with aromatic carbon structures and carbonyl groups formed after thermal treatment. This confirms development of more carbon-rich and stable biochar matrix. A strong peak observed around 1061 cm^{-1}, indicates Si-O-Si and Si-O stretching vibration, indicating presence of silica compounds retained in biochar. Additional peaks near 951 cm^{-1} and 799 cm^{-1} are associated with silicate as well as quartz-related vibrations, further confirming the silica-rich nature of rice husk biochar.

Overall, FTIIR result confirms biochar contains hydroxyl, aromatic carbon, aliphatic and silica-related functional groups and enhancement of silica and carbonaceous structures after pyrolysis indicate improved thermal stability and potential suitability of biochar as supplementary material in cementitious and sustainable construction applications.

c. FTIR analysis of hardened concrete with RHA and RHB properties

Figure 28, presents the FTIR spectra of hardened concrete containing rice husk ash and biochar. The spectra reveal the presence of important functional groups and hydration products formed within the cementitious matrix after incorporation of rice husk-derived materials.

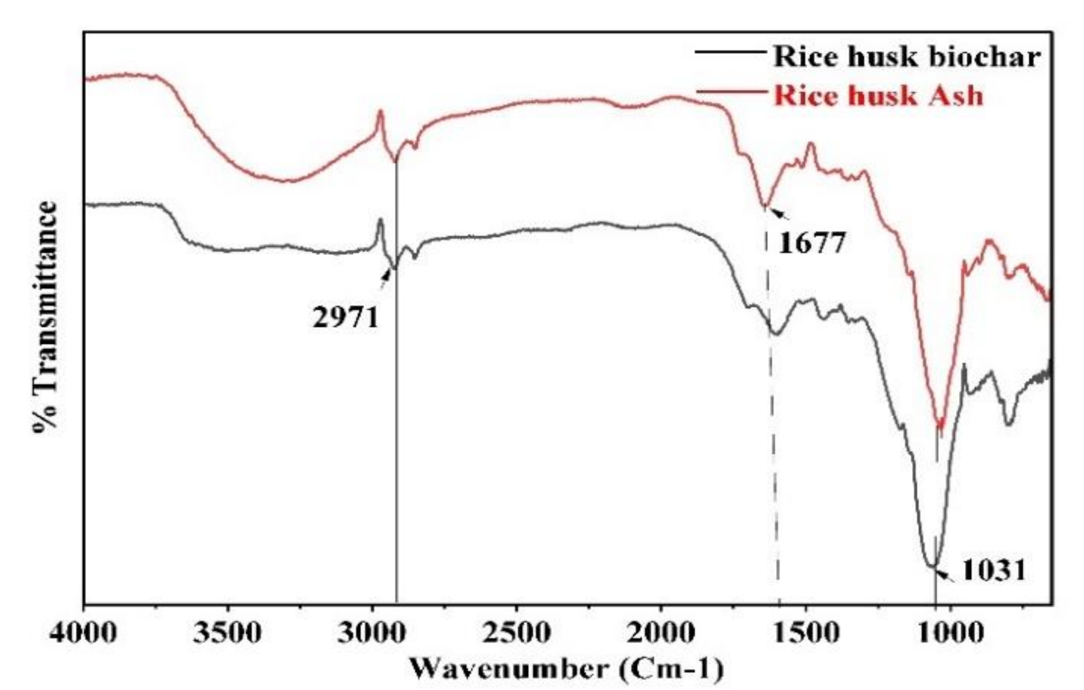


Figure 28: FTIR analysis of hardened concrete with Rice husk-derivatives

A broad absorption peak seen at around 3200-3600 cm^{-1}, associated with the stretching vibration of hydroxyl groups, indicates presence of absorbed water and hydrated cement compounds such as calcium silicate hydrate gel. The peak about 2971 cm^{-1}, indicates C-H stretching vibrations of residual organic compounds with carbonaceous structures, particularly more noticeable in the concrete containing rice husk biochar.

Nearly 1677 cm^{-1}, indicates bending vibrations of H-O-H and carbonyl-related functional groups, showed hydration reactions with formation of bound water within concrete. A strong peak observed at the approximately 1031 cm^{-1}, indicates Si-O-Si and Si-O stretching vibration, mainly related to silicate compounds with formation of secondary calcium silicate hydrate gel due to pozzolanic reactions.

The FTIR spectrum of concrete containing rice husk shows comparatively stronger silicate-related peak, suggests enhanced pozzolanic activity due of high silica content in ash. In contrast, the concrete containing rice husk biochar exhibits additional carbonaceous characteristics, indicates presence of stable carbon structures within concrete. The incorporation of both rice husk derivatives (RHA and RHB) contributes to the modification of the microstructure and hydration behavior of hardened concrete.

Overall, the FTIR analysis confirms the formation of hydration products and silicate structures in hardened concrete containing rice husk-derivatives. The presence of silica-rich functional groups demonstrates the potential of rice husk ash and rice husk biochar to improve the microstructural properties and sustainability of cement-based materials.

Table 25: Important FTIR Peaks in RH, RHA and RHB

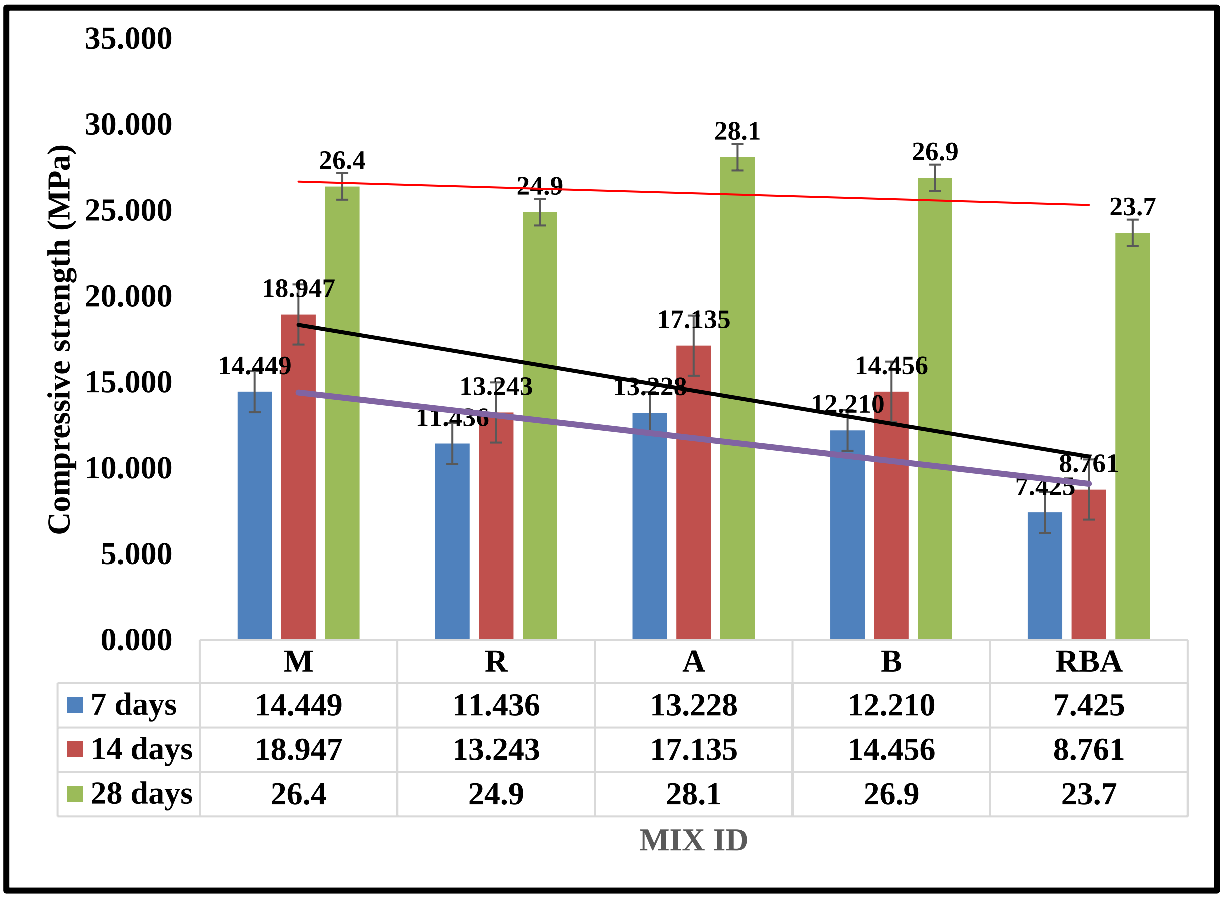
Wavenumber (cm^{-1})	**Functional Group**	**Interpretation**
3400-3600	O–H stretching	Moisture/hydroxyl groups
1500-1700	H–O–H bending	Water molecules

1000-1200	Si–O–Si stretching	Silica structure
600-900	Si–O vibration	Quartz phase
200-500	Si–O bending	Silicate

From the table 25, the FTIR analysis identifies the major functional groups and silica-related compounds present in RH, RHA, and RHB samples. The broad peak at 3400–3600 cm^{-1} represents O–H stretching, indicating the presence of moisture and hydroxyl groups. The peak around 1500–1700 cm^{-1} corresponds to H–O–H bending vibrations associated with water molecules. Strong peaks between 1000–1200 cm^{-1} indicate Si–O–Si stretching, confirming the presence of silica structure. Peaks within 600–900 cm^{-1} represent Si–O vibration related to quartz phases, while the lower range of 200–500 cm^{-1} corresponds to Si–O bending vibrations, indicating silicate compounds in the materials.

4.8 Overall Performance of M20 with Rice husk and Its derivatives

The overall performance of M20 concrete incorporating rice husk and its derivatives shows noticeable variation in strength development at different curing ages. Among all mixes, rice husk ash-based mixes demonstrated better long-term performance due to improved pozzolanic activity and silica contribution.



	M	R	A	B	RBA
🟦 7 days	14.449	11.436	13.228	12.210	7.425
🟥 14 days	18.947	13.243	17.135	14.456	8.761
🟩 28 days	26.4	24.9	28.1	26.9	23.7

Figure 29: Overall performance of M20 concrete with RH-derivatives

Figure 29 presents the compressive strength development of different M20 concrete mixes incorporating RH-derivatives at 7, 14, and 28 days of curing. The mixes considered were Control Mix (M), R, A, B, and RBA. In all mixes, compressive strength increased with curing age, indicating continuous hydration and progressive densification of the concrete matrix.

At 7 days, the control mix (M) achieved a compressive strength of 14.449 MPa. Among the modified mixes, Mix A showed comparatively higher early-age strength (13.228 MPa), followed by Mix B (12.210 MPa) and Mix R (11.436 MPa). The lowest strength was observed in Mix RBA with 7.425 MPa than the control mix, reduction in 7-day strength was approximately 20.9% for Mix R, 8.5% for Mix A, 15.5% for Mix B, and 48.6% for Mix RBA. The significant reduction in RBA may be attributed to slower pozzolanic reactivity and delayed strength gain during the early hydration stage.

At 14 days, all mixes exhibited noticeable strength improvement. The control mix attained 18.947 MPa, whereas Mixes R, A, B, and RBA achieved 13.243 MPa, 17.135 MPa, 14.456 MPa, and 8.761 MPa, respectively. Compared to the control mix, reductions in strength were about 30.1% for Mix R, 9.6% for Mix A, 23.7% for Mix B, and 53.8% for Mix RBA. Mix A demonstrated performance closer to the control mix, suggesting better compatibility and hydration efficiency among the RH-derived mixes.

At 28 days, substantial strength enhancement was observed in all mixes due to continued hydration and secondary pozzolanic reactions. The control mix achieved 26.4 MPa. Interestingly, Mix A attained the highest compressive strength of 28.1 MPa, representing an increase of approximately 6.4% over the control mix. Similarly, Mix B achieved 26.9 MPa, showing a slight increase of about 1.9% compared to the control mix. On the other hand, Mix R exhibited a marginal reduction of about 5.7%, with a compressive strength of 24.9 MPa, while Mix RBA showed the greatest reduction of approximately 10.2%, achieving 23.7 MPa.

The curing-age strength development trend indicates gained strength progressively from 7 - 28 days. The control mix showed an increase of approximately 31.1% from 7 to 14 days and 39.3% from 14 to 28 days. Mix A exhibited increases of about 29.5% and 39.0% over the same curing intervals, indicating efficient long-term pozzolanic activity. Mix B showed comparatively higher later-age gain, with an increase of approximately 86.3% from 14 to 28 days. Mix R also demonstrated significant later-age improvement, increasing by nearly 88.0% between 14 and 28 days. Although Mix RBA had the lowest overall strength, it still showed considerable long-term strength development, indicating delayed but continuous hydration.

The slight deviations observed among the mixes may be associated with differences in particle fineness, silica content, water demand, and bonding characteristics of the RH-derivatives within the cementitious matrix. The trend lines further indicate a gradual reduction in early-age strength for RH-modified mixes, while certain mixes, particularly Mix A and Mix B, exhibited improved later-age performance due to enhanced microstructural densification and secondary calcium silicate hydrate (C–S–H) gel formation.

Overall, the results suggest that selected RH-derivative combinations, especially Mix A and Mix B, can effectively enhance the long-term compressive strength performance of M20 concrete, despite slight reductions in early-age strength.

Table 26**:** Workability and Strength Summary

Mix	Workability	Strength Performance
M	Good	Reference
R	Slightly reduced	Moderate
A	Lower slump	Highest
B	Good slump	Comparable
RBA	Lowest slump	Slightly lower

From the table 26, we can with draw the following information as:

a) The performance of different cementitious mixes was evaluated in terms of workability and strength development.

b) The reference mix (M) demonstrated good workability and served as the baseline for comparison.

c) The R mix exhibited a slightly reduced workability with moderate strength, indicating the effect of the added material on flow and cohesion.

d) The A mix showed the lowest slump, reflecting reduced workability, but achieved the highest compressive strength, highlighting its superior structural performance.

e) The B mix maintained a good slump, comparable to the reference, and demonstrated strength performance similar to M, making it a balanced option between workability and strength.

f) The RBA mix exhibited the lowest workability and slightly lower strength than the other mixes, indicating that while it provides reinforcement, its flow characteristics are limited.

4.9 Discussion on Strength Development Behavior of RH-Derivative Mixes

The compressive strength results indicate that Mix A exhibited superior later-age strength performance compared to the control mix (M), whereas Mixes R and B were unable to achieve comparable strength development. This variation in behavior can be explained through the mineralogical composition, pozzolanic reactivity, particle characteristics, and microstructural interactions of the RH-derived materials used in the concrete mixes.

Among all the mixes, Mix A demonstrated the highest 28-day compressive strength (28.1 MPa), exceeding the control mix by approximately 6.4%. The enhanced performance of Mix A may be attributed to the presence of highly reactive amorphous silica and finer particles within the RH-derivative composition. Amorphous silica actively reacts with calcium hydroxide [$Ca\ (OH)_2$], released during cement hydration, producing additional secondary calcium silicate hydrate (C–S–H) gel. This secondary C–S–H contributes to improved interfacial bonding, pore refinement, and densification of the concrete microstructure, ultimately enhancing compressive strength at later curing ages.

Furthermore, finer particle size of the material used in Mix A may have contributed to a filler effect, where fine particles occupy micro-voids between cement grains and aggregates. This improves particle packing density and reduces capillary porosity, leading to higher strength gain during prolonged curing. The relatively small reduction in early-age strength and the significant increase at 28 days suggest that Mix A possessed sufficient pozzolanic activity and adequate compatibility with the cement hydration process.

In contrast, Mix R exhibited lower compressive strength than the control mix (M) throughout the curing period, although substantial later-age improvement was observed. The lower performance of Mix R may be associated with lower reactive silica content or a higher proportion of crystalline silica, which possesses limited pozzolanic reactivity compared to amorphous silica. Crystalline phases generally react slowly with calcium hydroxide and therefore contribute less effectively to secondary C–S–H formation.

Another possible reason for the reduced strength in Mix R is the presence of unburnt carbon or coarser particles within the RH-derived material. Unburnt carbon can increase water demand and reduce cement hydration efficiency, while coarse particles weaken the particle packing arrangement and create weak transition zones within the concrete matrix. Consequently, although Mix R gained strength with curing age due to gradual hydration, it could not surpass the control mix because the pozzolanic contribution remained insufficient.

Mix B showed better performance than Mix R and achieved strength very close to control mix at 28 days, with a slight increase approximately 1.9%. However, its performance remained lower than Mix A. This behavior may indicate moderate pozzolanic activity and partial micro-filler contribution. The RH-derived material in Mix B may contain a balanced combination of reactive and non-reactive mineral phases, enabling gradual strength enhancement but limiting the overall efficiency of secondary hydration reactions.

Additionally, the mineral composition of Mix B may have contained impurities such as alkali compounds or partially crystalline silica, which could reduce the extent of pozzolanic interaction. Although the material contributed to pore refinement and long-term hydration, the reaction kinetics were likely slower than those observed in Mix A. As a result, Mix B achieved acceptable later-age strength but lacked the highly reactive characteristics necessary to produce significant strength enhancement beyond control mix.

Poorest performance was observed in Mix RBA, which showed substantial reduction in compressive strength at all curing ages. This may be due to excessive replacement level, poor particle grading, high porosity, or inadequate silica reactivity. The combined effect of lower cementitious content and delayed hydration may have reduced the formation of sufficient C–S–H gel, thereby weakening the concrete matrix.

Overall, the results demonstrate that the strength development of RH-derived concrete is highly dependent on the mineralogical characteristics and physical properties of the replacement material. Mix A likely contained a greater proportion of reactive amorphous silica with finer particles, resulting in stronger pozzolanic reactions and denser microstructure formation. In contrast, Mixes R and B may have contained lower reactive silica content, coarser particles, or higher crystalline phases, limiting their ability to develop compressive strength comparable to or greater than the control mix.

CHAPTER 5: CONCLUSION AND RECOMMENDATION

5.1 Conclusions

This research focused on the **performance evaluation of M20 grade concrete** with partial replacement of cement by **rice husk (RH), rice husk ash (RHA), and rice husk biochar (RHB)**. Based on the experimental results, the following conclusions are drawn:

1. Workability of Concrete

The slump test results indicated that the workability of concrete decreased with the incorporation of rice husk and its derivatives. The control mix showed the highest slump value of 25 mm, whereas the combined RH+RHA+RHB mix recorded the lowest slump value of 16 mm. This reduction in workability is mainly attributed to the porous texture, finer particle size, and high-water absorption capacity of rice husk-based materials. The combined mix contained multiple replacement materials, which collectively increased surface area and water demand, resulting in lower consistency and reduced flowability of concrete.

Similar observations were reported by Habeeb and Mahmud (2010), Ganesan et al. (2011), and Sata et al. (2012), who stated that rice husk ash particles absorb more water because of their porous nature and therefore reduce concrete workability. The present study therefore validates previously reported fresh concrete behavior.

2. Compressive Strength of Concrete

The compressive strength results demonstrated that the 5% RHA replacement mix achieved highest 28-day compressive strength of 28.1 MPa**;** approximately 6.44% higher than the control mix strength of 26.4 MPa**.** This improvement confirms that a limited replacement level of ash, enhances concrete performance through pozzolanic reactions and micro-filling effects. The fine silica particles present in ash reacts with calcium hydroxide produced during cement hydration, forms additional calcium silicate hydrate (C-S-H) gel, which improves bonding and densifies the concrete matrix.

Similar strength enhancement at optimum replacement levels was reported by Zhang and Malhotra (2010), Sata et al. (2012), and Van Tuan et al. (2011), who observed that 5–10% RHA replacement improves long-term compressive strength due to higher silica reactivity and filler action. Kumar et al.

(2018) also reported that lower replacement levels provide sufficient reactive silica without significantly reducing cementitious binder content. Therefore, the present findings validate that 5% replacement is close to the optimum level for achieving improved strength in M20 concrete.

The RH mix achieved a 28-day strength of 24.9 MPa, showing a slight reduction of approximately 5.68% compared to the control mix. This reduction may be due to the lower pozzolanic reactivity of raw rice husk and the presence of unburnt organic content. Similar observations were reported by Prusty and Patro (2015) and Vignesh and Vivek (2015), who found that untreated agricultural waste materials generally produce lower strength compared to processed ash forms.

The RHB mix attained a 28-day compressive strength of 26.9 MPa, which is approximately 1.89% higher than the control mix. The improvement in strength validates that the controlled burning process converted rice husk into silica-rich ash with better pozzolanic properties. Proper preparation of RHB removed organic matter and increased amorphous silica availability, which contributed to additional C-S-H formation and improved concrete bonding. Similar findings were reported by Amran et al. (2021), Kumar et al. (2018), and Chandrasekhar et al. (2012), who stated that controlled burning significantly enhances the cementitious behavior of rice husk derivatives.

The combined RH+RHA+RHB mix showed the lowest 28-day compressive strength of 23.7 MPa**,** which is approximately 10.23% lower than the control mix. The reduction in strength is mainly attributed to excessive cement replacement and dilution of effective binder content. The simultaneous incorporation of RH, RHA, and RHB increased porosity, reduced hydration efficiency, and weakened particle packing within the concrete matrix. Excessive replacement also reduced the availability of cement required for proper hydration and strength development.

Similar reductions at higher replacement levels were reported by Safiuddin and Hearn (2010), Kumar et al. (2018), and Singh et al. (2016), who concluded that excessive pozzolanic replacement may adversely affect compressive strength due to insufficient cementitious compounds and incomplete hydration reactions. Therefore, the lower strength of the combined mix obtained in this study validates the limitations of excessive replacement percentages reported in previous studies.

The overall strength development trend observed in this study was:

RHA > RHB > Control > RH > RH+RHA+RHB

This trend is consistent with previously published studies and confirms the reliability of the experimental results obtained in this research.

3. FTIR and Microstructural Validation

FTIR analysis confirmed the presence of silica-related functional groups and Si–O–Si stretching vibrations in RHA and RHB samples. Strong peaks observed between **1000–1200 cm^{-1}** indicated reactive silica structures responsible for pozzolanic activity. Peaks corresponding to hydroxyl groups and silicate compounds further confirmed the formation of cementitious products contributing to concrete strength.

The stronger silica peaks observed in RHA and RHB validate the higher compressive strength obtained in these mixes. In contrast, the combined mix showed comparatively weaker crystallinity and lower structural uniformity, which explains the reduction in compressive strength. The FTIR results therefore directly support the mechanical performance observed in the study.

Similar FTIR characteristics were reported by Chandrasekhar et al. (2012), Tuan and Ye (2014), and Yin et al. (2017), who identified reactive silica phases and denser microstructures in rice husk ash concrete due to enhanced pozzolanic reactions.

4. Material Sustainability

The incorporation of rice husk and its derivatives reduced cement consumption and promoted sustainable construction practices by utilizing agricultural waste materials. The use of rice husk-based materials contributes to lower carbon emissions, reduced waste disposal problems, and eco-friendly concrete production.

Similar conclusions were reported by Amran et al. (2021), Sharma and Khan (2017), and Singh et al. (2016), who emphasized the environmental benefits of agricultural waste utilization in concrete technology.

5. Overall Assessment

Based on experimental results, comparative validation, FTIR analysis, and previous research findings, 5% RHA replacement is recommended for M20 concrete because it improves compressive strength, enhances microstructural properties, and maintains acceptable workability. Properly prepared RHB also demonstrated satisfactory performance due to increased silica availability after controlled burning.

The study further confirms that combined replacement exceeding 10% may adversely affect concrete performance because of excessive binder dilution, increased porosity, and reduced hydration efficiency. Therefore, optimum replacement levels should be carefully maintained to achieve balanced mechanical and durability performance in sustainable concrete production.

5.2 Recommendations

Based on the findings of this research, the following recommendations are made for practical applications and further study:

1. Optimal Replacement Level

a) Based on the experimental results, 5% replacement of cement with RHA is recommended as the optimum replacement level for M20 concrete, as it achieved the highest 28-day compressive strength of 28.1 MPa, exceeding the control mix strength of 26.4 MPa. Similar optimum replacement ranges were also reported by Zhang and Malhotra (2010), Sata et al. (2012), and Kumar et al. (2018), who concluded that lower RHA replacement levels improve pozzolanic activity and concrete densification.

b) Replacement levels exceeding 10% should be carefully controlled because excessive incorporation of RH derivatives may reduce workability and compressive strength due to binder dilution and insufficient hydration products. The combined RH+RHA+RHB mix in this study showed reduced strength (23.7 MPa), validating similar findings reported by Safiuddin and Hearn (2010) and Singh et al. (2016).

2. Application in Concrete Construction

a) RH, RHA, and RHB concrete mixes can be effectively utilized in non-critical structural elements, pavements, partition walls, blocks, and low-to-medium strength concrete applications where sustainable construction materials are preferred.

b) The RHA mix demonstrated superior mechanical performance and can therefore be considered suitable for medium-strength reinforced concrete applications. Similar recommendations were provided by Ganesan et al. (2011) and Van Tuan et al. (2011), who reported improved long-term strength and durability in RHA blended concrete.

c) Properly processed RHB may also be utilized as a supplementary cementitious material because the controlled burning process improves silica availability and enhances later-age strength development.

3. Future Research

a) Future studies should investigate the long-term durability performance of RH derivative concrete, including sulfate resistance, chloride penetration, carbonation resistance, water absorption, and shrinkage behavior to better evaluate field applicability.

b) Further research should explore hybrid concrete mixes incorporating RH derivatives with other supplementary cementitious materials such as fly ash, silica fume, and ground granulated blast furnace slag (GGBS) to improve both mechanical and durability performance.

c) Additional studies are recommended to determine the optimum particle size, controlled burning temperature, grinding duration, and treatment methods of RH, RHA, and RHB to maximize pozzolanic reactivity and silica availability.

d) Since the present study confirmed better performance at lower replacement levels, future investigations may focus on replacement ranges between 5–10% to identify the most efficient and economical mix proportions.

4. Microstructural and Advanced Testing

a) Advanced characterization techniques such as SEM (Scanning Electron Microscopy), TGA (Thermogravimetric Analysis), XRD (X-Ray Diffraction), and NMR (Nuclear Magnetic Resonance) should be employed to obtain deeper understanding of hydration products, pore structure, and microstructural development of RH derivative concrete.

b) The FTIR analysis performed in this study confirmed the presence of silica-related functional groups and Si–O–Si bonds responsible for pozzolanic activity. Future studies should correlate these microstructural findings with compressive strength, durability, and permeability characteristics to establish predictive relationships between material structure and concrete performance.

5. Sustainability Considerations

a) The use of rice husk and its derivatives in concrete should be promoted as a sustainable alternative material because it reduces cement consumption, lowers carbon emissions, and utilizes agricultural waste effectively.
b) The incorporation of RH derivatives can contribute to environmentally friendly and cost-effective construction practices, particularly in agricultural regions where rice husk waste is abundantly available.
c) Future research should conduct Life Cycle Assessment (LCA) and cost-benefit analysis of RH derivative concrete to quantify environmental, economic, and energy-saving benefits compared to conventional concrete.

5.3 Final Remark

This research demonstrates that rice husk and its derivatives can be effectively utilized as partial cement replacement materials in M20 concrete. Among all mixes, the 5% RHA replacement exhibited the best overall performance with improved compressive strength, satisfactory workability, and enhanced pozzolanic behavior validated through FTIR analysis and comparison with previous studies. Properly processed RHB also showed promising performance due to improved silica reactivity after controlled burning.

The experimental findings obtained in this study are consistent with previously published literature, validating the reliability of the results. However, excessive combined replacement of RH derivatives adversely affected strength and workability because of binder dilution and increased porosity. Therefore, optimum replacement levels and proper processing methods are essential for achieving durable, sustainable, and economical concrete production using rice husk-based materials.

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APPENDICES

Appendix A – Calculation of material

Concrete Ingredient:

Grade of concrete: M20

Ratio of M20: 1:1.5:3

For 1 cube specimen:

Total volume of concrete (as per mold Size): 150 ×150 ×150 mm3 = 0.003375 m3

Total weight of cement = 64 kg

Total weight of fine aggregate = Approx. 120 kg

Total weight of coarse aggregate = Approx. 245 kg

Total weight of water required (Assume 0.5 w/c ratio) = 32 kg

Replacement of cement by weight Material (RH and its derivatives) calculation:

Quantity of Raw Rice husk (RH) = 5% × 64kg = 1.28 kg (for 9 R + 9 RBA cubes)

Quantity of fine- Rice husk (RH) = 5% × 64kg = 1.28 kg (for 9 R+ 9 RBA cubes))

Quantity of Rice husk ash (RHA) = 5% × 64kg = 1.28kg (for 9 A + 9 RBA cubes)

Quantity of Rice husk biochar (RHA) = 5% × 6.4kg = 1.28kg (9 B + 9 RBA cubes))

Required Total quantity of raw rice husk = 15 kg for all RH and its derivatives preparation

Quantity of RH for each derivative = 3kg for Preparation of RH derivatives (fine RH, RHA and RHB)

% yielding of RH-derivatives =$\frac{3-1.28}{3} \times 100\%$= 57.33 % (Approx. 60% yielding is seen)

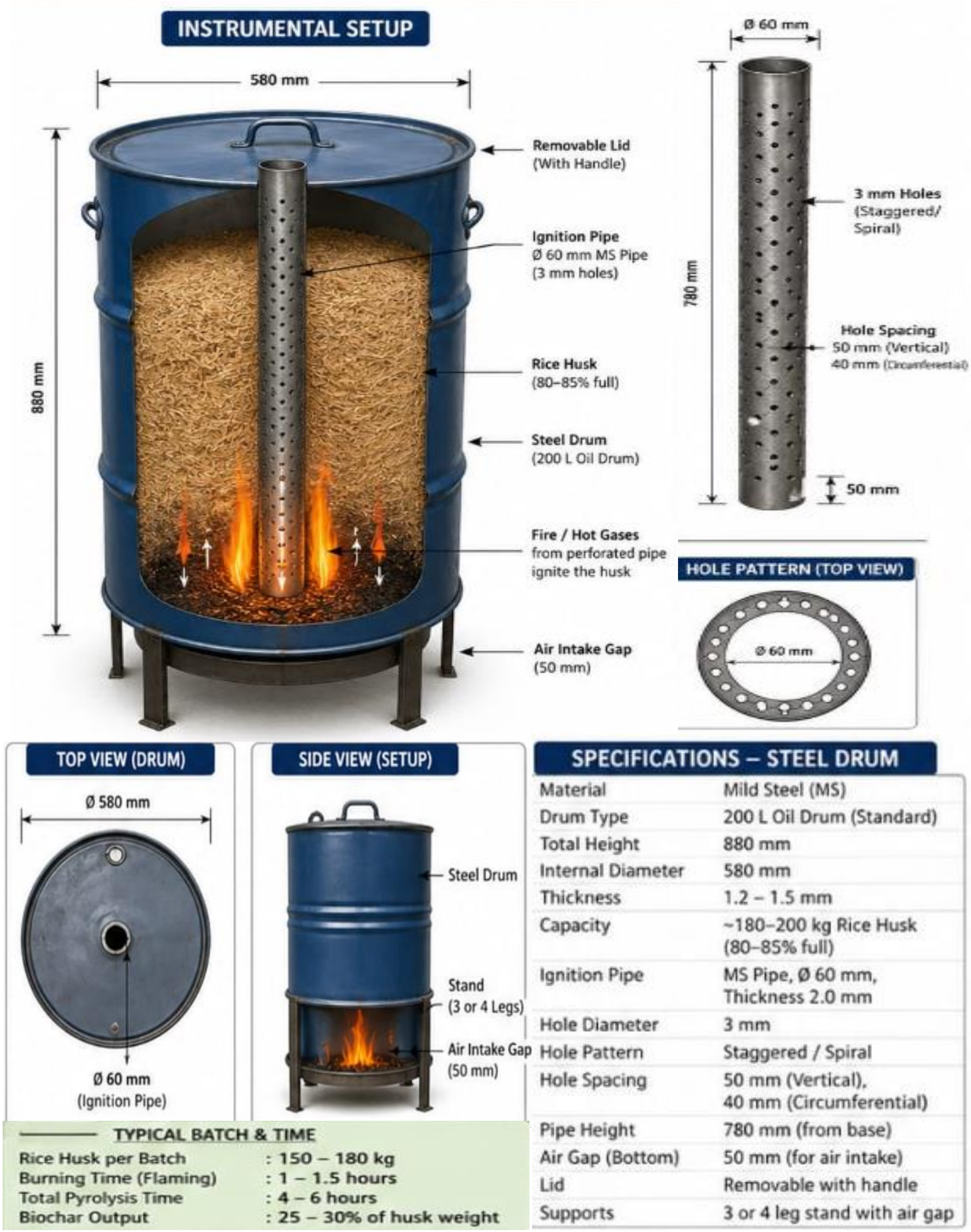
Note: Quantity of materials is calculated excluding 10% wastage for RH and its derivatives.

Appendix B – Detailed Nominal Mix Calculations

M20 Design nominal mix per IS 10262:2019

a) Water–cement ratio: 0.50
b) Target mean strength: 26.6 MPa
c) Water content: 191 kg/m^3
d) Cement content: 382 kg/m^3
e) Fine aggregate: 672 kg/m^3
f) Coarse aggregate: 1196 kg/m^3
g) RHA, RH, RHB partial replacements (5% each)
(Include stepwise calculations as shown in Chapter 3 Mix design calculation section 3.4 to 3.7)

Appendix C– Specification of drum (RHB)



TYPICAL BATCH & TIME

Rice Husk per Batch : 150 – 180 kg
Burning Time (Flaming) : 1 – 1.5 hours
Total Pyrolysis Time : 4 – 6 hours
Biochar Output : 25 – 30% of husk weight

SPECIFICATIONS – STEEL DRUM

Material	Mild Steel (MS)
Drum Type	200 L Oil Drum (Standard)
Total Height	880 mm
Internal Diameter	580 mm
Thickness	1.2 – 1.5 mm
Capacity	~180–200 kg Rice Husk (80–85% full)
Ignition Pipe	MS Pipe, Ø 60 mm, Thickness 2.0 mm
Hole Diameter	3 mm
Hole Pattern	Staggered / Spiral
Hole Spacing	50 mm (Vertical), 40 mm (Circumferential)
Pipe Height	780 mm (from base)
Air Gap (Bottom)	50 mm (for air intake)
Lid	Removable with handle
Supports	3 or 4 leg stand with air gap

Appendix D – Laboratory Photographs

Include clear, dated photographs of:

a) Material preparation (RH, RHA, RHB)

Figure 30 :Burning of RH for RHA

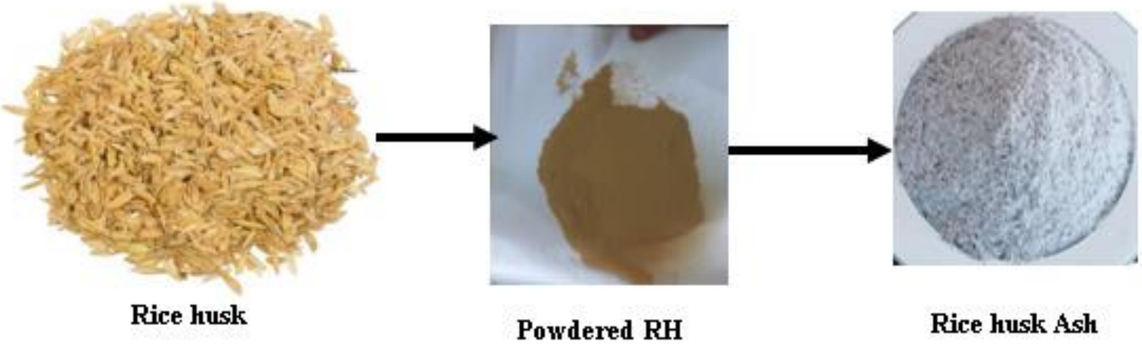


Figure 31: Rice husk to rice husk ash

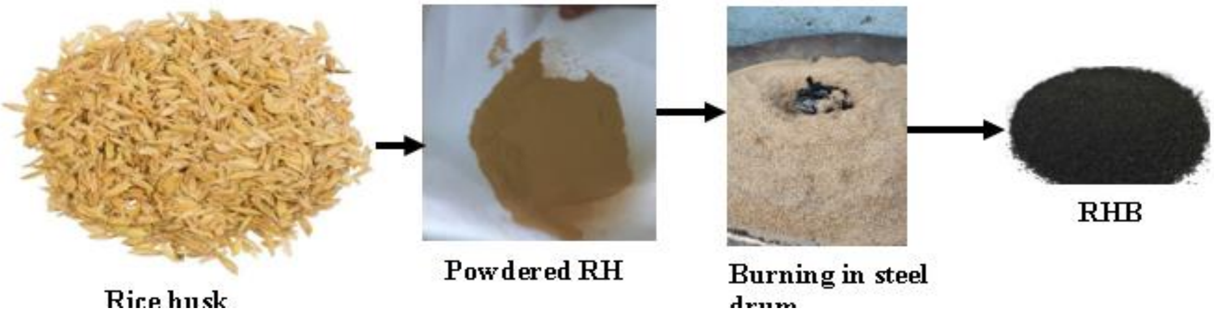


Figure 32: Rice husk to rice husk biochar

b) Slump test setup

Figure 33: Slump testing for fresh concrete

c) Mixing, Casting (molding) and curing of 150 mm cubes

Figure 34: Mold Cubes (150 mm × 150 mm × 150 mm)

Figure 35: casting of cubes

Figu*re* 36: De-molding of cubes after 24 hours

Figure 37: Curing of concrete for curing period of 7, 14 and 28 days

Figure 38: Weighing of wet cubes before drying

d)

Figure 39: Weighing of sunlight dry cubes

Figure 40: Cube specimens ready for testing in UTM

e) Hardened Concrete testing machine in operation

Figure 41: Testing of cube specimens for 7, 14 and 28 days

f) Failure patterns of cubes

Figure 42: After cube specimen keep under UTM: failure pattern

Appendix E – FTIR Spectra

Include raw FTIR graphs for:

- Rice Husk
- Rice Husk Ash (RHA)
- Rice Husk Biochar (RHB)
- Powdered crushed concrete specimen (control and each mix)

Label peaks at significant wavenumbers,

Peak at ~1100 cm^{-1}: Si–O–Si stretching (silica): Included RH-derivatives and Material characterization chapter-3 Methodology

Appendix F – Photographs of sieve analysis and Pycnometer test for specific gravity

Figure 43: Sieve Sizes set up for fine and coarse aggregate

Figure 44: Fine aggregate for sieve analysis (weighing: 300g):

Figure 45: coarse aggregate for sieve analysis (weighing: 300g)

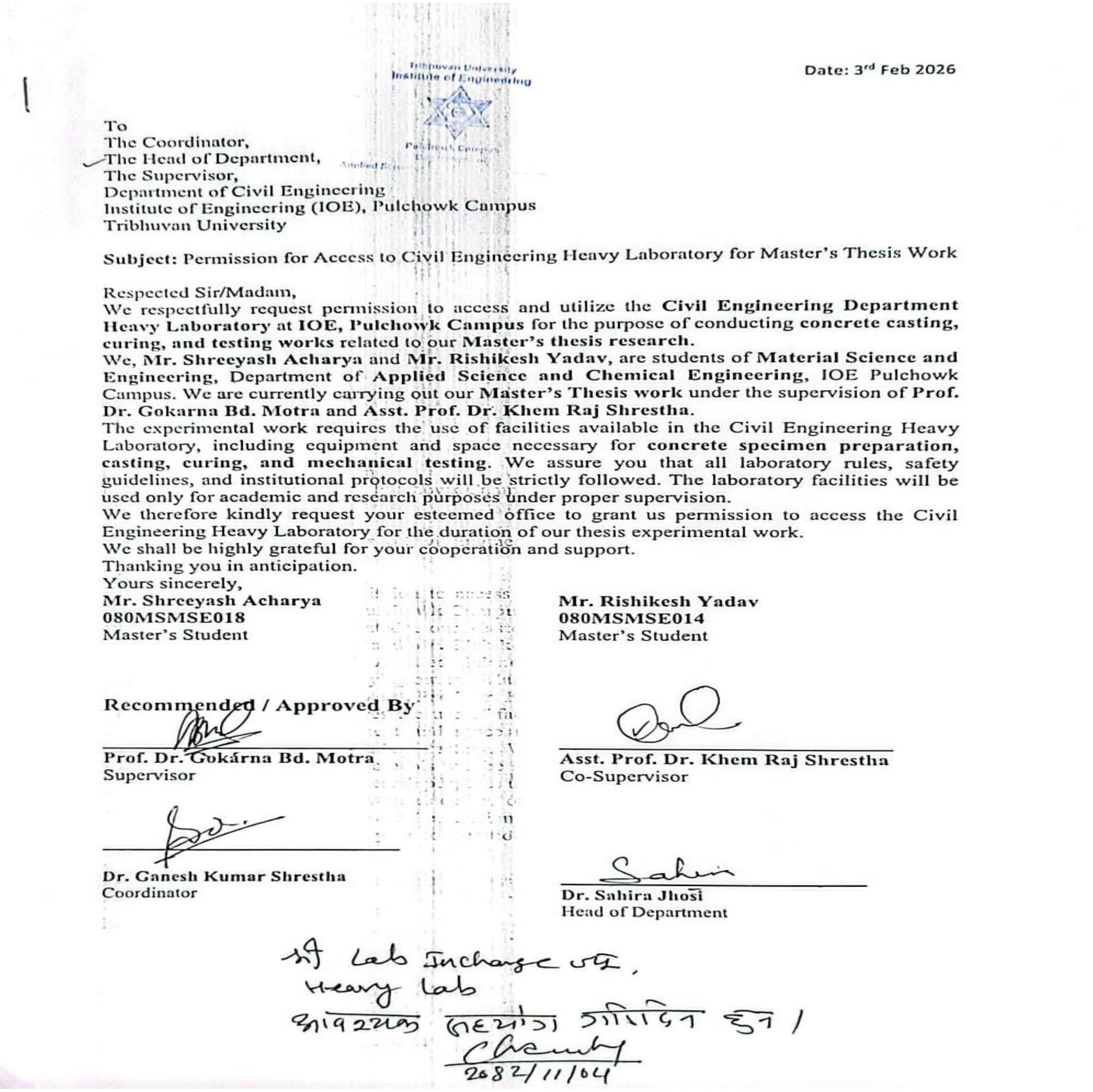
Figure 46: Empty pycnometer weighing

Figure 47 sample with water and pycnometer weighing

Figure 48 : water and pycnometer weighing

Figure 49: sand and pycnometer weighing

Appendix G – Laboratory permission letters



Date: 3rd Feb 2026

To
The Coordinator,
The Head of Department,
The Supervisor,
Department of Civil Engineering
Institute of Engineering (IOE), Pulchowk Campus
Tribhuvan University

Subject: Permission for Access to Civil Engineering Heavy Laboratory for Master's Thesis Work

Respected Sir/Madam,
We respectfully request permission to access and utilize the **Civil Engineering Department Heavy Laboratory** at **IOE, Pulchowk Campus** for the purpose of conducting **concrete casting, curing, and testing works** related to our **Master's thesis research**.
We, **Mr. Shreeyash Acharya** and **Mr. Rishikesh Yadav**, are students of **Material Science and Engineering**, Department of **Applied Science and Chemical Engineering**, IOE Pulchowk Campus. We are currently carrying out our **Master's Thesis work** under the supervision of **Prof. Dr. Gokarna Bd. Motra** and **Asst. Prof. Dr. Khem Raj Shrestha**.
The experimental work requires the use of facilities available in the Civil Engineering Heavy Laboratory, including equipment and space necessary for **concrete specimen preparation, casting, curing, and mechanical testing**. We assure you that all laboratory rules, safety guidelines, and institutional protocols will be strictly followed. The laboratory facilities will be used only for academic and research purposes under proper supervision.
We therefore kindly request your esteemed office to grant us permission to access the Civil Engineering Heavy Laboratory for the duration of our thesis experimental work.
We shall be highly grateful for your cooperation and support.
Thanking you in anticipation.
Yours sincerely,

Mr. Shreeyash Acharya
080MSMSE018
Master's Student

Mr. Rishikesh Yadav
080MSMSE014
Master's Student

Recommended / Approved By

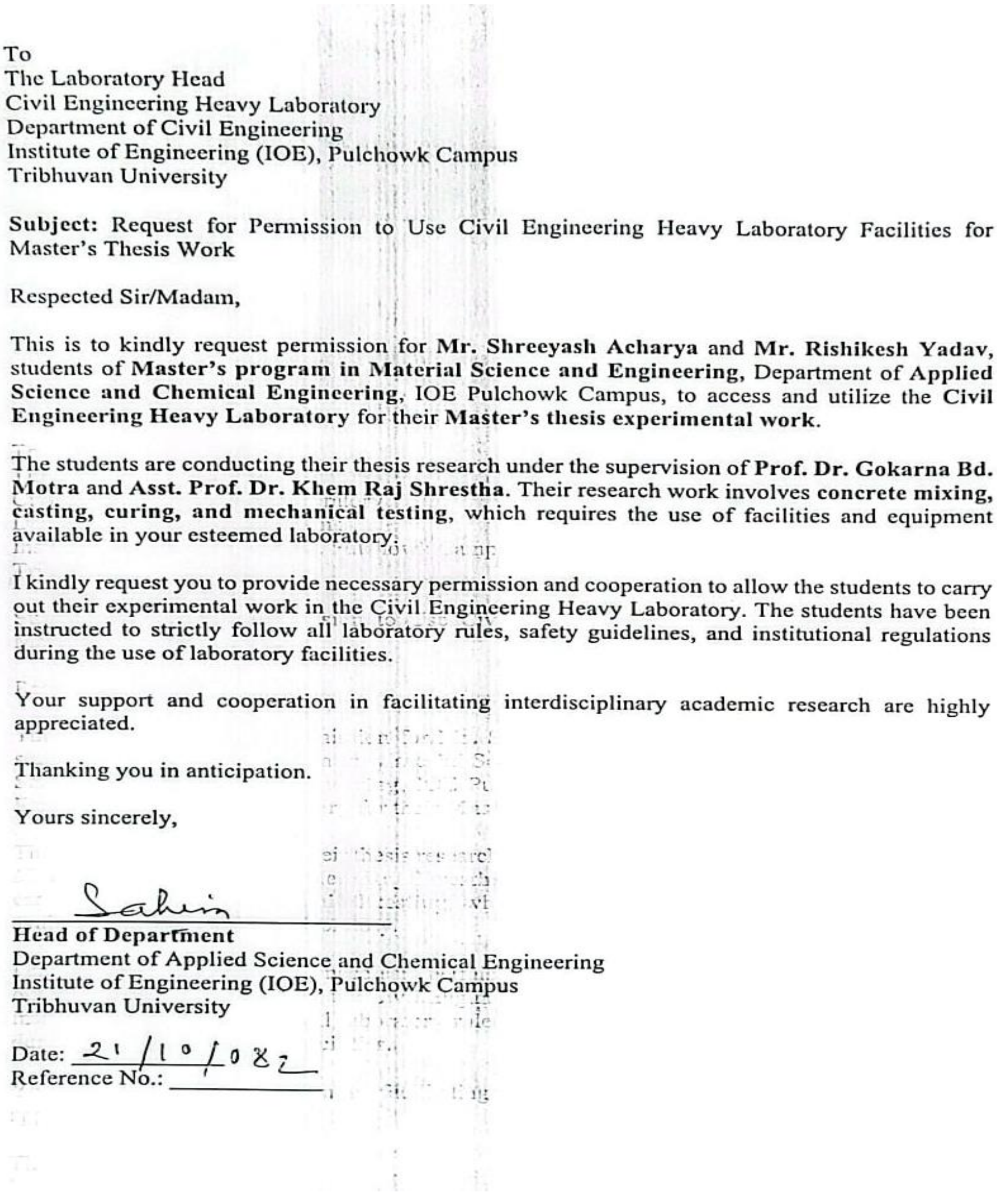
Prof. Dr. Gokarna Bd. Motra
Supervisor

Asst. Prof. Dr. Khem Raj Shrestha
Co-Supervisor

Dr. Ganesh Kumar Shrestha
Coordinator

Dr. Sahira Jhosi
Head of Department

श्री Lab Incharge ज्यू,
Heavy Lab
आवश्यक व्यवस्था मिलाइदिनु हुन ।
2082/11/04



To
The Laboratory Head
Civil Engineering Heavy Laboratory
Department of Civil Engineering
Institute of Engineering (IOE), Pulchowk Campus
Tribhuvan University

Subject: Request for Permission to Use Civil Engineering Heavy Laboratory Facilities for Master's Thesis Work

Respected Sir/Madam,

This is to kindly request permission for **Mr. Shreeyash Acharya** and **Mr. Rishikesh Yadav**, students of **Master's program in Material Science and Engineering**, Department of Applied **Science and Chemical Engineering**, IOE Pulchowk Campus, to access and utilize the **Civil Engineering Heavy Laboratory** for their **Master's thesis experimental work**.

The students are conducting their thesis research under the supervision of **Prof. Dr. Gokarna Bd. Motra** and **Asst. Prof. Dr. Khem Raj Shrestha**. Their research work involves **concrete mixing, casting, curing, and mechanical testing**, which requires the use of facilities and equipment available in your esteemed laboratory.

I kindly request you to provide necessary permission and cooperation to allow the students to carry out their experimental work in the Civil Engineering Heavy Laboratory. The students have been instructed to strictly follow all laboratory rules, safety guidelines, and institutional regulations during the use of laboratory facilities.

Your support and cooperation in facilitating interdisciplinary academic research are highly appreciated.

Thanking you in anticipation.

Yours sincerely,

Sahin

Head of Department
Department of Applied Science and Chemical Engineering
Institute of Engineering (IOE), Pulchowk Campus
Tribhuvan University

Date: 21/10/082
Reference No.:

त्रिभुवन विश्वविद्यालय
इन्जिनियरिङ अध्ययन संस्थान
पुल्चोक क्याम्पस
Department of Applied Sciences &Chemical Engineering
☎: ५५४३०७२

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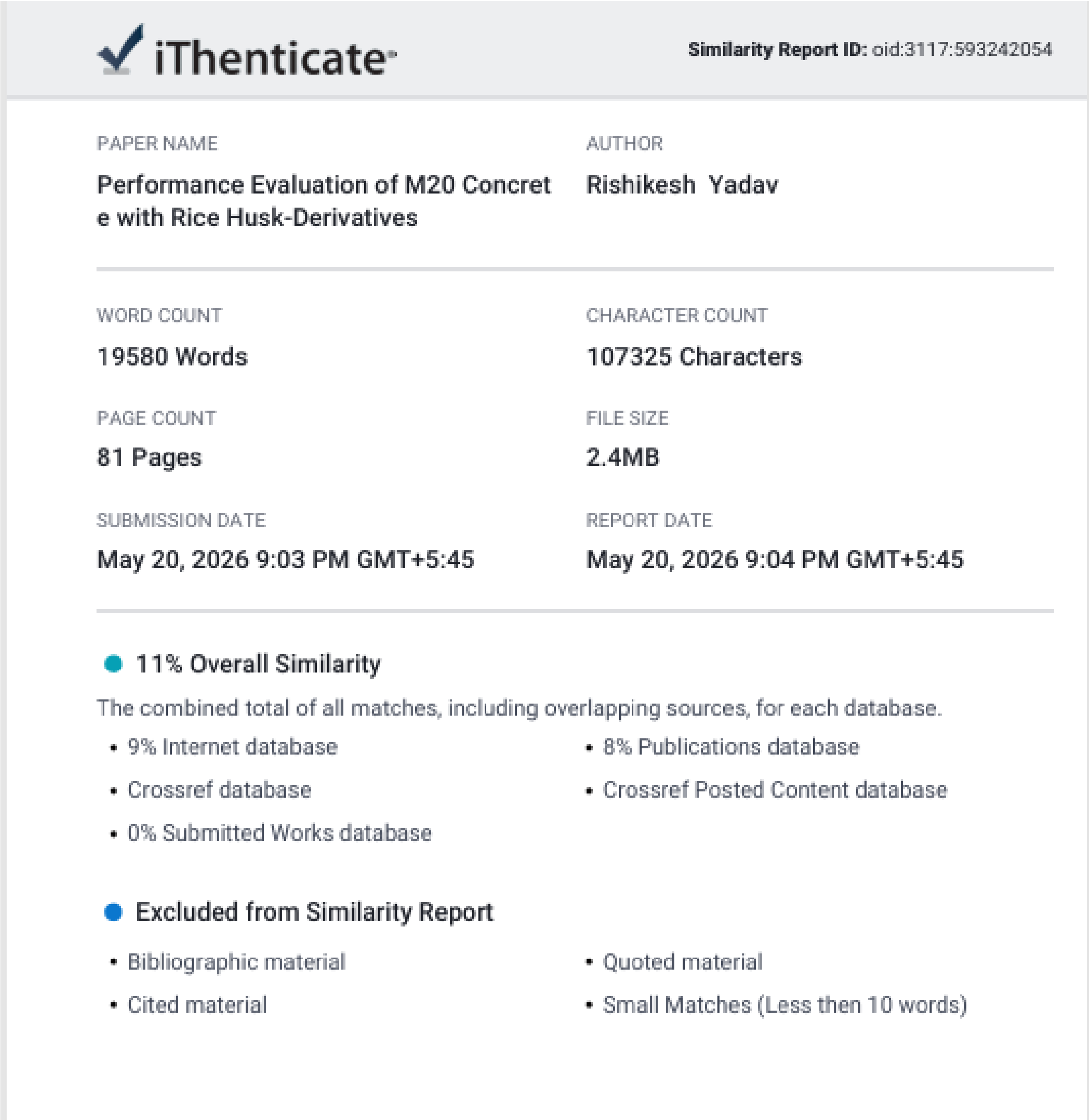
_च.न

श्रीमान प्रमुखज्यू
Concrete Testing. (Heavy Lab)
सिभिल इ. विभाग ।

विषयः आवश्यक सहयोग सम्वन्धमा ।

उपरोक्त सम्वन्धमा यस इ. विज्ञान तथा मानविकी विभाग अन्तर्गत M.Sc. in Material Science and Engineering स्नातकोत्तर तहमा अध्यनरत विद्ययार्थीहरु श्री ऋषिकेश यादव र श्रीयस आचार्य Thesis कार्यको लागि Concrete Casting and Testing को लागि आवश्यक भएको हुदाँ सो उपलब्ध गराई आवश्यक सहयोग गरिदिनु हुन अनुरोध गर्दछु ।

डा. गणेश कुमार श्रेष्ठ
प्रोग्राम को-अर्डिनेटर



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AUTHOR

Rishikesh Yadav

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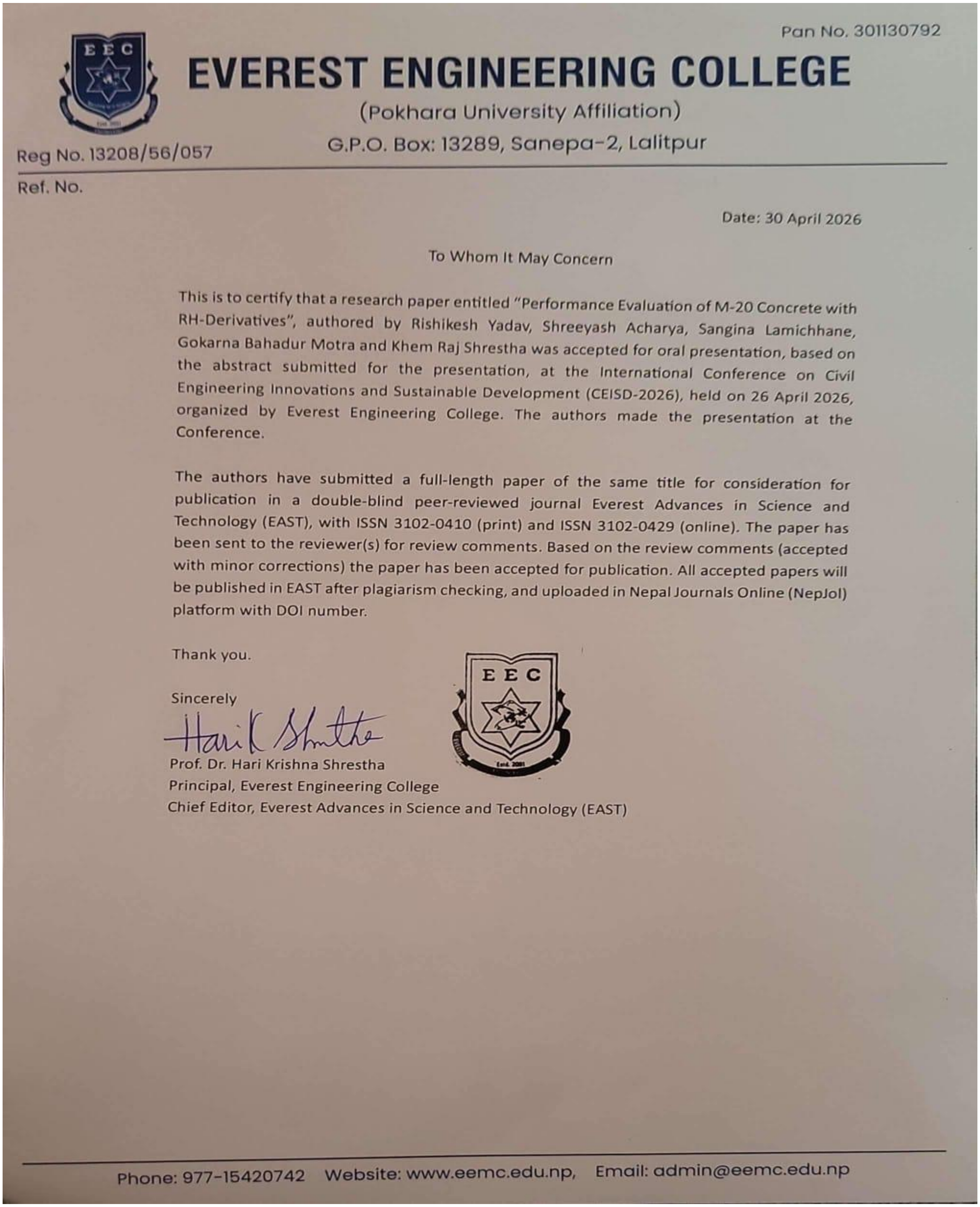
Appendix K – Abstract, Paper Acceptance Letter



Pan No. 301130792

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 "Performance Evaluation of M-20 Concrete with RH-Derivatives", authored by Rishikesh Yadav, Shreeyash Acharya, Sangina Lamichhane, 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

Hari K Shrestha

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

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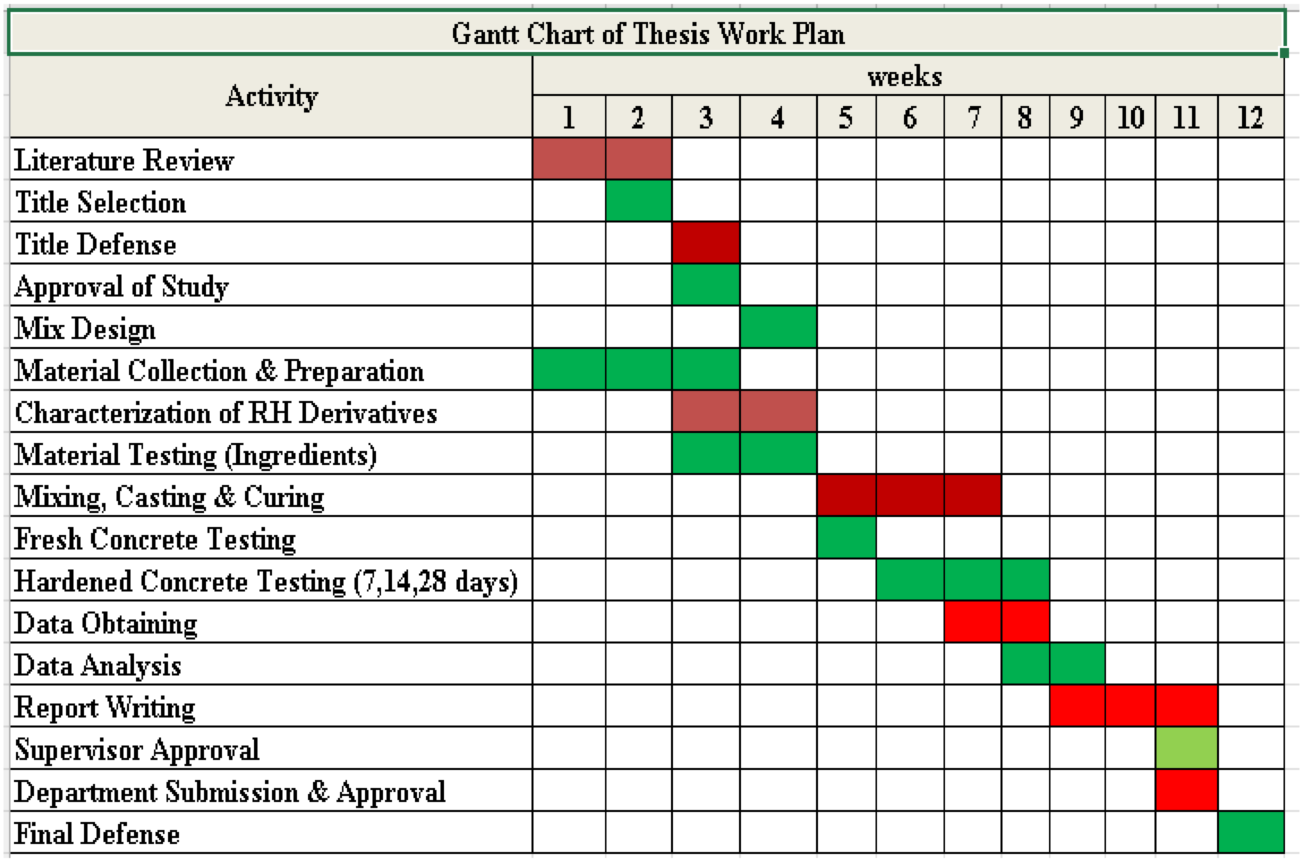
Appendix L – Gantt chart of thesis work plan



Gantt Chart of Thesis Work Plan

Activity	weeks											
	1	2	3	4	5	6	7	8	9	10	11	12
Literature Review	🟥	🟥										
Title Selection		🟩										
Title Defense			🟥									
Approval of Study			🟩									
Mix Design				🟩								
Material Collection & Preparation	🟩	🟩	🟩									
Characterization of RH Derivatives			🟥	🟥								
Material Testing (Ingredients)			🟩	🟩								
Mixing, Casting & Curing					🟥	🟥	🟥					
Fresh Concrete Testing					🟩							
Hardened Concrete Testing (7,14,28 days)						🟩	🟩	🟩				
Data Obtaining							🟥	🟥				
Data Analysis								🟩	🟩			
Report Writing									🟥	🟥	🟥	
Supervisor Approval											🟩	
Department Submission & Approval											🟥	
Final Defense												🟩

Appendix M – Bibliography of candidates and Supervisors

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Educational background: Bachelor's Degree in Civil Engineering, Janakpur Engineering College, Kupandole, Affiliated to Tribhuwan University

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: 3RB Construction Pvt Ltd., Suryabinayak, Bhaktapur

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