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This is to certify that the research work presented in this thesis, titled “**Performance Evaluation of Cement Containing Rice Husk Ash as Supplementary Material**” was conducted by “**Nimra Iqbal**” under the supervision of “**Dr. Shoukat Ali**”

No part of this thesis has been submitted anywhere else for any other degree. This thesis is submitted to the ‘**Faculty of Science**’, The Superior University, Lahore in partial fulfillment of the requirements for the degree of Master of Philosophy in the field of “**Chemistry**” in Faculty of Sciences at The Superior University, Lahore.

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Dedication

To

PROPHET MUHAMMAD (Peace Be Upon Him) and his Progeny

Blessing on whole Mankind

MY LOVING PARENTS

Whom

Prayers, love and guidance lightens my whole life

and are sources of inspiration for me

&

MY FAMILY

Without whom my life is incomplete

Acknowledgement

In the name of Allah, the most Gracious, the most Merciful.

All praises thanks for **Allah Almighty**, who bestowed us with the heart to feel and brain to think, so that we know, what we don't indeed. He is the best knower, the wisest, peace and blessing of Allah be upon **His Holy prophet Hazrat Muhammad (S.A.W.W)** who is the real role model for the mankind.

I feel highly indebted to my intellectual supervisor **Dr. Shaukat Ali** and guidance **Asif Hanif Chaudry** for their kind and affectionate attitude, guidance and keen interest throughout my research work. Their support has been instrumental in my success, I appreciate their mentorship and the opportunity they have provided. Thank you for believing in me and pushing me to excel. Their leadership has made significant impact on our teams' achievements. And I'm thankful for the trust they have placed in me and for their continued support.

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I dedicate my research work to my beloved and respectful father **Malik Muhammad Iqbal** for his countless prayers, salutary advices and emboldening attitude that kept my spirit alive. I am unable to show my gratitude to my loving and encouraging **Mother, Brother** and **Sisters** and my whole family. They are symbol of love for me, prayers, support, and encouragement provided by my whole family.

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List of Abbreviations

RHA	Rice Husk Ash
SCM	Supplementary cementing material
BFS	Blast furnace slag
Cao	Calcium Aluminate oxide
SiO ₂	Silicon Dioxide
MgO	Magnesium Oxide
MK	Metakaolin
LIO	Laser induced Oxidation
K ₂ O	Potassium Oxide
SO ₃	Sulfur Trioxide
TiO ₂	Titanium Oxide
Al ₂ O ₃	Aluminum Oxide
SCBA	Sugar cane bagasse ash
Na ₂ O	Sodium Oxide
EFA	Exploratory factor analysis
SF	Silica Fumes
Sox	Sulfur Oxides
NO _x	Nitrogen Oxides
ASR	Alkali- silica reaction
DTA	Differential Thermal analysis
TG	Thermogravimetry
XRD	X-Rays Diffraction
SEM	Scanning Electron Microscopy
RCPT	Rapid Chlorine Permeability Test

LC ₃	Lime Stone Calcinated Clay
A\C	Aggregate Cement
W\C	Water cement
RP	Recycled Powder
GO	Graphene Oxide
MIP	Mercury Intrusion Porosity
OPC	Ordinary Portland Cement
TEM	Transmission Electron Microscopy
FTIR	Fourier Transform Infrared Spectroscopy
XRF	X-Rays Fluorescence
HCL	Hydrochloric Acid
RCPT	Reinforced Composite Pipe Technology
PPC	Pozzolanic Portland Cement
AMLF	Acid Mass Loss Factor
ASLF	Acid Loss Factor
ADF	Acid Durability Facto
BCC	Blended Cement Concrete
CS	Compressive Strength
C-S-H	Calcium-Silicate-Hydrate
ASTM	American Society for Testing Material
BRS	Building Research Station
CTM	Compression Testing Machine

ABSTRACT

In Pakistan building industry, RHA is a good supplementary cementitious material for the production of concrete due to requiring low energy and negligible greenhouse gas emission during processing. Therefore, the presence of amorphous silica contents in RHA makes it highly pozzolanic reactive that can improve the mechanical property of concrete. This study is being designed to investigate the incorporation potential of supplementary cementitious material (RHA) in concrete to improve its compressive strength. Therefore, six different batches of RHA-blended concrete were prepared in order to cast the various concrete cubes and concrete cylinders. Then these poured concrete cubes and concrete cylinders were evaluated to determine their compressive strength at the age of 7, 14 and 28 days by CTM. It was observed from the obtained results that 1% anaerobic RHA-blended concrete cube and cylinder showed excellent compressive strength 3888 psi and 3240 psi against 3000 psi and 2400 psi at the age of 28 days respectively, which is almost 23-26% gained in compressive strength. However, the 1% aerobic RHA blended concrete cube and cylinder revealed outstanding early compressive strength 3666 psi and 3106 psi at the age of 7 days against 2000 psi and 1750 psi respectively, which is about 45 % in compressive strength gain. The surface microstructure analysis of concrete specimen was conducted through scanning electron microscopy. The SEM images revealed that the addition of RHA in concrete worked as a filler along with pozzolanic behavior to improve interfacial transition zone between cement and aggregate particles by making more refined dense structure.

Chapter 1

INTRODUCTION

Ordinary Portland cement is fundamental component of construction industry which serves as the binding agent in concrete. It is extensively used in various infrastructure development projects because it provides compressive and flexural strength to concrete. As the world population endures to cultivate progressively the demand of construction industry is rising extremely. Most of our construction system is very expensive and have some negative environmental impacts including elevated energy consumption and substantial greenhouse gas emissions. The production of cement emits a plenty of CO₂ in atmosphere. According to one estimate, cement manufacturing process produces 0.9 pound of producing one pound of cement. Cement is also costly material of construction industry but its production is not good for our environment due to releasing greenhouse gases. To address these concerns several studies were conducted to explore suitable alternative supplementary cementitious materials which replace conventional cementitious material. The use of these alternative SCMs enhances the durability stability of concrete, resistance power of concrete degradation and improve its strength.

Although cement is a frequently used material in the construction sector whereas High-performance concrete includes mainly ordinary Portland cement and an inclusive variety of extra materials which are commonly used in building sector [1]. It has been investigated that there are several Supplementary cementitious materials (SCM) that, when mixed with cement boost mechanical strength. (compressive and flexural strength). Most commonly used SCMs in concrete mixture are metakaolin, blast furnace slag, silica fume, laterites, fly ash, rice husk ash, nanomaterials, mixed cement, and sugarcane bagasse [2-4].

In new concrete qualities, mechanical strength assesses the growth of elastic modulus, strain owing to shrinkage compressive strength and flexural strength [5]. Conventional concrete like, blast furnace slag and fly ashes has been used for many decades to assess the effects on cement hydration and concrete behavior [6]. The physico-chemical properties of supplementary cementitious materials have a greater influence on their hydraulic or pozzolanic activity than their source. (Sersale 1993).

Arrangements of SCMs were based on their movement or performance in concrete (e.g., Mehta 1989) [7].

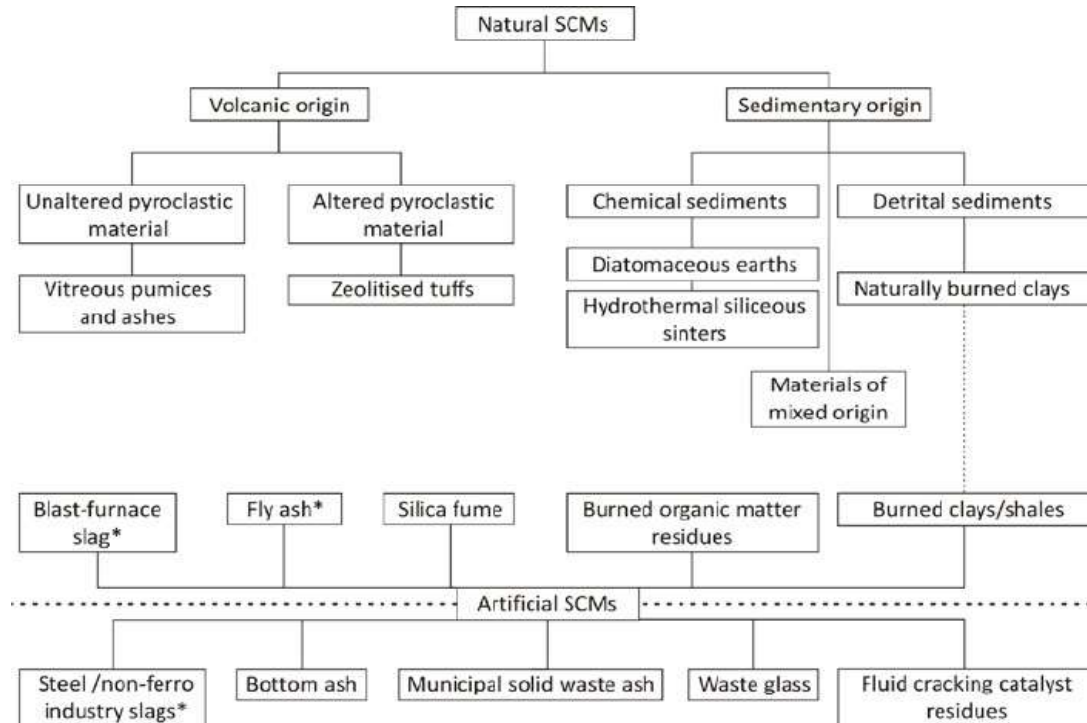


Figure 1 Classification for natural cementitious materials.

1.1 Blast furnace slag

Blast furnace slag was an industrial byproduct [8]. It was commonly utilized as a SCM in concrete due to its high hydration and large surface area. BFS was obtained from the iron-making process, and its physical and chemical qualities aided in the analysis of the cement hydration process [9]. The overall properties of BFS castoff aggregates in concrete were studied at high temperatures to assess their tensile strength, compressive strength, and elastic modulus. Recent studies suggested that recycling aggregates, BFS and other natural crushed stones could improve concrete quality [11].

BFS like other additional ingredients used in the building sector to improve cement potentials, boosted hydraulic belongings while also enhancing compressive strength and durability of concrete. The reactivity of BFS was determined by the characteristics of slag which varied depending on the slag source. Blast furnaces were

used to spray concrete for tunneling and underground construction. Blast furnace slag was a byproduct of the iron-making process. A combination of iron ore, coke, and limestone was heated in a blast furnace at 1500 degrees Celsius to reduce iron oxides in the ore. Molten iron collected at the bottom of the blast furnace. Due to its low-slung density, slag floated on top of the iron and separated easily in the skimmer. It was also concluded that using blast furnace slag as an alternate cementing material increased the uniformity of the concrete mixture. The use and efficiency of ground granulated blast furnace slag (GGBFS) in mortar and concrete production were investigated.

Due to its robust hydration properties blast furnace slag has been widely used as a supplementary material in cement and concrete. Research into the physical and chemical characteristics of blast furnace slag has provided valuable insights into the cement hydration process. The use of blast furnace slag as an alternative cementitious material was also explored, revealing that it enhances the uniformity of concrete mixtures. Incorporating pulverized slag into concrete offers several mechanical profits such as reduction in heat evolution increased strength and decreased chloride ion penetration. However, the importance of early treatment was emphasized to prevent potential negative effects. Additionally, the use of slag contributes to cost savings and reduced energy consumption in cement production [12-19]. Studies on the powered properties of concrete blended with pulverized slag at elevated temperatures have shown that its mechanical strength improves significantly by mitigating degradation.

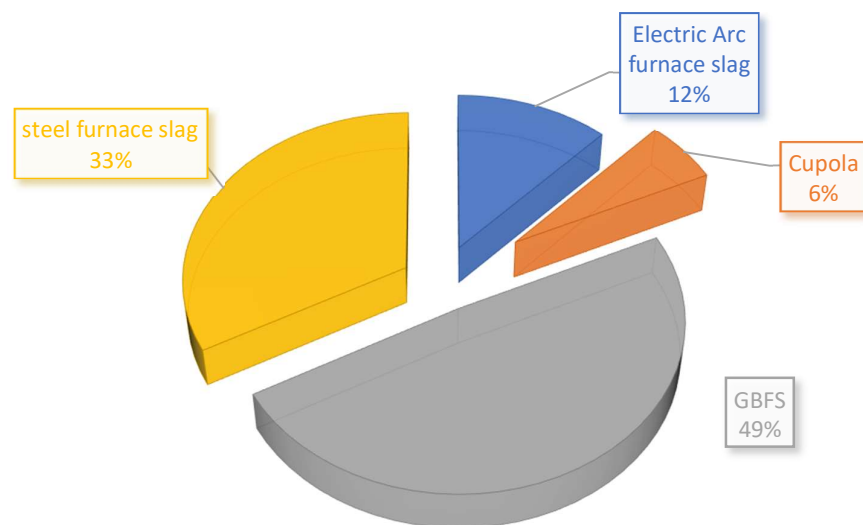


Figure 1.1 Sustainable construction material blast furnace slag [127].

Fast industrialization and development in developing countries have led to the generation of significant industrial waste which could be repurposed into eco-friendly building materials. This research explored the potential use of granulated blast furnace slag, steel furnace slag, electric arc furnace slag, and cupola slag in the production of infrastructure and concrete composites. The study demonstrated that waste slags have the potential to serve as sustainable building materials while also identifying gaps in the characterization of these materials. The work primarily aimed on the experimental viability and physico-mechanical behavior of these slag materials.

Table 1.1 Properties of blast furnace slag [20].

Sr.No.	Properties	BFS specification	Requirements
1	Unsolvable residue	1.5%	1.5% (max.)
2	Excellence (m^2/kg)	340	275(min.)
3	Sulfide sulfur	1.7%	2.00 (max)
4	Loss on ignition	1.0%	3.00 (max.)
5	Moisture content	1.0%	1.0 (max)
6	Chloride content	0.05%	0.10 (max.)
7	Glass content	90%	67 (min.)

1.2 Silica fumes

Silica fume was an industrial byproduct of silicon and ferrosilicon, consisting of tiny particles utilized as a supplemental factual in concrete. Owing to its fineness and huge surface area, it produced a reactive pozzolanic material. Silica fume improved concrete qualities such as mechanical strength, abrasion resistance, and impermeability, while also reducing bleeding and protecting the material from corrosion. It was demonstrated that the effectiveness of silica fume was not consistent

under all conditions. To assess efficiency, two approaches were used: the universal efficiency factor and the proportion efficiency factor [22].

Geopolymers and zero-waste materials were examples of building materials that protected finite natural resources while also overcome carbon dioxide emissions, thus helping to mitigate climate change. A scientometric review examined various findings from existing literature regarding the use of building materials. Silica fumes were found to improve material properties and offer environmental benefits. Geopolymers and zero-waste materials, which protect finite natural resources and reduce carbon dioxide emissions, were studied for their potential to mitigate climate change.

Portland cement was often replaced with readily available industrial waste, including slag, metakaolin, silica fumes, coal ash, and fly ash. It was shown that silica fumes were an exponentially pozzolanic substance. It was also concluded that incorporating ferrosilicon industrial by-products into concrete improved its mechanical properties. The accumulation of silica fume heightened the hydration process and, due to its high strength, enhanced the flexibility of the concrete. Silica fume consists of spherical particles with high pozzolanic reactivity and its extreme fineness significantly improved chloride ion resistance. The inclusion of SF in concrete contributed to early strength development, increased compressive and flexural strength, a higher modulus of elasticity, high bond strength, and overall durability. To maintain the desired slump, approximately 10% silica fume was incorporated to the concrete mix.

Portland cement was replaced with readily available industrial waste, including slag, metakaolin, silica fumes, coal ash and fly ash. It was discovered that silica fumes were an exponentially pozzolanic material. Furthermore, it was determined that the use of ferrosilicon industrial by-products improved the motorized goods of concrete. Silica fume reacted with lime in the presence of water, making it pozzolanic reactive and reducing concrete porosity. Due to its vast surface area, a high dose of silica fume increased setting time while decreasing workability [23]. Scientometric review methodologies were employed to assess various findings from recent literature on the use of construction materials.

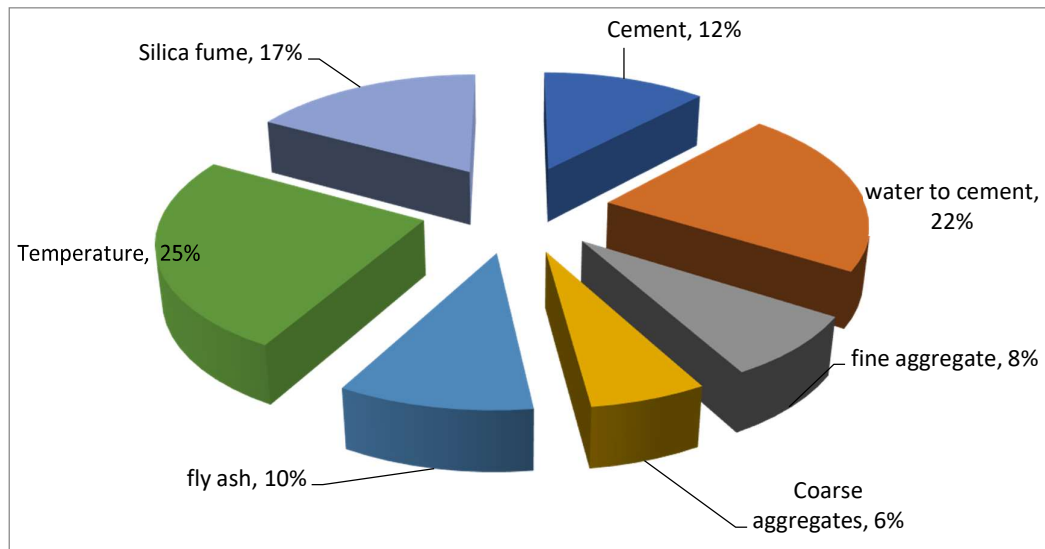


Figure 1.2 Permeability of self-compacting concrete with fly ash and silica fume evaluated [128].

Table 1.2 Feature and benefits of silica fumes

Feasibility of silica fumes	Benefits in concrete	Reaction in concrete	Commercial possibilities
Glassy (amorphous) spherical shape	Reduce steel corrosion. Grater abrasion and chemical resistance.	Lubricant ball-bearing effect	Reduce size and mass of element with higher strength
High SiO₂ contents (85%)	Reduced segregation and bleed. Reduced sprayed concrete rebound.	Extremely efficient improve tension zone between aggregates and paste.	Long service life for marine structure, easier pumping for tall building.
Ultra-small size (less than 1 micron).	Optimal high compressive and flexural strength.	Maximum particle packing. Reduce permeability	economical sprayed concrete

Silica fumes had a glassy and spherical shape with high silicon dioxide content. When mixed with concrete, they reduced abrasion damage, increased chemical resistance, and decreased segregation. Due to their lubricant nature and ball-bearing effects, silica fumes were highly effective in the tension zone between aggregates and paste, providing maximum particle packing and reducing permeability. In commercial applications, they helped increase the strength and extend the facility life of structures, as well as facilitated easier pumping in tall buildings. Silica fumes were mixed with recycled concrete to attain high performance.

The process of filling the pores of concrete floors with a chemical hardener was found to be reversible, as the distribution of particles varied. This process showed significant proportions and specific measurements between 10-100 μm . The formation of masses and collections of particles affected the size of the silica fumes. Cracking in concrete could occur when tension developed, leading to serviceability and durability issues. Research indicated that adding silica fume to concrete significantly enhanced its mechanical properties. However, determining the optimal percentage of silica fume substitution to achieve maximum concrete strength remained an ongoing investigation.

Silica fume, with its glassy, spherical shape and high silicon dioxide content, reduced abrasion damage, increased chemical resistance, and minimized segregation in concrete. Its lubricant-like nature and ball-bearing effects amend the tension region between collections and paste, subsequent in optimal particle packing and reduced permeability. In commercial applications, silica fume contributed to increased strength, longevity of structural elements, and facilitated easier pumping in tall buildings. The accumulation of silica fume accelerated the hydration process, leading to greater flexibility due to its high strength. The highly pozzolanic spherical particles of silica fume significantly impacted chloride ion penetration, enhancing early compressive and flexural. Approximately 10% silica fume was added to concrete to maintain the desired slump [25-30].

1.3 Metakaolin

Metakaolin was a natural by-product obtained from heating kaolin, typically appearing grey-white in color [31]. It is a type of clay formed through the calcination

process, requiring temperatures between 600-900°C to produce metakaolin [32-34]. As the demand for concrete increased due to global population growth, metakaolin's cementing ability made it an appreciated alternative material. Its use as a supplementary material provided environmental benefits and reduced concrete production costs.

Metakaolin, a dehydroxylated form of the clay mineral kaolinite, has been utilized in ceramics production and as a supplementary material to partially swap cement in concrete. Typically found in particle sizes of 1-2 μm , metakaolin particles are larger than those of silica fume, largely due to its significant surface area. Since the 1990s, metakaolin has been used in concrete to enhance automatic properties and durability. In concrete mixtures, metakaolin typically replaces 5-20 wt.% of cement, offering greater reactivity compared to silica fume and improving workability, strength, and permeability. Additionally, metakaolin helps protect concrete from cracking and shrinkage. Various studies have determined optimal values and characteristics, including the ratio of metakaolin to concrete, the surface area of metakaolin, its pozzolanic reactivity, and the resulting CS of concrete. Derived from heating kaolin, metakaolin presents a valuable alternative as global demand for concrete rises, providing environmental benefits and reducing production costs.

Table 1.3.1 Physical and chemical properties of Metakaolin

Sr. No	Physical properties	Chemical composition	
1	Off-white in color	Lime (CaO)	0.39%
2	Have explicit gravity (2.6)	Silica (SiO ₂)	96.88%
3	Bulk in density (800kg/m ³)	Fe ₂ O ₃ and Al ₂ O ₃	0.28%
4	Normal in particle size (1.5 μ)	Magnesia (MgO)	0.08%
5	Fineness (1500m ² /kg)	Insoluble residue	1.69%

The incorporation of metakaolin into concrete mixtures served as a cementitious material. Due to its low-cost production and easy availability the practice of metakaolin as a cementing material increased. Several studies highlighted the beneficial impacts of metakaolin on the mechanical and durable qualities of cementitious materials. When metakaolin was added to calcium hydroxide a new cementitious compound formed which enhanced compressive strength.

As global demand for concrete increased with the rising world population, the cementing ability of metakaolin as an alternative material gained prominence. Its use as a supplementary material provided significant environmental benefits and helped inferior the cost of concrete production. The highly pozzolanic material metakaolin remained stable under normal environmental conditions and improved both compressive and flexural strength. Additionally, it reduced shrinkage and permeability. Investigations also found that partial replacement of cement with metakaolin contributed to reduced environmental damage.

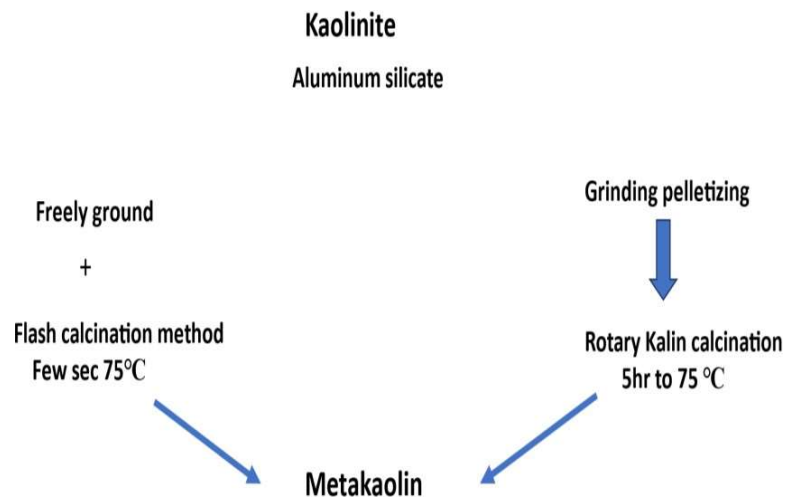


Figure 1.3 Manufacturing process of Metakaolin

Metakaolin is highly pozzolanic and stable under normal environmental conditions enhancing both compressive and flexural strength while reducing shrinkage and permeability. Studies have shown that partially replacing cement with metakaolin

can help mitigate environmental damage. When incorporated into concrete mixtures metakaolin acts as a cementitious material. Its low production cost and easy availability have led to increased application in construction.

Both poor and highly reactive kaolin have been tested at various temperatures and durations with evidence suggesting that even poor kaolin can produce highly reactive metakaolin. In the construction industry metakaolin is used as a supplementary material to diminish the permeability of hardened cement and decrease emissions. Its use not only provides environmental benefits but also contributes to cost reduction in concrete production [35-36].

Table 1.3.2 Chemical composition of MK [36].

Chemicals	Percentage (%)
SiO₂	62.62
Al₂O₃	28.63
Fe₂O₃	1.07
MgO	0.15
CaO	0.06
Na₂O	1.57
K₂O	3.46
TiO₂	0.36
LOI	2.00

Cement was substituted with up to 20% metakaolin (MK). The presence of MK reduced capillary action which is the entry of water into pores [37]. Increased humidity can lead to durability issues, but reduced absorption improves as MK levels rise mitigating capillary action [38]. The pore structure of concrete provides a reliable method for measuring the rate of absorption and this process is well documented [39-51]. Cement was partially replaced by MK at varying percentages and elasticity testing of cylinders of different sizes was conducted. Metakaolin improved the compressive and flexural strength of concrete. Consuming supplementary materials like metakaolin in concrete helps address environmental and economic concerns associated with cement production [52].

Table 1.3.3 Physical properties of MK [52].

Facts	Values
Arrival	Off-white powder
PH (10% solids)	4.0-5.0
Bulk thickness (kg/1)	0.4-0.5
Specific gravity	2.6
Loss of ignition	1.5
Lime reactivity	1050mg Ca(OH) ₂ /g

1.4 Laterite

Laterite was a soil type with high levels of iron, silica, and aluminum oxides, as well as a high concentration of residual products [53-57]. Laterite was employed as a precursor in the synthesis of viable geopolymers [58]. In recent years traditional erection materials such as stone, bricks, and concrete blocks were replaced. The usage of soil blocks could be well-organized yet defects in water absorption, strength, and durability prevented their widespread adoption in the construction industry. Without external stabilization, compressed soil blocks were unstable and had limited strength, limiting their use in areas with high rainfall [59-60]. Laterite soil appeared extensively over a vast surface area based on physical nature, chemical and geological characteristics that pivot different elements like origin process, atmosphere, surface attributes, and weathering that impacted these factors [64-74].

Laterite soils sometimes had unfavorable physical and chemical properties like standard gradation, low ratio, and high plasticity not always abiding by the specifications of high-volume roads [76]. Sand affected the cement properties which engaged the blocks. The use of these blocks was produced to determine density and tensile strength [77]. The use of lime for neutralization helped investigate the mechanical and thermal properties. Lime was an important factor for representing cement growth. For overall accessibility the global laterite emerged as a highly skilled choice for alkali-polymer binder manufacturing [78]. The durability and compressive strength of laterite cement contributed to the low permeability of soil content and

resistance to magnesium sulfate solution [79]. Initially, the actual strength of the cement reduced over the first three days due to the slow onset of the pozzolanic response, but it gradually increased over time [80].

Table 1.4 Physical properties of laterites [81].

physical properties	Laterite Aggregates
Moisture contents (%)	0.52
Aggregates impact values	28.70
10 % fine values	10.20
Aggregate crushing value	30.70
Specific gravity	2.54
Elongation index	8.00
Flakiness index	8.50
Water absorption	1.07

1.5 Fly ash

Fly ash is a finely separated scum are made during the burning of coal in exhaust gas chambers. Its pozzolanic reactivity is attributed to the conditions under which it is burned and the collection process [82]. The use FA in hydraulic cement has been explored for various construction applications [83]. Incorporating fly ash with high fineness and low carbon foot prints in concrete decrease water demand, improves workability, and minimizes issues like cohesion and segregation [84].

Table 1.5.1 Physical requirements of fly ash [85].

Sr. No.	Characteristics	Requirements
1	Soundness by auto- calved test expansion in % (max.)	0.8
2	Strength movement index with Portland cement in 7 and 28 days in % (min.)	75
3	Water requirements in% control in max.	105

4	Partial retained on 45 microns %	34
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To find the compressive strength of FA both assembled and non-assembled machines were used. Machine learning was utilized for testing the material used as a waste product (fly ash) providing accurate information and precise data. This study collected appropriate data described the study and helped to understand the methodologies involved. Fly ash could replace concrete by about 13-15%. Various studies were conducted on the mechanical and structural properties of concrete. These studies helped improve the reactivity of aggregates, protected against corrosion reduced costs and increased the durability and strength of material in construction systems.

Table 1.5.2 Chemical composition of fly ash used

Sr.No.	Composite	Content % wt.
1	LOI	4.62
2	K ₂ O	0.90
3	SO ₃	1.00
4	MgO	1.40
5	CaO	6.90
6	Fe ₂ O ₃	3.70
7	Al ₂ O ₃	21.00
8	SiO ₂	59.00

Fly ash was the exceptionally separated residue gained from the combustion process of coal and exhausted gases chamber. It was obtained from burning conditions and its collection mechanism made it pozzolanic reactive. Fly ash substituted the structure of cement paste which helped improve the durability of concrete. Some contents of calcium hydroxide present in it improved strength. When minerals were added to concrete, the setting time typically increased, but it was the opposite with fly ash as fineness increased, the setting time of cement decreased.

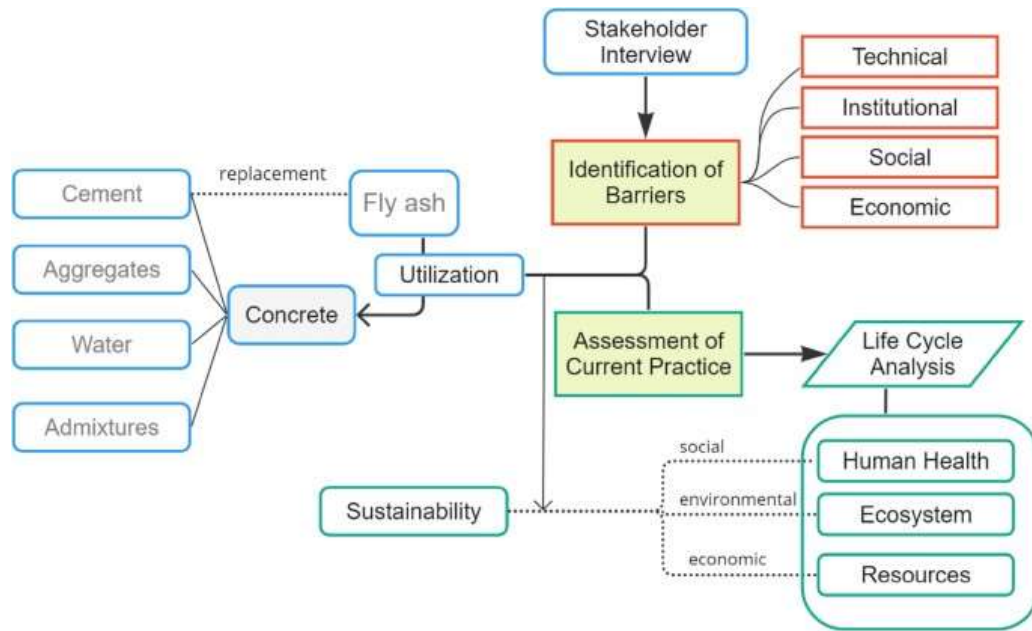


Figure 1.5 Consumption of fly ash in concrete (2023) [86].

Fly ash can put back concrete about 13-15%. Different studies executed about powered and structural properties of concrete. It helps to improve the reactivity of aggregates and protect from corrosion resistance, reduce cost and increase durability and strength of concrete in construction system [87].

1.6 Nano-material

The use of various nanoparticles such as Nano TiO_2 Nano Al_2O_3 Nano Fe_2O_3 and Nano ZrO_2 as partial replacement materials in concrete had a extensive impact on the compressive strength of the hardened concrete matrix [88]. Investigating compressive strength and resistance in nanomaterial concrete is the aim of this work. This also aids in the investigation of raw material concrete concrete mix designs (usage as a Partial substitute material and the ability of nanomaterial concrete to withstand sulfate assault were also investigated [89]. The application of nanomaterials in concrete underwent numerous concentrations to improve traditional concrete qualities. The size of the nanomaterial employed should be less than 200nm. Due to their nano size the applications should be estimated at 500nm. When nanomaterial is added to concrete it reduces cement content while increasing the binding effect. Nano silica, nano alumina, carbon nanotubes, polycarboxylate, nano clay and nano kaolin were all

employed in nanomaterial concrete [90]. Nanoparticles, such as nano-iron contributed to increased strength and the strongest match potential. Nano silica caused low resistance and issues. Nano-titanium was employed as a self-cleaning agent in concrete [91]. Nanotechnology raised awareness of nanomaterial properties and discovered better techniques to build progressive materials [92].

Table 1.6 Some utilization of nanomaterial in construction industry

Sr. No.	Nanomaterial used	Applications in construction	Properties	References
1	Al ₂ O ₃ nanoparticles	Asphalt concrete	Increased serviceability	[93]
2	Carbon nanotubes	Concrete	Crack prevention	[94]
3	Titania nanoparticles	Concrete	Self-cleaning, increase hydration	[95]
4	Silica nanoparticles	Concrete	Reinforcement of strength	[96]
5	Copper nanoparticles	Steel	Corrosion resistance	[97]
6	Iron oxides nanoparticles	Concrete	Increase compressive strength and abrasion resistant	[98]
7	Clay nanoparticles	Bricks and mortar	Increase surface roughness and compressive strength	[99]

When nanoparticles were introduced to cement the durability of the cement increased. In several studies the experimental study required that the size of nano material be less than 100 nm when mixed with concrete. Because of the occurrence of various particles in concrete the microstructure of nano-silica became solider and additional consistent than that of ordinary concrete [100].

1.7 Sugar-cane

Plant residue after juice extraction is a byproduct of the biomass combustion process from waste plants. Waste was collected rinsed in a water tank, sun-dried and converted into ash at temperatures up to 600°C. Approximately 600 million tons of sugarcane trash were acquired. The addition of biomass to cement increased its strength and durability while also exhibiting pozzolanic activity due to the presence of oxides [101-104]. Sugarcane derived from sugar was widely employed in the production of alcohol bioethanol and industrial bioproducts [105]. To create a commitment that absorbed less energy and released less energy as well as to develop a structure that would function effectively over time it was possible to replace bagasse in cement material. This improved cement quality while lowering construction costs. Ash comprised 51% cellulose 26% lignin, and 26% hemicellulose which boosted the workability of cement and the compressive strength of the material by approximately 5%. However, as the percentage of material increased, compressive and tensile strength fell [106].

Sugarcane bagasse was a tropical and subtropical crop. China was the world's third major producer of sugarcane producing 2 million tons each year. Sugarcane was utilized in fertilizers, geopolymers, ceramic raw materials, $\text{Fe}_2\text{O}_3\text{-SiO}_2$ nanoparticles, silica aggregates, nonporous silica aggregates to remove Cr [107-115]. Lightweight aggregate such as sugarcane bagasse had good pozzolanic reactivity comparable to RHA and many studies were conducted on its applications in cementing materials. Many ventures were launched, including conventional concrete, high-performance concrete, self-compacting concrete, recycled aggregate concrete [116-119].

In the laboratory researchers discovered that the majority of bagasse pyrolysis produced 33-28% of charcoal for fuel compacted blocks and particles. The heat of combustion exceeded the limit of carbocation. A revolving drum was necessary to dominate due to the large quantity of small particles and fiber structure in bagasse. Two-stage approaches were utilized to combine a furnace closed pyrolineous vapor, and a heat carrier system to regulate carbon monoxide emissions [120]. Bagasse could be utilized as an alternate wood source for charcoal production, despite having a relatively high thermal value of 18.5 kg and a moisture content of 11.9%. However,

bagasse and cane waste had significant disadvantages as fuel. In densely occupied zones bagasse-fired boilers could provide a substantial health danger due to airborne fly ash. Implementing appropriate emission control measures was a crucial step towards pollution mitigation. To combat excessive emissions under professional supervision, boilers and associated equipment had to be operated and maintained efficiently [121].

Table 1.7 Physical properties of sugar-cane bagasse powder [122].

Sr.No.	Physical parameters	Sugar-cane bagasse powder	Treated sugar-cane powder bagasse
1	Specific gravity	0.6	0.55
2	Bulk density	0.54	0.51
3	Porosity	61	69
4	Surface area	16	18
5	Avg. particle size	0.7	0.65
6	Moisture content	55.7	51.4
7	Loss in ignition	91.6%	91.22%
8	Al ₂ O ₃	2.3%	2.3%
9	SiO ₂	1.1%	1.1%
10	Fe ₂ O ₃	0.23%	0.23%

To pick the ideal energy crop and convert it into biofuels critical aspects such as suitability and cost-effectiveness must be considered [123]. In the sugar alcohol sector, a wide range of residual attributes exist. Various investigations have shown that sugarcane bagasse could be used for small-scale pyrolysis whereas other feedstocks were not suitable for large-scale pyrolysis. Large-scale applications were employed to manufacture biofuel feedstock. Bagasse pyrolysis produced a diverse spectrum of compounds that could be used as fuels and chemicals [124].

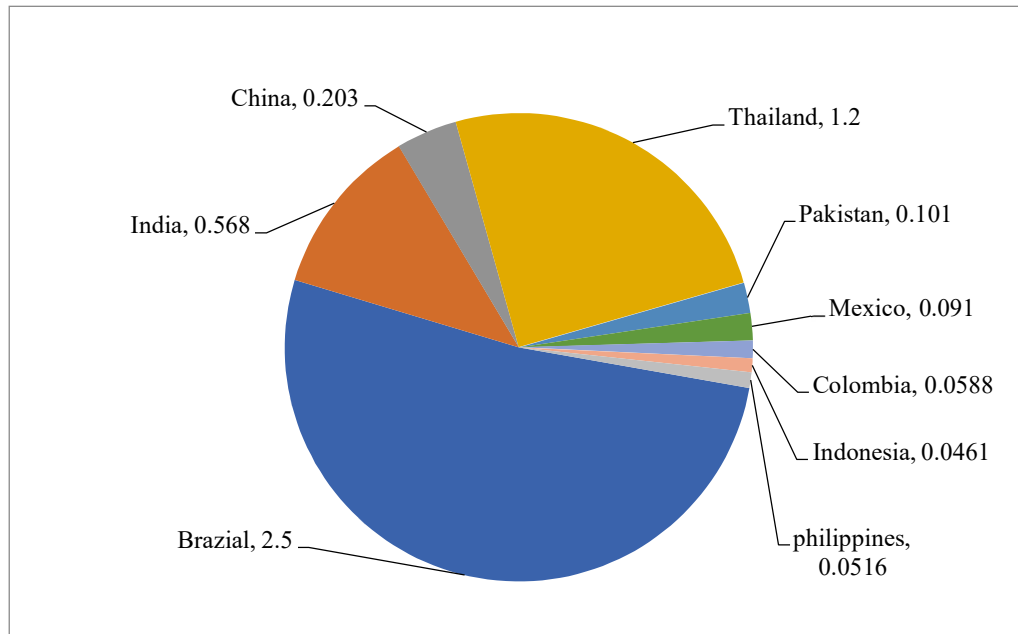


Figure 1.7 Utilization of SCBA as cement [125].

This work contributed to the investigation of sugarcane bagasse's use as a cement substitute in the building sector as well as its characterization and response mechanism. The SCBA affected both the new and tough state properties such as strength, modulus and resistance to adverse environmental effects [126].

1.8 Blended cement

The study of chloride corrosion began three decades ago when the demand for infrastructure led to increased use of reinforced concrete. The use of by-products from other industries for cement manufacture reduces emissions while conserving natural resources through aggregate replacement waste material recycling and water in concrete production. This type of cement significantly affects chloride ions influencing the deformational properties of concrete in blended cement [127]. Blended cement is created by substituting cement powder for several types of conventional Portland cement. The hardened mixed cement is stored under tap water for various periods of time. The composite materials are more resistant and durable than neatly integrated cement materials. Hydration of blended cement with 32 wt.% Na_2O and CaO helps to represent alternative auxiliary materials and can also be used to reduce emissions [128].

In ceramic materials clay roof tiles and Portland cement are suited for fine materials. Thermally treated clay was one of the first clays studied as a pozzolanic material. Material is eliminated for various reasons including the use of non-accurate temperatures mechanical and dimensional failure and reduced durability. The morphology of pozzolanic material and clay Portland cement is nearly the same and the hydration phases are studied using scanning electron microscopy and XRD techniques. The use of a blended cement binder reduces the environmental footprint of emissions produced during cement manufacture. To achieve better results thermal analysis, microstructural analysis, EDS analysis and testing are essential.

Table 1.8 chemical composition-based EDS analysis of blended cement [129].

Elements	Mass (%)	Atom (%)	Mass (%)	Norm	Abs.error(%)	Rel.error(%)
Titanium	0.6	0.73	0.96		0.04	0.77
Sulfur	0.7	0.38	0.5		0.04	1.55
Iron	1.50	5.0	9.23		0.06	4.66
Calcium	2.38	11.34	14.32		0.2	4.04
Potassium	0.71	3.38	4.19		0.07	6.84
Silicon	7.88	52.3	47.99		0.38	4.55
Sodium	0.13	0.96	0.74		0.05	29.06

1.9 Reduction of concrete

Environmental consequences in concrete have been a major topic of attention due to the need for sustainability in concrete production. CO₂ emissions are used to determine concrete production characteristics and to assess environmental impacts. Investigations focus on cement and cement replacement materials such as blast furnace slag, metakaolin, rice husk ash, and blended cement etc. Concrete and distributed steel, two key construction materials, account for 65% of building greenhouse gas emissions, with emissions from critical construction materials making up 40% of the total [130, 131]. Victor et al. (2008) established strategies for

minimizing emissions in low-cost concrete roads and bridges using U-shaped sections [132].

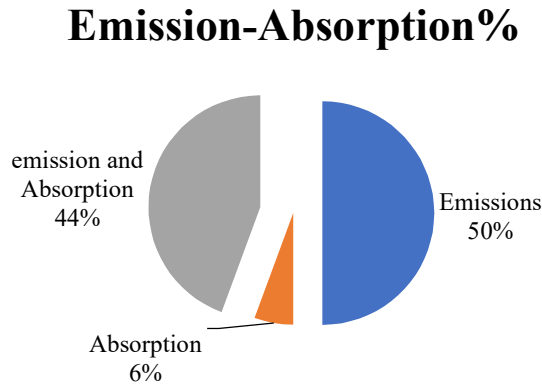


Figure 1.9 emission-Absorption in concrete for precast [133].

The figure depicts emission and absorption in concrete as percentages. If precast concrete production were examined, the absorption would be 6% and the emission would be 44%, resulting in a total of 50% emission and absorption.

Building on the research conducted on the use of fly ash, blast furnace slag, metakaolin, and other cement replacement materials, this learning purposes to explore the cementitious properties of rice husk ash which contains amorphous silica obtained from agro-industrial processes. RHA can serve as a supplementary cementitious material, with the replacement level carefully controlled to ensure it does not adversely affect the fineness mix proportions long term durability or serviceability of concrete. The amorphous silica in rice husk ash makes it pozzolanic reactive and an effective filler. Therefore, this research will investigate the cementitious properties of RHA, leveraging both its pozzolanic reactivity and filler effect. Incorporating RHA into cement not only reduces the environmental footprint but also offers potential benefits in terms of enhanced concrete performance and durability.

AIMS AND OBJECTIVE

The Aim and objective of this study is to clarify the application of rice husk ash as an additive to cement-based composites. It aims to give a thorough understanding of how rice husk ash affects concrete's durability mechanical qualities and environmental performance. The results should help advance the usage of eco-friendly materials in the construction sector and promote sustainable construction practices in the future.

Chapter 2

LITERATURE REVIEW

Lee *et al.*, (2019) has demonstrated that the long-standing practice of using blast furnace slag in the auxiliary of cement and concrete could promote sustainable development in the building sector. Due to its low hydraulicity and volumetric expansion problems, steel manufacturing slag is the second-largest waste of the steel industry is frequently utilized as a plaster material in the construction of embankments. On the other hand, new advancements in the steel-making process's quenching and selective separation have improved the slag's quality. Studying methods for turning steel-making slag into a more valuable product like adding it to concrete becomes more and more important as a result. The mechanical properties of concrete, comprising steel-making slag, granulated blast furnace slag and EAF oxidizing slag, were assessed in order to determine whether employing this slag as a binder was feasible.

The study inspected the slag concretes' compressive strength, split-cylinder tensile strength, shrinkage, and beginning and final setting times. The findings demonstrated that while substituting EAF oxidizing slag for cement overdue the hydration reaction at an initial age, it had no appreciable effect on shrinkage or strength development during the setting time [134].

Qingsen *et al.*, (2023) has stated that GBS slag was extensively employed in the cement and material of industries because of its superior hydration qualities. However, the steel and cement industries had a large capacity gap which resulted in a shortage of GBFS to fulfill the increasing demand. There weren't many studies at the time that concentrated on creating cementitious materials with characteristics akin to GBFS and there wasn't a thorough summary of the underlying mechanisms either. A specialized review attempted to fill that gap by characterizing the physical and chemical features of GBFS and thoroughly investigating its hydration progression in cement. The study also looked into the synergistic impacts of GBFS on numerous solid wastes such as other materials. The analysis discovered four strong synergistic paths between these medicines. Furthermore, the review presented a technique of consuming

solid waste as rare materials to manufacture a composite GBFS, which could provide a solution to the supply-demand imbalance.

[135].

Baijat and coworkers (2019) demonstrated that by Using Fine Blast Furnace Slag as a fractional extra material for cement improved the concrete's characteristics dramatically. In one study, BFS was used to substitute cement in concrete in various quantities, including 11%, 15.5%, 21%, 25%, and 31%. The findings indicated improvements in both renewed and hardened concrete characteristics.

The highest work process evaluated by slump and table tests was achieved with a 30.5% BFS addition. The VEBE-time which represents concrete's workability, decreased to about 4 seconds at 30.5% BFS, whereas the compaction feature peaked at 99% at 25% BFS. Adding 30% BFS resulted in a maximum fresh concrete density of 2180 kg/m³ and a hardened concrete density of 2430 kg/m³. The concrete had a maximum unit weight of 24 kN/m³ at 30.5% BFS. The concrete reached its specified strength in 1 week and 28 days, with even higher strengths at 56 and 84 days. Furthermore, applying BFS increased the bond and flexural loads [136].

Renan *et al.*, (2019) have demonstrated that replacing cement with tastes is critical for producing scattered concrete with the required motorized properties and endurance. However, the tunnelling lining is limited in BFS manufacturing due to its low reactivity. For the fractional replacement of cement, the chemical and mechanical properties of concrete of cement made from cement and BFS. By using isothermal calorimetry X-rays diffraction and temperature evaluation the hydration of kinetics has been investigated. On extracted cores the compressive strength test and needle penetration resistance were determined. Once the evolution class is founded the blast furnace slag is employed in spurted concrete applications [137].

Erdogan *et al.*, (2016) has illustrated GGBFS a derivative of iron blast furnaces has shown to be very useful in the manufacturing of mortar and concrete. The current study looked at the available literature on the application and usefulness of GGBFS in improving mortar and concrete properties. Over-all material around GGBFS synthesis the hydration process was obtained firstly. The researchers then examined fresh concrete structures such as workability, background time, exploiting, rheological

properties, crash loss, isolation confrontation, initial age rapid latent, and texture aptitude. [138].

Chishi *et al.*, (2023) has shown that technologies like geopolymers existing, zero-waste and the circular low-cost may be cast-off to shield limited ordinary possessions diminish emissions and address climate change. These materials totally replaced Portland cement with excess industrial materials like slag, metakaolin, silica fume, coal ash, and fly ash. These alternatives provide not only natural resources but also used as supplementary material so that this study focused on the highly pozzolanic material such as SF as a byproduct in industry that is used to improve mechanical properties durability of concrete. Portland cement is mixed with silica fumes or should be used in concrete directly. There results reveal that the substantial improvement in concrete by the addition of silica fumes into it so this is revealed that by adding silica fumes into concrete it will enhance their mechanical properties of concrete, so that is also a conventional method and used as high performance of concrete. Silica fume can be blended with silica dust and Portland cement or used directly in concrete. This study helps to examine the effects of silica fume on concrete workability, flexural strength and microstructure analysis [139].

Rahul Kumar (2023) has shown that the growing demand for infrastructure in both emerging and wealthy countries necessitated massive volumes of cement, with serious consequences for the environment and human health. These included greenhouse gas emissions (SO_x, NO_x, and particulate matter), as well as serious respiratory disorders like asthma and silicosis. To address these issues, lowering cement consumption in construction materials became critical. Recently, several unique auxiliary materials have been introduced to increase plaster and concrete performance. MK has become a popular cementitious material due to its ease of availability and low manufacturing costs. The article highlighted the compensations of metakaolin for the mechanical and durability properties of cementitious materials. Metakaolin reacts with calcium hydroxide to generate more cementitious compounds, which increases strength. It helps to improve the porosity and microstructure by decreasing permeability and transition zone. Enhanced the microstructure by decreasing porosity and expanding the interfacial transition zone [140].

Khan and coworker (2011) have indicated that, with growing environmental consciousness and concerns about harmful consequences, using industrial by-products has become an appealing option to removal. SF is a byproduct and made up of highly reactive pozzolanic material that help to enhance properties of concrete. By the addition of about 10-25% silica into concrete it will boost its flexural, mechanical and tensile strength because of its smelting process in the silicon in industries has shown that it is an incredible material for the development of high manufacturing performance of concrete. The physical and chemical properties of silica fume were described, as well as the reaction mechanisms. It helps to find out the effect of silica fume on concrete different parameters including permeability, resistance to freezing and corrosion, sulphate resistance, carbonation, and alkali-aggregate interactions [141].

Rafat Siddique (2011) has claimed that a variety of industrial by-products are produced, and with increased environmental awareness of their potential hazards, using these by-products has become an appealing other to disposal. Silica fume (SF) is a byproduct produced during the process of smelting in silicon industries. Silica fume has proved that the high-performance concrete has quite effective in development [142].

Pedro and coworker (2017) have considered that to conserve finite natural resources, reduce emissions, and to address these climate changes the material such as geopolymer and waste solutions were utilized for circular economy. These are the approaches that can change completely PC into waste material that can be used as supplementary material in concrete mixture. These are the substitutions that are not only easily available constituents but also lead to concrete that was commonly tougher and more durable than average combinations. The authors discussed the use of silica fume as partial replacement of cement that are finded as particle size which is 10 time fine than cement which is used to enhance all the properties of concrete. This study looked at the physical and chemical features of silica fume as well as its reaction mechanisms. The overall results shown that the use of silica fume in concrete as supplementary material help to enhance the mechanical strength of concrete and also its physical and chemical properties as well. Then the analysis should offer that the rapid estimation of simple proportion of SF replacement for high strength concrete

mixture. So that it has been looked that how silica fume can affect concrete workability and compressive strength [143].

Boddy *et al.*, (2000) has proposed that dissimilar types of silica fume such as compressed and slurried were used to improve transference and behavior properties over undensified SF. The effects of different SF can be produced on resistance to alkali-silica reaction expansion were examined by using concrete tests and paste pore solution analysis. The mixes examined consisted of 4.5%, 8.5%, and 12% SF replaced by mass of cement with standard Portland cement mixtures. At insecure SF replacement levels 4.5% performance according to that type of SF were employed. However, at longer additional levels (8.5% and 12%) were no important differences in the results of concrete prism expansion tests up to 1 year analysis among the 3 SF kinds were examined. The mortar bar test discover at all substitution levels has revealed that the undensified SFs more successful at regulation and expansion of reactive siliceous limestone aggregate [144].

Budogiannis *et al.*, (2005) demonstrated that Metakaolin concrete integrate as a mineral admixture that can improve mechanical properties and durability related to conventional concrete. These all techniques not only increase environmental concerns but also enhance its strength which are related with production of cement. These samples were heated at various temperatures for different times. These approaches includes that the calcination conditions by using XRD examination of raw material which can treat thermally of kaolin solution and analyze the pozzolanic movement of the final resulting metakaolin and also evaluate the strength development in cement combinations of MK.

This study helps to discover that the heating kaolin at low quality with low alunite contents at 650°C for 3 hours that resulted in extremely reactive metakaolin. However, for kaolins with important alunite concentration for 3-hour the thermal treatment at 850°C was necessary to remove unwanted SO₃. These findings demonstrate the that low-quality kaolins might be efficiently used to make highly reactive metakaolin [145].

Akbbar and co-worker (2012) has revealed that the durability of concrete is important for construction industry guessing properties as a high-quality pozzolanic material. The protentional use of MK is rarely produced and used in the Middle East

due to a lack of experimental indication. To fill this space the resident kaolin with a high kaolinite content was thermally processed at 800°C for 60 minutes in a modified furnace to yield metakaolin. The locally manufactured metakaolin were evaluated for compressive strength Permeability test and Concrete mixtures containing RCPT and electrical resistivity at 7, 28, 90, and 180-days microstructure of cement. The morphology of metakaolin was also investigated using XRD and SEM techniques. This study helps to examine the metakaolin additional fractions of 0%, 10.5%, 12%, and 14.5% by mass with water ratios of 0.35, 0.4 and 0.5 and a constant total folder content of 400 kg/m³. These results showed that metakaolin-containing concrete had improved compressive strength and durability as well as summary chloride diffusion. A link was found between chloride absorptivity and compressive strength as well as a significant linear association between the RCPT and salt ponding test findings [146].

Naili and coworker (2019) has suggested that the mineral blending have been used as adjusting additives multi-component has become a key trend in the expansion of Portland clinker based and non-clinker cements. There is a technical and manufacturing concentration in alkali activated folders that should be considered as environmentally and technically hopeful in inorganic materials. This improvement is being driven by developments in the construction and processing technologies of a broader range of mineral materials derived from both natural and waste sources as well as the ongoing development of the useless material base for alkali-activated materials. This paper examined metakaolin based cements containing mineral supplementary materials that concentrating on the raw materials used in these additions these characteristics of the reaction products qualities and the formation processes. It also looked at the many types and classifications of mineral additives utilized in alkali-activated metakaolin cements, as well as the possibilities for the improvement in structure and attributes of these alkali-activated metakaolin [147].

Alice and coworker (2019) has studied that the Metakaolin as a supplemental cementitious material has been the subjected the intensive research over the last two decades. Despite its relatively high cost primarily owing to limited worldwide manufacturing volumes metakaolin remains less expensive than Portland cement. However, the industry has been sluggish to use metakaolin in concrete applications. This important perspective was compared to the results of a study done in South Africa's Western Cape province which are evaluated the durability of metakaolin

concrete that are constructed with local resources. The concretes were made with three different water-binder ratios with metakaolin replacement levels of 0%, 10%, 14.5%, and 21%. The findings revealed that increasing metakaolin concentration greatly enhanced the transport qualities of the concrete, reduced ASR expansion from highly reactive local aggregates to non-detrimental levels, and had no negative impact on carbonation resistance. As a result, metakaolin was shown to be an effective SCM for improving concrete durability in tough local conditions [148].

Thankam *et al.*, (2020) has revealed that the traditional homogeneous cement has long been used in building, it is now being augmented or replaced with supplemental cementitious materials (SCMs). Metakaolin is a mineral additive generated from kaolinite ore has been found to improve the internal zone by increasing the packing of particles of cement aggregates. This enhancement results in decreases bleeding resulting into denser and uniform transition zone of microstructure. This paper examined the impact of metakaolin, a pozzolanic substance, on the fresh and hardened characteristics of concrete when employed as a fractional cement replacement. It also investigated the properties of high-performance concrete and self-compacting concrete using metakaolin [149].

Bukhari *et al.*, (2013) has revealed that there has been an increasing attention in using different industrial wastes byproduct and other materials as supplemental cementing materials which including crushed granulated blast furnace slag silica fume and fly ash. This study was done to evaluate the performance of laterite as an SCM with an emphasis on the compressive strength of blended cement with laterite percentages of 2.5%, 5.1%, 7.1%, and 10.1% by weight. This study helps to determine the effects and the laterites that are chemically depends on cement their qualities such as setting time of cement and insoluble residues with free lime. The compressive strength of all the cement cubes tested for 7, 14 and 28 days. This has been shown that the laterite with blended cement increase its strength has been used as supplementary material [150].

Laiwu *et al.*, (2009) has studied that in order to ascertain if laterite-cement mixes are a financially viable building material, the study assessed the variations in compressive strength in these mixes. The objective was to ascertain the top cement content limit that would result in a premium mix with the best strength as well as the

small amount of cement content needed to achieve sufficient strength for construction applications. Thirteen distinct mixes were made with cement contents that varied in 2% increments from 0% to 24% of the weight of the laterite. 100 mm cubes were molded using each combination and they were allowed to cure for 7, 14, 21 and 28 days. Twenty cubes were made by hand for each mix for a total of 260 cubes. At each curing interval, the CS of five cubes from each mix was measured, and the average strength was determined. Under laboratory circumstances with windows and doors open to allow for adequate air circulation, the curing process was carried out. According to the findings, compressive strength rose up to a cement content of 20% but decreased over that point. Furthermore, it was found that in order to obtain sufficient strength, the cement component in the laterite had to be at least 10% of its weight [151].

Dele *et al.*, (2021) has revealed that the Clay soil and limestone have been extensively available and abundant which drives their collective use as supplemental cementitious materials. Laterite which has a chemical makeup comparable to clay, is more readily available in tropical places and has the potential to replace clay soil as an SCMs.

To produce low-carbon cementitious materials these SCMs were used to substitute up to 45% of Portland cement. The SCMs were identified, and four concrete mixes were created: (1) 100% ordinary Portland cement; (2) 16-30-57% limestone-calcined clay-Portland cement; (3) 30-70% calcined laterite Portland cement; and (4) 16-30-57% limestone calcined laterite Portland cement. These mixtures were tested for workability, strength and durability with a special emphasis on how varied water to-binder ratios affected the performance of clay and laterite SCMs. It was determined that laterite might efficiently replace clay in mineral calcined clay cements, particularly in steamy locations where laterite is as common as extra abundant than clay. The study suggested additional seek for the determination of long-term material performance [152].

Mohamed *et al.* (2019) has illustrated the utilization of SCMs like Fly ash has a greatest popularity for its low cost and good performance and has been very efficiently way to substitute cement. However, the impact of these materials on concrete qualities varies greatly depending on factors such as cement grade

replacement percentage curing time and ambient conditions. A review of previous studies on FA containing concrete mixtures was undertaken to determine the influence of fly ash on the compressive strength and rheological properties of concrete. The results designated that incorporating low-calcium fly ash improved the compressive strength of hardened concrete over periods of 28 to 56 days and enhanced its rheological properties, as long as the replacement percentage was kept within reasonable limits. Consequently, when used in moderation, fly ash emerges as a cost-effective and sustainable alternative to traditional cement in the cement and concrete industry (153).

Guanlei et al. (2022) has reported that this study sought to improve understanding of FA as frequent industrial byproduct of a supplementary cementitious material. The study looked at the mechanical and microstructural aspects of cement-based composites that included fly ash. It also looked at the numerous elements that influence these qualities, as well as the constraints of retaining fly ash in concrete. Overall, the use of fly ash as an SCM improved material characteristics and provided environmental benefits. However, it was shown that there is an optimal inclusion level, which is often around 20%; exceeding this barrier may have an undesirable impact on the composite's concert. The literature evaluation found possible solutions to these issues and proposed upcoming research topics for employing more fly ash. One notable disadvantage of employing fly ash is the delayed development of early strength in cementing composites. This issue can be resolved by chemical activation and by adding the nanomaterials aspects that can allow for the high-volume utilization of fly ash. By Using fly ash as an SCM can rise up sustainable development by lowering the emissions and also preserving natural resources improving waste management minimize the environmental pollution and overcome excessive heat [154].

Wirth *et al.*, (2019) has studied that an effort to promote environmentally friendly and sustainable construction techniques, the study investigated the qualities of sandless concrete, a type of concrete created without natural sand but with fly ash substituting some of the cement. Initially, the study found the optimum mixture proportions to ensure that sandless concrete had the necessary qualities for structural uses. The researchers then investigated the effect of replacing up to 51% of the cement with Class-F fly ash on the fresh and hardened characteristics of sandless concrete.

Incorporating fly ash improved workability long-term strength reduced drying shrinkage and increased resistance to chloride incursion [155].

Tao *et al.*, (2021) has studied that Powdered particles have major influence on the technical performance of regenerated aggregates and concrete also, which can be increases attention for the wastage of highly used powder. This study helps to illustrate that the initiation of regenerated powder with nano-CaCO₃ (NC) and nano-graphene oxide. So that the collected data can help to demonstrated that the nanomaterial successfully initiated the stronger effect of recycled particles (RP). Moreover, the further investigation should use XRD and SEM help to rise up the degree of hydration which can result the creation of more Ca (OH)₂ (CH) and a refined alignment index of CH. This study suggests an effective approach for activating RP, allowing it to reach its full potential as a unique supplemental cementitious material [156].

Maria and coworker (2015) suggested Supplementary cementitious materials are routinely cast-off in concrete mixtures to substitute some of the cement. This approach benefits the industry by resulting in more cost-effective concrete and have a lower environmental impact and amended long-term strength and durability. SCMs have been utilized in Portland cement concrete for decades and their possessions have been widely studied. Recent SCM research has concentrated on several critical areas, including the discovery of new materials, boosting replacement levels, establishing improved test methods processing or altering materials, and integrating performance-enhancing additives such as limestone or nano silica. The study examined the advances in knowledge made as a result of this research, emphasizing its significance to the discipline [157].

Zhifang *et al.*, (2020) suggested that the nanoscale chemical and physical processession have considerable influence on the behavior of cement-based materials. As a result, by using nanoparticles into civil engineering to create nano modified cement-based materials has been ascended as an exciting research topic. In recent decades numerous researchers have attempted to progress the characteristics of cement-based materials by including different nanomaterials and investigating the mechanisms that underpin their strengthening effects. This paper offerings a complete overview of the most recent developments in nano-modified cement-based materials. It begins by looking at the fundamental properties and dispersion strategies of

regularly utilized nanomaterials such carbon nanotubes carbon nanofibers, graphene, nano calcium carbonate and nano calcium silicate hydrate. The paper then discusses current advances in nano-engineered cementitious composites, focusing on topics such as speeding cement hydration, improving mechanical characteristics, and increasing durability. The paper also briefly discusses the soq applications of nanoparticles in cement-based materials which including cost considerations based on market surveys. Finally, it discusses current research obstacles and suggests directions for future progress [158].

Beverly *et al.*, (2021) has demonstrated that the fast expansion of infrastructure construction that show a remarkable increase in cement demand with international consumption impending 30 billion tons of concrete each year. To meet this need in a sustainable manner experts around the world are looking for many kinds of strategies for the achievement of carbon neutral construction practices. One such technique the use of Sugarcane bagasse ash as a byproduct in sugar mills that contain a large amount of silica that make it pozzolanic material in concrete and also beneficial for construction industry as well. This study helps to investigate the physical and chemical properties of sugar cane bagasse and also help to study various methods that can influence the ash and the main performance of concrete. The review examines concrete blended with varied SCBA dosages, examining both its fresh and hardened qualities. The results demonstrated that integrating sugarcane bagasse ash improved concrete performance by providing benefits such as higher strength for better pozzolanic reactions to lower heat of hydration and decreased permeability due to refinement in the blended concrete. The paper also makes recommendations for further research into improving the usage of bagasse ash in concrete [159].

Laxman *et al.*, (2020) has examined that the recent research has increasingly focused on lowering the use of ordinary Portland cement (OPC) by using industrial byproducts as supplemental cementitious materials (SCMs). Sugarcane bagasse ash (SCBA) is one of these byproducts that has received interest as a possible SCM. SCMs which are primarily pozzolanic materials high in alumina and silica are not logically cementing material but can take counterpart with calcium hydroxide and water for the formation of cementitious compounds. This research examines the ways for converting sugarcane bagasse ash into a supplemental cementitious material, focusing on the structured approach to producing SCBA as a pozzolanic material. The chemical

structures and physical potentials of SCBA are derived from diverse sources as well as the effects of grinding and calcination on these attributes. SCBA was characterized according to its physical, chemical, and microstructural properties. These experiments found that grinding created finer SCBA particles, whereas calcination reduced carbon content and improved amorphous reactivity due to the increased presence of pozzolanic oxides as legalized by X-ray fluorescence (XRF) [160].

Saad *et al.*, (2022) has reported that the interest in finding partial alternatives for cement which is derived from cement industry. Sugar cane bagasse is a byproduct of sugar industry. When the bagasse is burned at high temperature it will convert into ash. This ash should be mixed with concrete as supplementary material. Different studies have been conducting research on it and prove that sugarcane bagasse ash as potential backbone for construction industry due to its diverse qualities. The paper then assesses the impact of adding SCBA to concrete and focusing on slump and mechanical characteristics for water absorption permeability and microstructure. The literature reveals that the slump of concrete can rise or decrease depending on the SCBA percentage and the treatments used such as heating and milling. The ideal replacement ratio for improving mechanical qualities was found to be between 5% and 10% [161].

Loganayagan *et al.*, (2021) has reported that the qualities of SCBA as an addition in concrete mixtures. SCBA was obtained from several sugarcane juice businesses in Sathya Mangalam. The bagasse was dehydrated for two days before being torched to produce ash which was collected and analyzed. It has been investigated that the chemical and physical properties of the SCBA and utilized it to substitute cement in amounts ranging from 5% to 15%. SCBA was combined with cement and superiority tests were run to determine consistency, as well as the start and final setting timeframes. It was also investigated the compressive strength of concrete using various SCBA ratios. To mitigate the potential environmental consequences of discarding this chemical, we used it as a positive supplement. Based on our findings, we chose to replace 10% of the cement with SCBA. The findings revealed that the attributes of SCBA-treated concrete were comparable to those of normal concrete, implying that the replacement percentage might be increased for future performance testing [162].

Sagar *et al.*, (2015) has suggested that the sugarcane bagasse ash utilized as a pozzolanic material have extra strength concrete that can help to overcome environmental impacts. Ordinary Portland Cement was used as limited replacement of cement. The water-cement ratios ranged between 0.45 and 0.64 and the evaluations should be tested for 7, 28, 56 and 90 days for the examination for the examination of concrete properties. [163].

Minnu *et al.*, (2021) has suggested that the use of bagasse ash in the construction industry that can been limited due to a shortage of detailed research on its effects on concrete. To increase the reception of evolution with rice husk ash a well-known agricultural byproduct was done. This comparison can focus on the determination of physical and morphological properties of bagasse ash. The Concrete mixtures containing ashy elements and also showed the substantial resistance to chloride, water and air permeability at various temperature replacement levels. The data suggest that bagasse ash can be a feasible supplemental cementitious material, providing equivalent gains in strength and durability to rice husk ash. This comparative investigation demonstrates bagasse ash's ability to effectively improve concrete characteristics, enabling its widespread usage in the cement industry [164].

Yogitha et al. (2020) has reported that the agricultural wastes like sugarcane bagasse ash and rice husk ash have been studied and to investigate the possible use of supplementary cementitious materials These ashes are produced from grasses and contain large amount of silica into it which are very useful for concrete for the production of cement. The study examined concrete mixtures with SCBA substitutions of 5%, 10%, 15%, and 20% for compressive strength and splitting tensile strength. The results showed that replacing up to 15% with SCBA increased strength, reduced water absorption, and decreased permeability. Notably, concrete with a 15% SCBA replacement cured for 56 days had the maximum durability when associated to samples preserved for 28 or 56 days. This improved performance was linked to the creation of a dense lattice structure in the concrete, resulting in increased densification and overall durability [165].

Jorgen and coworker (2019) have suggested that recent discoveries have considerably improved our understanding of how supplementary cementitious materials (SCMs) help to build sustainable, low-carbon cements. A primary goal has

been to maximize the usage of SCMs in blended cements, which needed a full understanding of their impact on cement hydration. Accurate modeling of this process is dependent on the reactivity of SCMs, which has traditionally been difficult to assess. Establishing obvious correlations between SCMs' inherent features and their responsiveness became critical for progressing this subject. Recent extensive assessments have provided important insights into these dynamics. To further understand SCM reactivity, researchers conducted foundational investigations with synthetic SCMs, dissolution experiments, and model systems. These investigations elucidated how SCMs alter the hydration of Portland clinker, a key component of cement. Furthermore, studies on the effects of commonly used SCMs on hydration processes and the microstructure of mixed cements have yielded notable results. Notably, research on calcined clays has been gained a lot of attention due to their intriguing features. According to studies, calcined clays can have a considerable impact on hydration and improve the performance of blended cements. This collection of study has advanced our understanding of SCMs paving the door for more efficient and sustainable cement composition [166].

Praveen and coworker (2019) have suggested that the mechanical and durable qualities of blended concrete mixes of varying grades (30, 50, and 70 MPa) were investigated. These concrete mixes included three mineral admixtures as partial substitutes for cement such as fly ash silica fume and lime sludge. The results shown that these minerals are added into concrete for the increment of strength. Specifically, the blended concrete mixes' compressive strength rose by 42.95% for the 30 MPa grade, 32.48% for the 50 MPa grade, and 22.79% for the 70 MPa grade are associated to the control mix. Furthermore, the blended concrete mixes outclassed the regulator mix in terms of acid attack resistance and chloride ion intrusion that reveal the helpful effects of mineral admixtures on total concrete durability [167].

Lvan *et al.*, (2023) has suggested that Pozzolanic blended cements are extensively used to improve their environmental performance while possesses sing equivalent compressive strength. various SCMs are industrial byproducts that need a little processing. The results explained that the engaging SCMs as partial replacements for pozzolanic blended cement improved its reactivity and improved the compressive strength of the cementitious pastes. However, the environmental impact varied according to each SCM's replacement level compressive strength and total mark.

While some SCMs had positive environmental effects, others exhibited negative consequences, highlighting the need of carefully examining these issues when choosing SCMs for cement substitution [168].

Fahid and coworker (2024) has illustrated that the increased usage of Portland cement raises significant environmental problems prompting the investigation of supplemental cementitious materials as alternatives in the construction sector. The addition of SCMs to blended cement concrete has been proven that it increases mechanical and durability abilities. However, forecasting the compressive strength of BCC is very problematic due of its multifaceted composition. This study presents a better method to estimate the compressive strength of blended cement concrete giving useful tools for improving accuracy and expanding understanding of the impact of SCMs [169].

Wu and coworker (2017) suggested that SCMs such as FA and blast furnace slag these are extensively used as supplementary material in cement and lowering costs and emissions. Carbonation involves a significant proportion of calcium-silicate-hydrate (C-S-H) with a low calcium-to-silicon (Ca/Si) ratio in SCM-blended cement paste. Understanding the effects of C-S-H on pore structure of SCM blended cement paste is not suitable for influential durability. Mercury Intrusion Porosimetry was used to demonstrate the volume and size distribution of capillary pores in cement paste. The results showed that carbonation of most C-S-H species improved porosity in the cement paste. So, the total porosity of cement paste has significant qualities of BFS increased after carbonation. This increased porosity can have a negative impact on the blended cement and durable concrete when exposed to carbonation to make it more sustainable over time. In conclusion, the study found that carbonation of C-S-H in SCM-blended cement pastes increases porosity, particularly in pastes with high BFS concentration, which may jeopardize the concrete's durability under carbonating conditions [170].

Rachel *et al.*, (1996) has demonstrated that Blended cements are commonly used in Europe, but are less frequent in North America, where supplemental cementitious elements are often added directly to concrete. Nonetheless, there is growing interest in mixed cements in North America due to their numerous benefits for producers. These include increased manufacturing capacity, lower carbon dioxide

emissions, and decreased fuel usage. Users may profit from blended cements in numerous ways. They can be designed to optimize chemistry for better sulfate resistance, change particle size distributions to reduce water use while achieving the appropriate reactivity, and customize strength properties to meet specific requirements. Furthermore, blended cements offer better quality control during manufacture. However, using clinker with supplementary cementitious materials does not guarantee these benefits. Without proper optimization, mixed cements may underperform standard Portland cement.

This paper investigates the properties of numerous components used in blended cements and provides a detailed discussion of how these components interact and influence the behavior of concrete [171].

Rusheng *et al.* (2022) has illustrated that Supplementary cementitious materials are efficiently used as partial replacement of cement. The study found that sodium potassium and sulfate ions were the main components of pore solutions. As the w/c ratio grew and SCM doses increased, the concentrations of these ions fell, resulting in decreasing conductivities. The conductivity progression of the pore solutions occurred in three separate phases: an induction period of less than 5 hours, an acceleration phase from 5 hours to 7 days, and a deceleration phase after 7 days. The model accurately predicted the conductivity of pore solutions for pastes with varying w/c ratios, attaining a R^2 value of more than 0.90. However, the existence of SCMs diminished the model's efficacy. The ions OH^- , K^+ , and SO_4^{2-} made up over 90% of the overall conductivity, decreasing in order [172].

Sarawathy *et al.*, (2007) has proposed that as the global development and growth of population is increasing the demand for construction has sky rocked. The need for raw material for building, as well as use of high energy and high-cost demand are all viable in construction industry. The notable amount of waste is generated during the manufacturing and construction phases, which contributes the environmental damages. Cement and concrete is very popular due to its high strength, mechanical properties and good durability. For cement production raw resources are required such as limestone and consume a lot of energy and CO_2 emission during cement production raises concern about sustainability. Many research has found that by using of supplementary material such as silica, blast furnace slag, rice husk and fly ash and so

on can improve the characteristics of concrete while also being cost effective. The quantity of rice husk in many regions of world makes it appropriate for building while also environmentally friendly. RHA has high Pozzolanic behavior and compatible bond strength of supplementary material. By using of RHA in concrete as supplement material lessen the environmental impacts of cement production. RHA contain large amount of amorphous silica contents about 90% which makes it Pozzolanic reactive. Calcium oxide and non-reactive silica is used in concrete. China and India are the largest rice production countries. RHA is used as fertilizer in agricultural field and used in steel cement refractory bricks industries used as waste management, as absorbent and catalyst [173].

Isberto *et al.*, (2019) has assessed that RHA is a by -product obtained from milling process. First the burning process start we can burn at 600–800-degree temperature as the burning increase silica quantity in RHA increased. Silica is very important because they contain silicon and oxygen atoms. In rice husk ash about 85-0-90% silica is present and works as binding agent in concrete and protect from air damages. RHA in powder form mixed with concrete because we use RHA as supplementary material in concrete. Then RHA is mixed with water and other components as it is mix it fills the gaps between cement particles and reduce the pore size and increase its strength, it concrete compressive as well as flexural strength. Awareness of RHA is due to huge volume of amorphous silica is present in it, and have substantial surface area. Small particle size of RHA made it Pozzolanic reactive increases its workability and strength. Combustion methods are used to make ash from husk these are self-made combustion method and oven combustion in laboratory. self-combusting method consist of two stoves and one combustion chamber. RHA burned from both controlled and un controlled methods. However, these optimum values are largely reliant on the RHA burning preparation method, which influences the content of amorphous silica and as a result RHA pozzolanic activity in concrete. This study focuses on the use of RHA as a fractional cement replacement and explores how the burning and preparation of RHA can improve its pozzolanic qualities and composition. SCMs have long played an important role in concrete manufacturing, motivated by the desire to reduce environmental impact and improve sustainability [174].

Brown *et al.* (2012) has demonstrated that the given high cost of Portland cement in developing countries this study explores the feasibility of using rice husk

ash from Cambodia as a substitute for Portland cement in concrete. The study compared five distinct Cambodian ashes and concluded that a 20% replacement of cement with RHA is appropriate for small-scale rural construction. Furthermore, the study discovered that low-tech grinding procedures greatly increased the compressive strength of RHA-cement mortars compared to unground RHA. However, there was a significant difference in performance between RHA-concrete beams and mortars in laboratory and field experiments. Regular concrete performed worse than field beams, while RHA-containing mortars did much worse. The observed differences in water/binder ratios between laboratory mortars and field beams are due to differences in sample preparation. These variations could be attributed to the MIT mortar mixes adhering to a higher ASTM standard than Cambodian regulations [175].

Chapter 3

MATERIAL AND METHOD

All the experimental work was done with Shaukat research group in Building Research Station Lahore, Communication and Works Department, Government of the Punjab and in the office of Geological Survey of Pakistan at Lahore. This chapter comprises of three portions i.e. selection of material, experimental section and methodology for evaluation of engineering properties.

3.1 Material

The following materials were used in this research work which are depicted as under: -

3.1.1 Rice Husk

The rice husk was collected from Tatar Wala District Rajanpur Punjab Pakistan.

3.1.2 Fine Aggregates

Fine aggregate (sand) was collected from river Ravi near Ravi Toll Plaza Lahore.

3.1.3 Coarse Aggregates

The coarse aggregate of Sargodha quarry was obtained from project executing with the name of Multi Story Flat/Suits in the primacies of Building Research Station, Lahore. The coarse aggregate used in concrete was strong, workable, durable and appropriate grading which ensured that the aggregate fit together to reduce voids. Moreover, the grading of coarse aggregate for concrete was in accordance with specification as mentioned in various standards such as ASTM C39 and BS 882 (176).

3.1.4 Cement

Ordinary Portland Cement of Pioneer manufacturing company having grade 46 was gifted by BRS which satisfied the standards of the ASTM C1-50 (177). The term "grade 46" relates with compressive strength of cement having at least 46 MPa.

3.1.5 Water

Tap water was being used in performing experiment.

3.2 Apparatus

Followings apparatus were being used during performing of experiment which are mentioned below: -

- (i) Mud Pot
- (ii) Weighing Balance
- (iii) Iron molds having dimension 6×6×6 cubes and 6×14 cylinders
- (iv) Mechanical full load mixture
- (v) Water curing tank
- (vi) Compression Testing machine

3.3 General procedure for preparation of Aerobic Rice Husk Ash

The step wise procedure for the preparation of aerobic rice husk was given below: -

3.3.1 Preparation Anaerobic rice husk ash

The rice husk was collected from Tatar Wala District Rajanpur Punjab Pakistan and dried it to sun expose up to 5-days for 6 hours to reduce moisture contents, which can hinder combustion. The sun drying reduced moisture by making it more suitable to convert into ash.

3.3.2 Preparation of the Mud Pot

The mud pot was chosen for its ability to withstand high temperatures and its insulating properties. It was fresh and free from any moisture or contaminants that might affect the combustion process.

3.3.3 Loading the Pot

A layer of rice husks was evenly spread at the bottom of the mud pot. The thickness of this layer depends on the desired duration of burning and heat output.

3.3.4 Ignition:

The rice husk was ignited using a flame source such as a match or lighter. Care was carried out to ensure even ignition across the surface of the husks.



Figure 3.1: Synthesis of Rice husk anaerobically

3.3.5 Covering the Pot

Once the husk was ignited, the mud pot was covered with a lid or another pot to restrict airflow. This created an anaerobic environment inside the pot, promoting incomplete combustion.

3.3.6 Temperature Regulation

The temperature inside the pot increased as the rice husks burnt. The lid was adjusted to control the airflow and regulate the temperature. Higher temperatures could be achieved by allowing more airflow, while reducing airflow lowers the temperature.

3.3.7 Monitoring

The burning process was monitored to ensure that the rice husk was combusting evenly and efficiently. Adjustments might be made to the airflow or the arrangement of the husks to optimize combustion.

3.3.8 Safety Measures

Safety precautions were adopted to prevent accidents or injuries during the burning process. This might include keeping flammable materials away from the pot, using heat-resistant gloves when handling the pot, and ensuring proper ventilation to avoid carbon monoxide buildup.

3.3.9 collection of ash

After the rice husks have been burned completely, the ash residue was allowed to cool the ash was collected from pot and it was used as cementitious material empowering concrete cube.

3.4 Aerobic Rice Husk Ash

Depending upon the manufacturing nature, two types of RHA were selected. Aerobic rice husk ash was purchased from Agricultural Service Garden Center Nursery and Gardening Store, PWD, Islamabad, Pakistan. Whereas anaerobic rice husk ash was manufactured in the office of Geological Survey of Pakistan near Expo Centre, Lahore.

3.5 General procedure for preparation of concrete cubes and cylinders

The concrete cubes and cylinder were prepared according to literature protocol like ASTM C39 and British Standard BS 1881: Part 225 (177,178). Six different batches of concrete mix were prepared with concentration of aerobic RHA 0.5%, 1%, 1.5%, 2% and 1% of anaerobic RHA for making concrete cubes and cylinders to determine their compressive strength. Stepwise procedure was mentioned below as under: -

3.5.1 Mixing of materials

Six different batches of concrete matrix were prepared by mixing all materials such as cement, sand and aggregate in the ratio of 1:2:4 respectively. The aerobic and anaerobic rice husk ash were also added in five batches in percentage as mentioned

above. For this purpose, firstly 50 kg of cement, 100 kg of fine aggregate and 400 kg of coarse aggregate were mixed in mechanical full load mixture and allowed to mix it for 10 minutes. Then calculated amount of water was added in mixture to make homogeneous concrete matrix. One batch was prepared without RHA. Whereas four batches were prepared with percentage of aerobic RHA 0.5%, 1%, 1.5%, 2% while one batch was prepared with 1% of anaerobic RHA.

3.5.2 Casting of concrete cubes

To cast concrete cubes, iron molds having dimensions of 6×6×6 inch were filled with newly prepared RHA-blended concrete in three layer by hammering 25 stocks in each layer. Whereas, iron cylinders having size 6 ×14 were poured with RHA-blended concrete in laboratory. The casted cylinders and cubes were left for 24 hours at room temperature for early setting.

3.5.3 Curing of concrete cylinders and cubes

After 24 hours, the casted concrete cubes and cylinders were removed from iron mold and put them in water curing tank. Curing was conducted using normal curing method at room temperature for three different ages such as 7, 14 and 28 days. This curing in water helped to maintain a moist environment, promoting hydration and strengthening of the concrete.

3.5.4 Collection of concrete cubes

The concrete cylinders and cubes were collected from the water curing tank after stipulated curing period (7, 14 and 28 days). Care was taken to handle the cylinders and cubes gently to avoid any damage that could affect the test results.

3.5.5 Determination of Compressive strength

The collected concrete cylinder and cubes were transported to the laboratory for testing.

Each concrete sample was placed in a Compression Testing Machine. The compressive machine applied a gradual and uniform load on the cube until it fractures. The load at which the cube fails was recorded and the compressive strength was calculated using the formula:

Compressive Strength=maximum load/cross-sectional area of the cube

Chapter 4

Results

Table No. 4.1 Determined compressive strength of concrete Cube against specified compressive strength 2000 psi @07 days as BS 1881: Part 225

Cube No.	Age in days	Load applied in Lbs.	Cross area in inches	Determine compressive strength in psi
1	7	110016	36	3056
2	7	132000	36	3666
3	7	120313	36	3342
4	7	115000	36	3149
5	7	92000	36	2555
6	7	70000	36	1944

Table No. 4.2 Determined compressive strength of concrete cylinder against specified compressive strength 1750 psi @07 days as ASTM C39

Cylinder No.	Age in days	Load applied in Lbs.	Cross area in inches	Determine compressive strength in psi
1	7	75674	28.3	2674
2	7	87900	28.3	3106
3	7	82756	28.3	2925
4	7	77977	28.3	2755
5	7	63193	28.3	2233
6	7	47883	28.3	1692

Table No. 4.3 Determined compressive strength of concrete Cube against specified compressive strength 2400 psi @014 days as BS 1881: Part 225

Cube No.	Age in days	Load applied in Lbs.	Cross area in inches	Determine compressive strength in psi
7	14	118224	36	3284
8	14	140000	36	3888
9	14	120000	36	3333
10	14	118000	36	3277
11	14	92000	36	3416
12	14	95000	36	2638

Table No. 4.4 Determined compressive strength of concrete cylinder against specified compressive strength 2000 psi @14 days as ASTM C39

Cylinder No.	Age in days	Load applied in Lbs.	Cross area in inches	Determine compressive strength in psi
7	14	60109	28.3	2124
8	14	66363	28.3	2345
9	14	78603	28.3	2250
10	14	61807	28.3	2184
11	14	64439	28.3	2277
12	14	54900	28.3	1940

Table No. 4.5 Determined compressive strength of concrete Cube against specified compressive strength 3000 psi @ 28 days as BS 1881: Part 225

Cube No.	Age in days	Load applied in Lbs.	Cross area in inches	Determine compressive strength in psi
13	28	112140	36	3115
14	28	118000	36	3277
15	28	110000	36	3055
16	28	100000	36	2777
17	28	140000	36	3888
18	28	105000	36	2916

Table No. 4.6 Determined compressive strength of concrete cylinder against specified compressive strength 2500 psi @28 days as ASTM C39

Cylinder No.	Age in days	Load applied in Lbs.	Cross area in inches	Determine compressive strength in psi
13	28	73863	28.3	2610
14	28	76806	28.3	2714
15	28	72023	28.3	2545
16	28	65486	28.3	2314
17	28	91692	28.3	3240
18	28	68769	28.3	2430

Chapter 5

DISCUSSION

This chapter deals with results and discussion of prepared concrete cubes and cylinders which is divided into 2 portions

- i. Concrete cube and cylinder preparation
- ii. Compressive strength evaluation

According to my research work plan, various attempts were performed to prepare different batches of concrete matrix to cast concrete cubes and cylinders as reported in literature [BS 882]. The automatic mechanical full load mixture was being used to mix all materials homogeneously. RHA with various percentages was added in different batches during mixing. The prepared concrete cubes and cylinders were evaluated for their compressive strength by CTM which were supported by microscopic examination such as SEM and XRD.

The prepared concrete cubes from 1 to 6 are evaluated for determination of their compressive strength against 2000 psi at 7 days. It was noted that cube 6 composed of cement, fine aggregates and coarse aggregates in a 1:2:4 ratio without the addition of RHA, demonstrated a compressive strength of 1944 psi. Cube 1 with 0.5kg RHA blended concrete revealed 3056 psi at 7 days age. Moreover, cube 2 with the same composition ratio but including 1 kg of aerobic RHA showed a compressive strength of 3666 psi. Cube 3 also composed of cement fine and coarse aggregates in a 1:2:4 ratio but with the addition of 1.5 kg of aerobic RHA exhibited a compressive strength of 3342 psi. Cube 4 with the same cement to aggregate ratio and 2% aerobic RHA achieved a compressive strength of 3149 psi. Additionally, cube 5 consisting of cement, sand, fine and coarse aggregates in a 1:2:4 ratio with 1% anaerobic RHA, recorded a compressive strength of 2555 psi at the age of 7 days

Similarly, the prepared concrete cylinder 1 to 6 showed compressive strength in the range of 1692 psi to 3106 psi against specified compressive strength 1750 psi as reported in ASTM C39 at the age of 7 days curing which are depicted in table 4.2. Cylinder 6 is a reference sample which revealed compressive strength 1692 psi after 7 days. Whereas cylinder no. 1 to 4 are aerobic RHA blended concrete samples with varying 0.5 to 2% RHA contents and cylinder 5 is anaerobic RHA blended concrete

with 1% contents. The cylinder 2 has shown promising compressive strength 3106 psi having 1% RHA in blended concrete. While cylinder 3 revealed excellent compressive strength 2925 psi with 1.5% RHA content at the age of 7 days. Moreover 4 also gave good compressive strength with 2% RHA contents after 7 days curing. Further cylinder 1 with 0.5% RHA contents revealed compressive strength 2674 psi at the age of 7 days. However, cylinder 5 having 1% anaerobic RHA contents showed compressive strength after 7 days 2233 psi.

The prepared concrete cubes 7-12 are evaluated for determination of their compressive strength against 2000 psi at 7 days. It was noted that cube 12 composed of cement, fine aggregates and coarse aggregates in a 1:2:4 ratio without the addition of RHA demonstrated a compressive strength of 2638 psi. Cube 7 with 0.5kg RHA blended concrete revealed 3284 psi at 7 days age. Moreover, cube 8 with the same composition ratio but including 1 kg of aerobic RHA showed a compressive strength of 3888 psi. Cube 9 also composed of cement, fine and coarse aggregates in a 1:2:4 ratio but with the addition of 1.5 kg of aerobic RHA exhibited a compressive strength of 3333 psi. Cube 10 with the same cement to aggregate ratio and 2% aerobic RHA achieved a compressive strength of 3277 psi. Additionally, cube 11 consisting of cement, sand, fine and coarse aggregates in a 1:2:4 ratio with 1% anaerobic RHA recorded a compressive strength of 2638 psi at the age of 7 days

Likewise, the prepared concrete cylinders (7-12) are tested at the age of 14 days in order to evaluate increment in their compressive strength. The controlled cylinder sample gave compressive strength 1940 psi against specified compressive strength 2000 psi at the age of 14 days which is slightly lower. Whereas, cylinder 8 with 1% RHA contents revealed excellent compressive strength 2345 psi at the age of 14 days. Moreover, cylinder 9 gave strength 2250 psi with 1.5% RHA contents and cylinder 14 exhibited compressive strength 2184 psi. Furthermore, cylinder 7 as shown 2124 psi compressive strength and cylinder 11 gave compressive strength 2277psi.

The prepared concrete cubes from 13 to 18 are evaluated for determination of their compressive strength against 2000 psi at 7 days. It was noted that cube 18 composed of cement, fine aggregates and coarse aggregates in a 1:2:4 ratio without the addition of RHA demonstrated a compressive strength of 2916 psi. Cube 13 with 0.5kg RHA blended concrete revealed 3115 psi at 7 days age. Moreover, cube 14 with

the same composition ratio but including 1 kg of aerobic RHA showed a compressive strength of 3277 psi. Cube 15 also composed of cement, fine and coarse aggregates in a 1:2:4 ratio but with the addition of 1.5 kg of aerobic RHA exhibited a compressive strength of 3055 psi. Cube 16 with the same cement to aggregate ratio and 2% aerobic RHA achieved a compressive strength of 2777 psi. Additionally, cube 17 consisting of cement, sand, fine and coarse aggregates in a 1:2:4 ratio with 1% anaerobic RHA, recorded a compressive strength of 3888 psi at the age of 7 days

Similarly, the prepared RHA blended concrete cylinders from 13 to 18 were tested to determine their compressive strength at the age of 28 days as per standard specified strength 2500 psi. The reference cylinders revealed 2430 psi which is slightly lower than 2500 psi. The cylinder 17 with 1% of anaerobic RHA contents showed outstanding compressive strength 3240 psi against 2500 psi. Whereas, cylinder 14 revealed 2714 psi with 1% RHA contents. Moreover, 2610 psi is given by cylinder 13. Furthermore, cylinder 15 also gave 2545 psi compressive strength the age of 28 days. However, concrete cylinder 16 revealed abnormal behavior by showing 2314 psi against which is lower than 2500 psi.

It was surprisingly noted that RHA blended concrete cube and cylinders with 1% rice husk ash contents showed excellent compressive strength at the age of 7 and 14 days against standard specified strength. Notably, these samples gave less compressive strength at the age of 28 days which does not meet the standard specified strength. This less compressive strength due to amorphous aerobic RHA which act as a filler in early stage to provide good early strength but loose strengthen properties with the passage of time. Whereas, anaerobic RHA provide gradual increase in the compressive strength of RHA blended concrete due to formation of crystalline phase of CN tubes over the time.

XRD analysis shows that amorphous and crystalline phase of CN tubes obtain from rice husk, cement, fine aggregates, coarse aggregates, sand and water. XRD result shown reasonable reflection oblige peak represent amorphous nature of rice husk (CNT) carbon nano tubes. Fine and coarse aggregates give characteristic peak at....

Cubes and cylinder of concrete represent by more intense peak at which confirm increase crystalline structure of concrete but when concrete blocks cubes and cylinder were prepared by using RHA CN tubes decrease reflection intensity which represent decreasing crystalline behavior. However concrete blocks and cylinders were prepared by using amorphous rice husk using nanotubes give the same reflection intensity for

7- and 14-days curing. But for 28 days intensity was increased due to anaerobic rice husk ash which show increased crystalline behavior with the passage of time. This will also show that crystal was developed slowly with the passage of time.

CONCLUSION

The presented research work is about “performance evaluation of cement containing rice husk ash as supplementary material” in this thesis. RHA is produced from rich in silica contents Argo industrial by-product rice husk which make it pozzolanic material. The potential effect of supplementary cementitious material RHA incorporation into concrete was investigated to enhance its mechanical performance and durability. For this purpose, six different concrete batches with and without RHA (aerobic and anaerobic) were prepared. Total 36 concrete specimens comprising of 18 concrete cubes and 18 concrete cylinders were casted from these prepared concrete matrix batches. The concrete specimens 6, 12 and 18 were considered as reference sample. Whereas, all other concrete specimen were referred as test samples. CTM was used for determination of compressive strength of all casted concrete specimens after 7, 14 and 28 days. SEM was used for microstructure analysis. It was surprisingly observed that the concrete cubes containing 1% aerobic RHA revealed outstanding compressive strength 3666 psi against specified strength 2000 psi after 7 days curing at room temperature and 3888 psi against 2400 psi at the age of 14 days. Whereas, cube with same RHA blended concrete revealed 3277 psi which is less for long term durability as compared to 7 days and 14 days compressive strength. However, the concrete cylinder containing 1% anaerobic RHA showed excellent compressive strength 3240 psi against the specified compressive strength 2400 after 28 days curing at room temperature. This high achieved CS might be due to two reasons. Firstly, the presence of active amorphous silica contents in RHA reacts with cement’s hydration products to produce secondary C-S-H gel. Secondly, the obtained high compressive strength was due to both the pozzolanic and filler effect of RHA in concrete.

REFERENCES

- [1] Camargo-Pérez NR, Abellán-García J, Fuentes L. Use of rice husk ash as a supplementary cementitious material in concrete mix for road pavements. *Journal of Materials Research and Technology*. 2023 Jul 1; 25:6167-82.
- [2] Aïtcin PC. Portland cement. In: Scrivener KL, Favier V, editors. *Science and technology of Concr admixtures*. Woodhead Publishing; 2016. p. 27-51.
- [3] NT C. Portland cement. 1984.
- [4] Scrivener KL, Juilland P, Monteiro PJM. Advances in understanding hydration of Portland cement. *Cement and Concr Res*. 2015; 78:38-56.
- [5] Boscaro F, Palacios M, Flatt RJ. Formulation of low clinker blended cements and concrete with enhanced fresh and hardened properties. *Cem Concr Res*. 2021; 150:106605.
- [6] Nwankwo CO, Bamigboye GO, Davies IE, Michaels TA. High volume Portland cement replacement: A review. *Constr Build Mater*. 2020; 260:120445.
- [7] Solomon AE, Woubishet ZT, Vo DH, Yehualaw MD. Rice Husk Ash in Concrete. *Sustainability*. 2023;15(1):137.
- [8] Yuksel I. Blast-furnace slag. In: Dhir RK, Newlands MD, editors. *Waste and supplementary cementitious materials in concrete*. Woodhead Publishing; 2018. p. 361-415.
- [9] Zeng Q, Liu X, Zhang Z, Wei C, Xu CC. Synergistic utilization of blast furnace slag with other industrial solid wastes in cement and concrete industry: Synergistic mechanisms, applications, and challenges. *Green Energy Resour*. 2023;1(2):100012.
- [10] Tung TM, Babalola OE, Le DH. Experimental investigation of the performance of ground granulated blast furnace slag blended recycled aggregate concrete exposed to elevated temperatures. *Cleaner Waste Syst*. 2023; 4:100069.
- [11] Majhi RK, Nayak AN, Mukharjee BB. Development of sustainable concrete using recycled coarse aggregate and ground granulated blast furnace slag. *Constr Build Mater*. 2018; 159:417-30.
- [12] Xuan D, Zhan B, Poon CS. Assessment of mechanical properties of concrete incorporating carbonated recycled concrete aggregates. *Cem Concr Compos*. 2016; 65:67-74.

- [13] Tam VW, Gao XF, Tam CM. Microstructural analysis of recycled aggregate concrete produced from two-stage mixing approach. *Cem Concr Res.* 2005;35(6):1195-203.
- [14] Li W, Xiao J, Sun Z, Kawashima S, Shah SP. Interfacial transition zones in recycled aggregate concrete with different mixing approaches. *Constr Build Mater.* 2012; 35:1045-55.
- [15] Kou SC, Poon CS, Agrela F. Comparisons of natural and recycled aggregate concretes prepared with the addition of different mineral admixtures. *Cem Concr Compos.* 2011;33(8):788-95.
- [16] Maier PL, Durham SA. Beneficial use of recycled materials in concrete mixtures. *Constr Build Mater.* 2012; 29:428-37.
- [17] Kou SC, Poon CS. Long-term mechanical and durability properties of recycled aggregate concrete prepared with the incorporation of fly ash. *Cem Concr Compos.* 2013; 37:12-9.
- [18] Ann KY, Moon HY, Kim YB, Ryou J. Durability of recycled aggregate concrete using pozzolanic materials. *Waste Manag.* 2008;28(6):993-9.
- Çakır Ö. Experimental analysis of properties of recycled coarse aggregate (RCA) concrete with mineral additives. *Constr Build Mater.* 2014; 68:17-25.
- [19] Pal SC, Mukherjee A, Pathak SR. Investigation of hydraulic activity of ground granulated blast furnace slag in concrete. *Cem Concr Res.* 2003;33(9):1481-6.
- [20] Khan MI, Siddique R. Utilization of silica fume in concrete: Review of durability properties. *Resour Conserv Recycl.* 2011; 57:30-5.
- [21] Babu KG, Prakash PS. Efficiency of silica fume in concrete. *Cem Concr Res.* 1995;25(6):1273-83.
- [22] Mazloom M, Ramezaniapour AA, Brooks JJ. Effect of silica fume on mechanical properties of high-strength concrete. *Cem Concr Compos.* 2004;26(4):347-57.
- [23] Bhanja S, Sengupta B. Influence of silica fume on the tensile strength of concrete. *Cem Concr Res.* 2005;35(4):743-7.
- [24] Toutanji HA, Bayasi Z. Effect of curing procedures on properties of silica fume concrete. *Cem Concr Res.* 1999;29(4):497-501.
- [25] Zhou FP, Barr BIG, Lydon FD. Fracture properties of high strength concrete with varying silica fume content and aggregates. *Cem Concr Res.* 1995;25(3):543-52.

- [26] Sharma R, Khan RA. Effect of different supplementary cementitious materials on mechanical and durability properties of concrete. *J Mater Eng Struct*. 2016;3(3):129-47.
- [27] Goldman A, Bentur A. The influence of micro fillers on enhancement of concrete strength. *Cem Concr Res*. 1993;23(4):962-72.
- [28] Bhanja S, Sengupta B. Investigations on the compressive strength of silica fume concrete using statistical methods. *Cem Concr Res*. 2002;32(9):1391-4.
- [30] Yogendran V, Langan BW, Haque MN, Ward MA. Silica fume in high-strength concrete. *Mater J*. 1987;84(2):124-9.
- [31] Justice JM, Kurtis KE. Influence of metakaolin surface area on properties of cement-based materials. *J Mater Civ Eng*. 2007;19(9):762-71.
- [32] Khatib JM, Baalbaki O, ElKordi AA. Metakaolin. In: Dhir RK, Newlands MD, editors. *Waste and supplementary cementitious materials in concrete*. Woodhead Publishing; 2018. p. 493-511.
- [33] Sabir BB, Wild S, Bai J. Metakaolin and calcined clays as pozzolans for concrete: a review. *Cem Concr Compos*. 2001;23(6):441-54.
- [34] Wang F, Kovler K, Provis JL, Buchwald A, Cyr M, Patapy C, et al. Metakaolin. In: RILEM Technical Committee 238-SCM, Working Group 4. *Properties of Fresh and Hardened Concrete Containing Supplementary Cementitious Materials: State-of-the-Art Report*. 2018. p. 153-79.
- [35] Badogiannis E, Kakali G, Tsivilis S. Metakaolin as supplementary cementitious material: optimization of kaolin to metakaolin conversion. *J Therm Anal Calorim*. 2005;81(2):457-62.
- [36] Aiswarya S, Prince Arulraj G, Dilip C. A review on use of metakaolin in concrete. *Eng Sci Technol*. 2013;3(3):592-7.
- [37] Cadrin SX, Karr LA, Mariani S. Stock identification methods: an overview. *Stock Identification Methods*. 2014;1-5.
- [38] Bredy P, Chabannet M, Pera J. Microstructure and porosity of metakaolin blended cements. *MRS Online Proc Libr*. 1988; 136:275-80.
- [39] Buenfeld NR, Newman JB. The permeability of concrete in a marine environment. *Mag Concr Res*. 1984;36(127):67-80.
- [40] Senbetta E, Scholar CF. Absorptivity, a measure of curing quality as related to durability of concrete surfaces. In: *Proceedings of the Second International*

Conference on the Durability of Building Materials and Components. 1981 Sep. p. 153-9.

[41] Hall C. Water movement in porous building materials—IV. The initial surface absorption and the sorptivity. *Build Environ.* 1981;16(3):201-7.

[42] Ho DS, Lewis RK. The water sorptivity of concretes: the influence of constituents under continuous curing. *Durab Build Mater.* 1987;4(3):241-52.

[43] Kelham S. A water absorption test for concrete. *Mag Concr Res.* 1988;40(143):106-10.

[44] Hall C. Water sorptivity of mortars and concretes: a review. *Mag Concr Res.* 1989;41(147):51-61.

[45] McCarter WJ, Ezirim H, Emerson M. Absorption of water and chloride into concrete. *Mag Concr Res.* 1992;44(158):31-7.

[46] Parrott LJ. Variations of water absorption rate and porosity with depth from an exposed concrete surface: Effects of exposure conditions and cement type. *Cem Concr Res.* 1992;22(6):1077-88.

[47] Khatib JM, Mangat PS. Absorption characteristics of concrete as a function of location relative to casting position. *Cem Concr Res.* 1995;25(5):999-1010.

[50] Gopalan MK. Sorptivity of fly ash concretes. *Cem Concr Res.* 1996;26(8):1189-97.

[51] McCarter WJ, Ezirim H, Emerson M. Properties of concrete in the cover zone: water penetration, sorptivity and ionic ingress. *Mag Concr Res.* 1996;48(176):149-56.

[52] Khatib JM, Clay RM. Absorption characteristics of metakaolin concrete. *Cem Concr Res.* 2004;34(1):19-29.

[53] John N. Strength properties of metakaolin admixed concrete. *Int J Sci Res Publ.* 2013;3(6):1-7.

[54] Kaze RC, à Moungam LB, Djouka MF, Nana A, Kamseu E, Melo UC, Leonelli C. The corrosion of kaolinite by iron minerals and the effects on geopolymerization. *Appl Clay Sci.* 2017; 138:48-62.

[55] Lemougna PN, Madi AB, Kamseu E, Melo UC, Delplancke MP, Rahier H. Influence of the processing temperature on the compressive strength of Na activated lateritic soil for building applications. *Constr Build Mater.* 2014;65:60-6.

[56] Wang YS, Alrefaei Y, Dai JG. Silico-aluminophosphate and alkali-aluminosilicate geopolymers: A comparative review. *Front Mater.* 2019;6:106.

- [57] Aziz A, Felaous K, Alomayri T, Jindal BB. A state-of-the-art review of the structure and properties of laterite-based sustainable geopolymer cement. *Environ Sci Pollut Res*. 2023;30(19):54333-50.
- [58] Walker PJ. Strength, durability and shrinkage characteristics of cement stabilised soil blocks. *Cem Concr Compos*. 1995;17(4):301-10.
- [59] Mansour MB, Jelidi A, Cherif AS, Jabrallah SB. Optimizing thermal and mechanical performance of compressed earth blocks (CEB). *Constr Build Mater*. 2016; 104:44-51.
- [60] Sore SO, Messan A, Prud'Homme E, Escadeillas G, Tsobnang F. Stabilization of compressed earth blocks (CEBs) by geopolymer binder based on local materials from Burkina Faso. *Constr Build Mater*. 2018; 165:333-45.
- [61] Zhang L, Gustavsen A, Jelle BP, Yang L, Gao T, Wang Y. Thermal conductivity of cement stabilized earth blocks. *Constr Build Mater*. 2017; 151:504-11.
- [62] Sharma V, Marwaha BM, Vinayak HK. Enhancing durability of adobe by natural reinforcement for propagating sustainable mud housing. *Int J Sustain Built Environ*. 2016;5(1):141-55.
- [63] Cid-Falceto J, Mazarrón FR, Cañas I. Assessment of compressed earth blocks made in Spain: International durability tests. *Constr Build Mater*. 2012; 37:738-45.
- [64] Galán-Marín C, Rivera-Gómez C, Petric J. Clay-based composite stabilized with natural polymer and fibre. *Constr Build Mater*. 2010;24(8):1462-8.
- [65] Nagaraj HB, Sravan MV, Arun TG, Jagadish KS. Role of lime with cement in long-term strength of Compressed Stabilized Earth Blocks. *Int J Sustain Built Environ*. 2014;3(1):54-61.
- [66] Jose A, Kasthurba AK. Laterite soil-cement blocks modified using natural rubber latex: Assessment of its properties and performance. *Constr Build Mater*. 2021; 273:121991.
- [67] Maclaren M. On the origin of certain laterites. *Geol Mag*. 1906;3(12):536-47.
- [68] Maclaren M. On the origin of certain laterites. *Geol Mag*. 1907;3(12):536-47.
- [69] Sivarajasingham S. The Nature and Origin of Laterite. Cornell University; 1959. Maignien R. Review of Research in Laterites.
- [70] Brown ET, Bourlès DL, Colin F, Sanfo Z, Raisbeck GM, Yiou F. The development of iron crust lateritic systems in Burkina Faso, West Africa examined with in-situ-produced cosmogenic nuclides. *Earth Planet Sci Lett*. 1994;124(1-4):19-33.

- [71] Achyuthan H. Geomorphic evolution and genesis of laterites around the east coast of [72] Madras, Tamil Nadu, India. *Geomorphology*. 1996;16(1):71-6.
- [73] Reddy DV. *Engineering geology*. Vikas Publishing House; 2010.
- [74] Tran NQ, Hoy M, Suddeepong A, Horpibulsuk S, Kantathum K, Arulrajah A. Improved mechanical and microstructure of cement-stabilized lateritic soil using recycled materials replacement and natural rubber latex for pavement applications. *Constr Build Mater*. 2022; 347:128547.
- [75] Assiamah S, Danso H. Effects of sand on the properties of cement-laterite interlocking blocks. In: *Proc., Conf. Paper at West Africa Built Environment Research (WABER)*. Reading, UK: West Africa Built Environment Research; 2021.
- [76] Kaze CR, Lecomte-Nana GL, Kamseu E, Camacho PS, Provis JL, Duttine M, et al. Mechanical and physical properties of inorganic polymer cement made of iron-rich laterite and lateritic clay: A comparative study. *Cem Concr Res*. 2021; 140:106320.
- [77] Lasisi F, Osunade JA, Adewale AO. Short-term studies on the durability of laterized concrete and laterite-cement mortars. *Build Environ*. 1990;25(1):77-83.
- [78] Bukhari SA, Chaudhry AH, Iqbal MN, Siddiquib RH. Performance of cement containing laterite as supplementary cementing material. *J Chem Chem Eng*. 2013;62(3):65-70.
- [79] Muthusamy K, Kamaruzzaman NW, Zubir MA, Hussin MW, Sam ARM, Budiea A. Long term investigation on sulphate resistance of concrete containing laterite aggregate. *Procedia Eng*. 2015; 125:811-7.
- [80] McCarthy MJ, Dyer TD. Pozzolanas and pozzolanic materials. In: *Lea's Chemistry of Cement and Concrete*. 5th ed. 2019. p. 363-467.
- [81] Halstead WJ. Use of fly ash in concrete. *NCHRP Synthesis of Highway Practice*. 1986;(127).
- [82] Thomas MDA. Optimizing the use of fly ash in concrete. Skokie, IL, USA: Portland Cement Association; 2007. Report No. 5420.
- [83] Song Y, Zhao J, Ostrowski KA, Javed MF, Ahmad A, Khan MI, et al. Prediction of compressive strength of fly-ash-based concrete using ensemble and non-ensemble supervised machine-learning approaches. *Appl Sci*. 2021;12(1):361.
- [84] Soni S, Ojha D. A study on use of rice husk ash in concrete. *J Mech Constr Eng*. 2021;1(1):1-4.

- [85] Mounika G, Baskar R, Sri Kalyana Rama J. Rice husk ash as a potential supplementary cementitious material in concrete solution towards sustainable construction. *Innov Infrastruct Solut.* 2022;7(1):51.
- [86] Nayak DK, Abhilash PP, Singh R, Kumar R, Kumar V. Fly ash for sustainable construction: A review of fly ash concrete and its beneficial use case studies. *Cleaner Materials.* 2022 Sep 27:100143.
- [87] Ismail KN, Hussin K, Idris MS. Physical, chemical and mineralogical properties of fly ash. *Journal of Nuclear and Related Technology.* 2007 Jul 1; 4:47-51.
- [88] Norhasri MM, Hamidah MS, Fadzil AM. Applications of using nano material in concrete: A review. *Construction Building Material.* 2017; 133:91-7.
- [89] Goel G, Sachdeva P, Chaudhary AK, Singh Y. The use of nanomaterials in concrete: A review. *Mater Today Proc.* 2022; 69:365-71.
- [90] Bautista-Gutierrez KP, Herrera-May AL, Santamaría-López JM, Honorato-Moreno A, Zamora-Castro SA. Recent progress in nanomaterials for modern concrete infrastructure: Advantages and challenges. *Mater.* 2019;12(21):3548.
- [91] Rocha Segundo IGD, Dias EAL, Fernandes FDP, Freitas EFD, Costa MF, Carneiro JO. Photocatalytic asphalt pavement: The physicochemical and rheological impact of TiO₂ nano/microparticles and ZnO microparticles onto the bitumen. *Road Mater Pavement Des.* 2019;20(6):1452-67.
- [92] Indukuri CSR, Nerella R, Madduru SRC. Effect of graphene oxide on microstructure and strengthened properties of fly ash and silica fume based cement composites. *Constr Build Mater.* 2019; 229:116863.
- [93] Khooshechin M, Tanzadeh J. Experimental and mechanical performance of shotcrete made with nanomaterials and fiber reinforcement. *Constr Build Mater.* 2018; 165:199-205.
- [94] Staub de Melo JV, Trichês G. Study of the influence of nano-TiO₂ on the properties of Portland cement concrete for application on road surfaces. *Road Mater Pavement Des.* 2018;19(5):1011-26.
- [95] Diamond SA, Kennedy AJ, Melby NL, Moser RD, Poda AR, Weiss Jr CA, Brame JA. Assessment of the potential hazard of nano-scale TiO₂ in photocatalytic cement: application of a tiered assessment framework. *NanoImpact.* 2017; 8:11-9.
- [96] Sikora P, Cendrowski K, Markowska-Szczupak A, Horszczaruk E, Mijowska E. The effects of silica/titania nanocomposite on the mechanical and bactericidal properties of cement mortars. *Constr Build Mater.* 2017; 150:738-46.

- [97] Saloma A, Imran I, Abdullah M. Experimental investigation on nanomaterial concrete. *Int J Civ Environ Eng*. 2013;13(3):15-20.
- [98] Hussien NT, Oan AF. The use of sugarcane wastes in concrete. *J Eng Appl Sci*. 2022;69(1):31.
- [99] Ganesan K, Rajagopal K, Thangavel K. Evaluation of bagasse ash as supplementary cementitious material. *Cem Concr Compos*. 2007;29(6):515-24.
- [100] Sengul O. Use of electrical resistivity as an indicator for durability. *Constr Build Mater*. 2014; 73:434-41.
- [101] Yoon S, Moon J, Bae S, Duan X, Giannelis EP, Monteiro PM. Chloride adsorption by calcined layered double hydroxides in hardened Portland cement paste. *Mater Chem Phys*. 2014;145(3):376-86.
- [102] Moretti JP, Sales A, Almeida FC, Rezende MA, Gromboni PP. Joint use of construction waste (CW) and sugarcane bagasse ash sand (SBAS) in concrete. *Constr Build Mater*. 2016; 113:317-23.
- [103] de Sande VT, Sadique M, Pineda P, Bras A, Atherton W, Riley M. Potential use of sugar cane bagasse ash as sand replacement for durable concrete. *J Build Eng*. 2021; 39:102277.
- [104] Mahesh B, Kumar TM, Nikhil U, Yakaswamy A. Usage of sugarcane bagasse ash in concrete. *Int J Eng Res Gen Sci*. 2017;5(2):218-24.
- [105] Nakanishi EY, Frías M, Santos SF, Rodrigues MS, de la Villa RV, Rodriguez O, Junior HS. Investigating the possible usage of elephant grass ash to manufacture the eco-friendly binary cements. *J Clean Prod*. 2016; 116:236-43.
- [106] Rahman NA, Widhiana I, Juliastuti SR, Setyawan H. Synthesis of mesoporous silica with controlled pore structure from bagasse ash as a silica source. *Colloids Surf A Physicochem Eng Asp*. 2015; 476:1-7.
- [107] Lyra GP, dos Santos V, De Santis BC, Rivaben RR, Fischer C, Pallone EMDJ A, Rossignolo JA. Reuse of sugarcane bagasse ash to produce a lightweight aggregate using microwave oven sintering. *Constr Build Mater*. 2019; 222:222-8.
- [108] Montakarntiwong K, Chusilp N, Tangchirapat W, Jaturapitakkul C. Strength and heat evolution of concretes containing bagasse ash from thermal power plants in sugar industry. *Mater Des*. 2013; 49:414-20.
- [109] Bahurudeen A, Kanraj D, Dev VG, Santhanam M. Performance evaluation of sugarcane bagasse ash blended cement in concrete. *Cem Concr Compos*. 2015; 59:77-88.

- [110] Cordeiro GCC, Toledo Filho RD, Tavares LM, Fairbairn EMR. Experimental characterization of binary and ternary blended-cement concretes containing ultrafine residual rice husk and sugar cane bagasse ashes. *Constr Build Mater.* 2012; 29:641-6.
- [112] Akram T, Memon SA, Obaid H. Production of low-cost self-compacting concrete using bagasse ash. *Constr Build Mater.* 2009;23(2):703-12.
- [113] Sua-Iam G, Makul N. Use of increasing amounts of bagasse ash waste to produce self-compacting concrete by adding limestone powder waste. *J Clean Prod.* 2013; 57:308-19.
- [114] Le DH, Sheen YN, Lam MNT. Fresh and hardened properties of self-compacting concrete with sugarcane bagasse ash–slag blended cement. *Constr Build Mater.* 2018; 185:138-47.
- [115] Kunchariyakun K, Asavapisit S, Sinyoung S. Influence of partial sand replacement by black rice husk ash and bagasse ash on properties of autoclaved aerated concrete under different temperatures and times. *Constr Build Mater.* 2018; 173:220-7.
- [116] Ganesan K, Rajagopal K, Thangavel K. Evaluation of bagasse ash as supplementary cementitious material. *Cem Concr Compos.* 2007;29(6):515-24.
- [117] Ganesan K, Rajagopal K, Thangavel K. Evaluation of bagasse ash as supplementary cementitious material. *Cem Concr Compos.* 2007;29(6):515-24.
- [118] Wu N, Ji T, Huang P, Fu T, Zheng X, Xu Q. Use of sugar cane bagasse ash in ultra-high performance concrete (UHPC) as cement replacement. *Constr Build Mater.* 2022; 317:125881.
- [119] Zandersons J, Gravitis J, Kokorevics A, Zhurinsh A, Bikovens O, Tardenaka A, Spince B. Studies of the Brazilian sugarcane bagasse carbonisation process and products properties. *Biomass Bioenergy.* 1999;17(3):209-19.
- [120] Calvin WD. Thermal drying: turning bagasse from a problem to a profit center. *IPPTA.* 1996; 8:61-8.
- [121] Farabi H, Ramroop I. Bagasse: controlling pollution from a free fuel.
- [122] Yogeshwaran V, Priya AK. Removal of hexavalent chromium concentration from the aqueous solution using chemically treated sugarcane bagasse powder. *J Indian Chem Soc.* 2020;97(9b):1467-77.

- [123] Miranda NT, Motta IL, Maciel Filho R, Maciel MRW. Sugarcane bagasse pyrolysis: A review of operating conditions and products properties. *Renew Sustain Energy Rev.* 2021; 149:111394.
- [124] Khalil MJ, Aslam M, Ahmad S. Utilization of sugarcane bagasse ash as cement replacement for the production of sustainable concrete—A review. *Constr Build Mater.* 2021; 270:121371.
- [125] Meshram S, Raut SP, Ansari K, Madurwar M, Daniyal M, Khan MA, Hasan MA. Waste slags as sustainable construction materials: a compressive review on physico mechanical properties. *J Mater Res Technol.* 2023; 23:5821-45.
- [126] Kazemi R, Gholampour A. Evaluating the rapid chloride permeability of self-compacting concrete containing fly ash and silica fume exposed to different temperatures: An artificial intelligence framework. *Constr Build Mater.* 2023; 409:133835.
- [127] Bjegovic D, Stirmer N, Serdar M. *Materials and Corrosion.* 2012 Dec;63(12):1087-96.
- [128] Abdel-Rahman HA, Younes MM. Performance of irradiated blended cement paste composites containing ceramic waste powder towards sulfates, chlorides, and seawater attack. *J Vinyl Addit Technol.* 2020;26(1):24-34.
- [129] Moesgaard M, Poulsen SL, Herfort D, Steenberg M, Kirkegaard LF, Skibsted J, Yue Y. Hydration of Blended Portland Cements Containing Calcium-Aluminosilicate Glass Powder and Limestone. *J Am Ceram Soc.* 2012;95(1):403-9.
- [130] Sánchez de Rojas MI, Marin F, Rivera J, Frías M. Morphology and properties in blended cements with ceramic wastes as a pozzolanic material. *J Am Ceram Soc.* 2006;89(12):3701-5.
- [131] Mokhtari P, HasanNezhad K, Bundur ZB, Donmez S, Gulgun MA, Kriven WM. Optimization of Ca/Si ratio in schists to enhance the pozzolanic supplementary cementitious material for OPC blending. *Int J Ceram Eng Sci.* 2023; e10206.
- [132] Dimoudi A, Tompa C. Energy and environmental indicators related to construction of office buildings. *Resour Conserv Recycl.* 2008;53(1-2):86-95.
- [133] Yepes V, Martí JV, García-Segura T. Cost and emission optimization of precast–prestressed concrete U-beam road bridges by a hybrid glowworm swarm algorithm. *Autom Constr.* 2015; 49:123-34.

- [134] Lee JY, Choi JS, Yuan TF, Yoon YS, Mitchell D. Comparing properties of concrete containing electric arc furnace slag and granulated blast furnace slag. *Materials*. 2019 Apr 27;12(9):1371.
- [135] Zeng Q, Liu X, Zhang Z, Wei C, Xu CC. Synergistic utilization of blast furnace slag with other industrial solid wastes in cement and concrete industry: Synergistic mechanisms, applications, and challenges. *Green Energy and Resources*. 2023 Jun 1;1(2):100012.
- [136] Al-Baijat H, Sarireh M. The use of fine blast furnace slag in improvement of properties of concrete. *Open Journal of Civil Engineering*. 2019 Apr 24;9(2):95-105.
- [137] Salvador RP, Rambo DA, Bueno RM, Silva KT, de Figueiredo AD. On the use of blast-furnace slag in sprayed concrete applications. *Construction and Building Materials*. 2019 Sep 10; 218:543-55.
- [138] Özbay E, Erdemir M, Durmuş Hİ. Utilization and efficiency of ground granulated blast furnace slag on concrete properties—A review. *Construction and Building Materials*. 2016 Feb 15; 105:423-34.
- [139] Chishi AK, Gautam L. Sustainable use of silica fume in green cement concrete production: a review. *Innovative Infrastructure Solutions*. 2023 Jul;8(7):195.
- [140] Kumar R. Effect of metakaolin on mechanical characteristics of the mortar and concrete: A critical review. *Materials Today: Proceedings*. 2023 Jul 29.
- [141] Khan MI, Siddique R. Utilization of silica fume in concrete: Review of durability properties. *Resources, Conservation and Recycling*. 2011 Dec 1; 57:30-5.
- [142] Siddique R. Utilization of silica fume in concrete: Review of hardened properties. *Resources, Conservation and Recycling*. 2011 Sep 1;55(11):923-32
- [143] Pedro D, De Brito J, Evangelista L. Evaluation of high-performance concrete with recycled aggregates: Use of densified silica fume as cement replacement. *Construction and Building Materials*. 2017 Aug 30; 147:803-14.
- [144] Boddy AM, Hooton RD, Thomas MD. The effect of product form of silica fume on its ability to control alkali–silica reaction. *Cement and Concrete Research*. 2000 Jul 1;30(7):1139-50.

- [145] Badogiannis E, Kakali G, Tsivilis S. Metakaolin as supplementary cementitious material: optimization of kaolin to metakaolin conversion. *Journal of thermal analysis and calorimetry*. 2005 Jul;81(2):457-62.
- [146] Ramezaniapour AA, Jovein HB. Influence of metakaolin as supplementary cementing material on strength and durability of concretes. *Construction and Building materials*. 2012 May 1; 30:470-9.
- [147] Rakhimova NR, Rakhimov RZ. Reaction products, structure and properties of alkali-activated metakaolin cements incorporated with supplementary materials—a review. *Journal of Materials Research and Technology*. 2019 Jan 1;8(1):1522-31.
- [148] Bakera AT, Alexander MG. Use of metakaolin as supplementary cementitious material in concrete, with focus on durability properties. *RILEM Technical Letters*. 2019 Nov 12; 4:89-102.
- [149] Thankam GL, Thurvas Renganathan N. Ideal supplementary cementing material—Metakaolin: A review. *International Review of Applied Sciences and Engineering*. 2020 Apr 27.
- [150] Bukhari SA, Chaudhry AH, Iqbal MN, Siddiqui RH. Performance of cement containing laterite as supplementary cementing material. *Kemija u industriji*. 2013 Mar 1;62(3):65-70.
- [151] Aguwa JI. Study of compressive strengths of laterite-cement mixes as a building material. *AU JT*. 2009;13(2):114-20.
- [152] Musbau KD, Kolawole JT, Babafemi AJ, Olalusi OB. Comparative performance of limestone calcined clay and limestone calcined laterite blended cement concrete. *Cleaner Engineering and Technology*. 2021 Oct 1; 4:100264.
- [153] Lamine Zeggag M, Azline N, Azizi Safiee N. Fly ash as supplementary material in concrete: A review. In *IOP Conference Series: Earth and Environmental Science* 2019 Nov 1 (Vol. 357, No. 1, p. 012025). IOP Publishing.
- [154] Li G, Zhou C, Ahmad W, Usanova KI, Karelina M, Mohamed AM, Khallaf R. Fly ash application as supplementary cementitious material: a review. *Materials*. 2022 Apr 5;15(7):2664.
- [155] Wirth X, Benkeser D, Yeboah NN, Shearer CR, Kurtis KE, Burns SE. Evaluation of alternative fly ashes as supplementary cementitious materials. *ACI Materials Journal*. 2019 Jul 1;116(4):69-77.
- [156] Meng T, Dai D, Jia Y, Ying K, Meng R, Hong Y. Comparative study of

nanomaterials activated recycled powders from demolition and decoration wastes as supplementary cementitious material. *Case Studies in Construction Materials*. 2023 Dec 1;19: e02543.

[157] Juenger MC, Siddique R. Recent advances in understanding the role of supplementary cementitious materials in concrete. *Cement and concrete research*. 2015 Dec 1; 78:71-80.

[158] Zhao Z, Qi T, Zhou W, Hui D, Xiao C, Qi J, Zheng Z, Zhao Z. A review on the properties, reinforcing effects, and commercialization of nanomaterials for cement-based materials. *Nanotechnology Reviews*. 2020 Apr 21;9(1):303-22.

[159] Thomas BS, Yang J, Bahurudeen A, Abdalla JA, Hawileh RA, Hamada HM, Nazar S, Jittin V, Ashish DK. Sugarcane bagasse ash as supplementary cementitious material in concrete—a review. *Materials Today Sustainability*. 2021 Nov 1; 15:100086.

[160] Yadav AL, Sairam V, Muruganandam L, Srinivasan K. An overview of the influences of mechanical and chemical processing on sugarcane bagasse ash characterisation as a supplementary cementitious material. *Journal of Cleaner Production*. 2020 Feb 1; 245:118854.

[161] Agwa IS, Zeyad AM, Tayeh BA, Adesina A, de Azevedo AR, Amin M, Hadzima-Nyarko M. A comprehensive review on the use of sugarcane bagasse ash as a supplementary cementitious material to produce eco-friendly concretes. *Materials today: proceedings*. 2022 Jan 1; 65:688-96.

[162] Loganayagan S, Mohan NC, Dhivyabharathi S. Sugarcane bagasse ash as alternate supplementary cementitious material in concrete. *Materials Today: Proceedings*. 2021 Jan 1; 45:1004-7.

[163] Dhengare SW, Raut SP, Bandwal NV, Khangan A. Investigation into utilization of sugarcane bagasse ash as supplementary cementitious material in concrete. *Int. J*. 2015 Apr 4; 3:109.

[164] Jittin V, Minnu SN, Bahurudeen A. Potential of sugarcane bagasse ash as supplementary cementitious material and comparison with currently used rice husk ash. *Construction and Building Materials*. 2021 Mar 1; 273:121679.

[165] Bayapureddy Y, Muniraj K, Mutukuru MR. Sugarcane bagasse ash as supplementary cementitious material in cement composites: strength, durability, and microstructural analysis. *Journal of the Korean Ceramic Society*. 2020 Sep; 57:513-9.

- [166] Skibsted J, Snellings R. Reactivity of supplementary cementitious materials (SCMs) in cement blends. *Cement and Concrete Research*. 2019 Oct 1; 124:105799.
- [167] Kumar VP, Prasad DR. Influence of supplementary cementitious materials on strength and durability characteristics of concrete. *Advances in concrete construction*. 2019 Apr;7(2):75.
- [168] Navarrete I, Valdes J, Lopez M, Vargas F. Replacement of pozzolanic blended cement by supplementary cementitious materials: Mechanical and environmental approach. *Construction and Building Materials*. 2023 Aug 29; 394:132263.
- [169] Aslam F, Shahab MZ. Supplementary cementitious materials in blended cement concrete: Advancements in predicting compressive strength through machine learning. *Materials Today Communications*. 2024 Mar 1; 38:107725.
- [170] Wu B, Ye G. Development of porosity of cement paste blended with supplementary cementitious materials after carbonation. *Construction and Building Materials*. 2017 Aug 1; 145:52-61.
- [171] Detwiler RJ, Bhatti JI, Battacharja S. Supplementary cementing materials for use in blended cements. 1996.
- [172] Qian R, Zhang Y, Liu C, Liu Z, Zhang Y, Liu G. Effects of supplementary cementitious materials on pore-solution chemistry of blended cements. *Journal of Sustainable Cement-Based Materials*. 2022 Nov 2;11(6):389-407.
- [173] Saraswathy V, Song HW. Corrosion performance of rice husk ash blended concrete. *Construction and building materials*. 2007 Aug 1;21(8):1779-84.
- [174] Isberto CD, Labra KL, Landicho JM, De Jesus R. Optimized preparation of rice husk ash (Rha) as a supplementary cementitious material. *GEOMATE Journal*. 2019;16(57):56-61.
- [175] Brown DK. Unprocessed rice husk ash as a partial replacement of cement for low-cost concrete (Doctoral dissertation, Massachusetts Institute of Technology

