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Improvement in the strength of unburnt bricks using fly ash and bagasse ash as cementitious material

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1 Contents

ABSTRACT

This research delves into enhancing the mechanical performance of two environmentally friendly construction materials: high-strength concrete and unburnt bricks. The study focuses on utilizing sugarcane bagasse ash, a byproduct of the sugar industry, as an additive to enhance the mechanical properties of these materials. Extensive assessments were carried out, which involved compressive, split tensile, and flexural tests, were conducted to evaluate the effects of varying proportions of sugarcane bagasse ash on the strength and structural behavior of the materials.The results suggest that incorporating 10% sugarcane bagasse ash instead of cement in high-strength concrete yields the greatest compressive strength, underscoring its potential as a sustainable choice. Likewise, in unburnt bricks, the inclusion of sugarcane bagasse ash leads to a notable enhancement in compressive strength, making it a promising sustainable option for construction projects. These findings underscore the importance of thoughtful material selection, harnessing the benefits of sugarcane bagasse ash to optimize mechanical properties while minimizing environmental impact and waste generation. This study provides valuable insights to encourage the widespread adoption of eco-friendly construction materials, fostering a greener and more resilient construction industry.

1 Introduction

1.1 Background

Concrete is a man-made construction material that is very popular all over the world. Its widespread use is due to the abundance of raw materials available to make it. Concrete is known for its durability, excellent hardening properties, and excellent workability, which allow it to be processed into many forms. During use, it shows high flexibility and excellent performance in both compressive and bending loads, which results in low maintenance and repair costs. High-performance concrete is used frequently and outperforms ordinary strength concrete on modern construction sites, primarily because of its superior qualities like high mechanical strength and increased durability. High performance concrete is a formulation that shows higher durability and strength than normal concrete. This includes the use of one or more water reducers and one or more cementitious materials, such as fly ash or silica fume. The combination of these cementitious materials improves the strength, efficiency and durability of concrete [1]. In recent years, the construction industry has seen a significant increase in the use of high-performance concrete, especially high-strength concrete. Cement, fly ash, silica fume, coarse and fine aggregates, and other components required to make high-strength concrete are now in higher demand as a result of this trend. The rapid development of the infrastructure sector has created a large and unpredictable demand for cement, with global consumption reaching 30 billion tons per year. The booming construction industry worldwide has significantly increased the consumption of raw materials used to produce high-strength concrete, depleting non-renewable resources. Growing concerns about resource scarcity highlight the need for sustainable practices and innovative solutions in the construction sector [2]. Cement production is increasing rapidly to meet the growing demand. From 2005 to 2020, cement production increased from 2.3 billion tons to 3.5 billion tons (Gt), representing an annual growth rate of about 2.5%. Forecasts show that by 2050, cement production will reach the range of 3.7-4.4 Gt. This upward trend highlights the urgent need of this industry to address sustainability and resource management towards a greener future [1, 2]. Roughly one metric ton of CO2 is released through the breakdown of gypsum and limestone used as raw materials and fuel used in the combustion process to produce 1 ton of Portland cement. This high amount of CO_2 emissions contributes significantly to global warming. Researchers have looked carefully at substitute materials for cement in construction applications as a way to solve this problem and lower CO_2 emissions. These investigations aim to uncover alternative solutions that are more sustainable and ecologically conscious, with the goal of diminishing the environmental consequences associated with traditional cement manufacturing.[1–3].

Much research has focused on exploring alternatives to cement in concrete production. These alternatives include various agricultural and industrial wastes that are considered disposable and of low value. Extensive research has been conducted to investigate whether wastes with pozzolanic properties are suitable as supplementary cementitious materials in terms of effectiveness, efficiency, and availability. The goal is to find appropriate and environmentally friendly solutions that can reduce cement consumption and, at the same time, effectively use these wastes in concrete production [2, 4].

Garbage is produced worldwide as a by-product. They are produced in different sectors, including agriculture, industry, and urban and rural areas. These wastes are a potential threat to the environment and have negative environmental effects if not properly managed and disposed of [4]. The increasing challenge of waste disposal comes from the accumulation of decomposed waste. A potential solution to this problem is to recycle these wastes and turn them into valuable products. The use of different wastes and byproducts, such as silica fume, fly ash, rice husk ash, sugarcane bagasse ash, and wheat straw ash, as a cement substitute has been studied by researchers and industry. This approach not only helps with waste management but also with more sustainable construction practices. In contemporary construction settings, supplementary cementitious materials hold significance by serving as pozzolanic elements in the formulation of high-strength concrete. The blending enhances concrete's durability, diminishes permeability, and boosts overall performance.Various types of pozzolans are widely used throughout the world as additives or substitutes for Portland cement in concrete mixes. Consequently, the incorporation of these pozzolanic materials helps to reduce cement demand in concrete production and contributes to more sustainable and resource-efficient construction practices [2, 4].

In pursuit of environmentally friendly construction methods, researchers have developed several solutions by converting waste from the industrial sector into sustainable resources. Sugarcane bagasse ash (SCBA), a common byproduct of the sugar and ethanol industries, causes environmental problems when used as fertilizer or disposed of in landfills. However, the high content of amorphous silica makes it a potential pozzolanic component in concrete, making it an environmentally friendly alternative. With an estimated 8% contribution, the cement industry significantly contributes to the global greenhouse effect.The manufacturing of cement is additionally a significant contributor to carbon dioxide emissions. Brazil, India, and China are the leading producers of sugarcane, while Pakistan has also seen significant growth in sugarcane production over the years. After milling, it was observed that every 10 tons of sugar cane produced approximately 3 tons of bagasse, resulting in an estimated annual production of 11.42 million tons of sugarcane bagasse. This yields around 0.62% ash for every ton of sugarcane burned. However, the properties of bagasse ash from different sugar mills can vary, with some exhibiting excessive porosity, rough surfaces, large sizes, and asymmetrical shapes.

To optimize its use in concrete, the researchers milled the SCBA for 2 hours while burning at temperatures between 700 and 900 °C to obtain ultrafine SCBA with an average particle size of 2.7 mm. The recovered SCBA showed a density of 2560 kg/m3 and a fineness of blaine of 893 m2/kg. The use of sugarcane bagasse ash as a sustainable building material is now possible thanks to these findings.

In this study, bagasse ash obtained from the sugar industry of Khyber Pakhtunkhwa was used in high-strength Portland cement mortar. This research focused on the physical and mechanical properties of mortars, such as compressive strength, consistency, hardening time, and chloride release, with different bagasse ash contents. As a result, bagasse ash acts as a pozzolanic and mineral additive, and at 20% replacement of cement with bagasse ash, the chloride content is reduced without adversely affecting other properties of hardened cement mortar. 50% [5, 6].Incorporating pozzolanic materials enhances the mechanical characteristics of cement, as the silica (SiO_2) within the pozzolanic substance reacts with the liberated free lime during hydration, resulting in the formation of surplus calcium silicate hydrate (C-S-H) as a fresh product of hydration.The responsiveness of amorphous silica, affected by the ash's particular surface area, correlates directly with the amorphous ash-phase cement. This type of cement is generated by carefully calcining agricultural residue at temperatures below 700 °C for a duration of 1 hour. This ash can be ground or crushed to the desired fineness and mixed with cement to create blended cement [5]. The current study aims to determine the ideal degree of replacement by evaluating BA as an additional cementitious material in relation to the mechanical and permeability characteristics of hardened concrete. In order to do this, experiments were conducted in two phases in accordance with accepted test methods. The initial stage involved determining BA's chemical makeup, physical characteristics, and characterization. Apart from evaluating water consistency, initial setting time, final setting time, and compressive time, the assessment encompassed the determination of compressive strength for cement mixed with BA. [7, 8].

Each year, Pakistan produces 50 million tons of sugarcane. After sugarcane is used for sugar production, bagasse is produced. When bagasse is burned as a fuel source, ash is produced, which is known as sugarcane bagasse ash (SBA). The annual production of SBA in Pakistan is about 0.25 million tons [9, 10]. SBA is a waste product, but there is no proper way to get rid of it. As a result, it not only harms the environment but also increases the stress on landfills. After adding SBA to burnt clay bricks, it is possible to make light-weight bricks [10]

The use of fired clay bricks dates back approximately 6,000 years, with traces of their existence discovered in Babylonia. It is considered one of the oldest industries in the world. Initially, bricks were made by hand.The inaugural clay-working machine was activated in 1619. From that point until 1958, molded clay underwent firing in rudimentary, less efficient kilns. Hoffmann was the first to develop a proper kiln in which each fire was fired sequentially and continuously. Because of the continuous fire, the kiln is heated only once, and the heat is efficiently used before releasing it into the environment [10, 11]. The characteristics of clay bricks vary depending on several variables, including the characteristics of the raw materials, the manufacturing process, and the firing process. Brick properties are significantly affected by soil characteristics. If the moisture content and lime content are high, more energy is required to dissolve the calcium components and remove water from the bricks. Fire temperature also affects bond formation. Generally, chemicals are injected for bond enhancement in clay bricks [10, 11].

Pakistan produces about 50 million tons of sugarcane annually, most of which is used for sugar production. As a result, bagasse, comprising approximately 24–30% of sugarcane, is generated and employed as a fuel within the sugar industry. After burning, the resulting by-product is called sugarcane bagasse ash (SBA), which mainly consists of silicon and aluminum oxides. About 81% of the sugar industry's consumption is sugarcane. After burning more than 11 million tons of bagasse every year in Pakistan, 0.26 million tons of bagasse ash are produced, which can be used to make bricks [10].

Since the beginning of time, masonry has been utilized, but in modern times, cost has become a crucial factor because materials are expensive, and the designer must only use the minimum amount of material necessary to meet strength and serviceability standards. Aside from fresh building supplies,

As a building material, Burnt Bricks have experienced a constant development process. The most important truth about today's burned construction bricks is that they are the most affordable and accessible materials. They are non-combustible; hence, they have fire resistance. Burnt bricks have incredible fire-resistant capabilities. BBs are frequently used as infill and partition walls in frame construction. It is anticipated that concrete's ability to withstand fire and display various fires will be similar to that of concrete in behavior and capacity to support loads. Several scholars have recently worked to examine the fire performance of brick masonry [11, 12]. Most of these studies provide great information on brick masonry's fire performance. The test results, however, are consistent with post-fire (residual property) circumstances. Typically, property statistics do not accurately reflect how well structures operate when exposed to fire. This calls for data on the material's characteristics at high temperatures [10]. The commercial use of burnt bricks (BBs) is being practiced. In the construction industry, the fire response of BBs is not taken into account. In evaluating the fire response of structures, understanding specific properties becomes essential. For instance, in the case of burnt bricks (BBs) used in masonry-related building materials, there is limited research available. There is a lack of comprehensive studies on how altering the constituent materials and shape of masonry affects its mechanical properties or addresses any weaknesses. Among these properties, the compressive strength of brick masonry stands out as the most significant consideration. Therefore, there is a need for further research and exploration in this area to enhance our understanding and optimize the performance of masonry structures, particularly in fire scenarios. [13]

When we talk about the durability of brick masonry, fire resistance is also an important factor. Thermal properties, comprising thermal conductivity, specific heat, thermal diffusivity, and thermal expansion, as well as deformation properties like creep and mechanical properties such as compressive strength, splitting tensile strength, and elastic modulus, play a crucial role in influencing the fire response of a structural system. However, our primary focus lies in evaluating the mechanical properties, including compressive strength, splitting tensile strength, and elastic modulus, under fire conditions. In recent years, many incidents have taken place in Pakistan. In 2012, at a Karachi garment factory, a fire killed 298 workers. In Lahore, in 2012, the shoe-making factory caught fire, which damaged the building a lot. In 2013, a fire destroyed five buildings at LDA Plaza in Lahore, killing eight people. There are a few fire accidents that suggest the need for the incorporation of fire safety design in the building infrastructure of Pakistan. Therefore, considering the fire resistance of buildings, the behavior of building materials at elevated temperatures is of supreme importance to engineers so that they can build structures. Among the construction materials, concrete and BBs are widely used. The fire behavior of conventional concrete has been excessively interesting, and it is that concrete loses its strength at elevated temperatures.

This study aims to explore the utilization of sugarcane bagasse ash waste in the production of clay bricks for civil construction. While the potential of the ceramic sector in managing solid wastes is promising, there is limited knowledge regarding the reuse of sugarcane bagasse ash waste in clay ceramics [14]. The scarcity of information on sugarcane bagasse ash waste is evident, especially in developing nations where its production is prevalent. Nonetheless, the increasing global interest in Brazilian flex-fuel technology for automobiles is expected to lead to a higher production of sugarcane bagasse ash waste, highlighting the need for further research in this area [14].

This mineral has demonstrated its potential as a promising pozzolanic component, showing successful applicability as an additive to Portland cement in both mortar and concrete.

For instance, it was shown that adding BA reduced conventional concrete's maximum adiabatic temperature rise by wt%. The sugar cane bagasse ash, obtained through air calcination at 600°C with a heating rate of 10°C/min, features amorphous silica, a notable surface area, and minimal carbon content[52]. Similar to how adding BA to concrete will increase the retail value of waste products while reducing global CO2 emission [4].

1.2 Problem statement

Environmental pollution caused by resource depletion and associated CO2 emissions is one of today's major concerns. To solve this concern, there is an increasing emphasis on using the potential of agricultural and industrial wastes as supplementary cement materials. Among the typical industrial byproducts are ashes from sugarcane bagasse, corn cobs, and fly ash, as well as residues from rice husks, palm oil fuel, and wood waste. Additionally, blast furnace slag and silica fume are also part of this category. Incorporating these wastes into construction sites can provide sustainable solutions and reduce the environmental impact of conventional cement production. When wastes act as pozzolanic components, they play an important role in cement mixtures.The silica (SiO2) present in these materials interacts with the free lime released during the hydration of cement. This reaction produces excess calcium silicate hydrate (CSH) as a new hydration product. These recently generated hydration products contribute to the mechanical qualities of high strength concrete-mixes being improved. Using waste in this way not only improves the overall performance of concrete, moreover it encourages a sustainable methodology by advocating the recycling and repurposing of industrial and agricultural residues..

The production of ecologically friendly concrete using waste products from industry, such as bagasse ash, is the basis of this research, which is based on issues identified by earlier studies. After developing this environmentally friendly high strength concrete, the mechanical performance of bagasse ash high strength concrete was evaluated.

1.3 Aims and objectives

The aim of this research is to develop eco-friendly high strength concrete using bagasse ash as the supplementary cementitious material and to evaluate the mechanical performance of Bagasse Ash on the strength of concrete. This aim is achieved using the following main objectives:

1. To use bagasse ash to create environmentally friendly, high-strength concrete
2. To assess how Bagasse Ash influences the mechanical characteristics of high-strength concrete.
3. To examine the bending response of structural members like beams cast with bagasse ash high-strength concrete.
4. To investigate the effect of sugarcane bagasse ash on the mechanical properties of unburnt bricks.

1.4 Scope

Researchers are directed to tackle the pressing problems of resource depletion and increasing global pollution. In order to promote the sustainable development of the local construction industry, they focus on the use of industrial and agricultural wastes such as silica fume, fly ash, rice husk ash, corn cob ash in concrete. The aim is to create environmentally friendly high-strength concrete by incorporating bagasse ash in different proportions (0%, 5%, 10%, 15%) as an alternative to cement by weight. The goal of this innovative approach is to optimize the mechanical properties of concrete while promoting environmental responsibility through the use of waste and reducing cement consumption [16].Of particular interest is bagasse ash, a residue derived from the sugar industry, renowned for its chemical and mineralogical composition. This ash holds potential as a valuable additive for high-strength concrete. The purpose of this research is the casting of structural members such as beams and columns using controlled and modified high-strength concrete mixtures. Evaluation of these structural members based on mechanical properties, especially flexural strength,to understand the behavior of different high strength concrete formulations. By using bagasse ash in this study, the aim is to investigate the potential of bagasse ash to improve the performance and strength of concrete while contributing to sustainable waste management practices.

1.5 Significance

This research holds significant importance as it investigates the mechanical behavior of high-strength concrete when incorporating environmentally friendly resources like bagasse ash as supplementary cementitious materials. This study involved the collection of sugarcane bagasse ash and the findings showed that the combustion of sugarcane bagasse at 800°C for 1 hour resulted in the highest amount of amorphous silica among the different ashes examined[6, 8]. Subsequently, this ash is employed as a substitute for cement in environmentally conscious high-strength concrete. The objective of this study is to incorporate environmentally friendly bagasse ash into the creation of high-strength concrete. The utilization of such eco-friendly substances, like bagasse ash, will contribute to a reduction in environmental pollution and preservation of natural resources within the cement industry. Structural members like beams will be cast using eco-friendly high-strength concrete. The mechanical performance-like behavior under flexural loading of a structural member-like beam cast from eco-friendly high-strength concrete is studied.

1.6 Novelty

In previous studies eco-friendly high strength concrete has been developed using different industrial and agricultural waste like silica fume, fly ash, rice husk ash, corncob ash, bagasse ash etc. This study focuses on evaluating the Bagasse ash.

Literature Review

Concrete is widely preferred as the most commonly employed construction material, owing to its numerous and firmly established advantages, including affordability, widespread availability, and versatile applicability. Notwithstanding these merits, concrete is recognized as a semi-brittle substance, with its brittleness escalating as its strength rises.[1]. The progress in modern civil engineering construction has given rise to a crucial need for novel concrete types that exhibit enhanced qualities like high strength, toughness, and durability. Notable examples of these concrete types are high-strength concrete (HSC), high-performance concrete (HPC), and high-performance fiber-reinforced concrete (HPFRC). The properties of these advanced concretes display significant improvements compared to conventional concrete.[1].

1.7 High Strength Concrete

1.8 High-strength concrete is characterized by having a compressive strength that exceeds 41 MPa, as specified by the ACI Committee 363. Generally, it is acknowledged as high-strength concrete when it attains a 28-day cylinder compressive strength exceeding 6000 psi or 42 MPa.**[17].** High-strength concrete is further distinguished by having a uniaxial compressive strength higher than what is typically achieved in a specific region, as the maximum strength of concrete produced can vary significantly from one region to another[18].Employing high-strength concrete enables the construction of structures featuring reduced cross-sectional dimensions, leading to decreased dead loads. This engineering benefit facilitates the construction of taller skyscrapers and bridges with extended spans.

1.9 Advantages of High-Strength Concrete

1. Opting for high-strength concrete results in a decrease in the cross-sectional area of diverse structures, consequently augmenting the available space.
2. Due to the use of high-strength concrete, the structure's self-weight is reduced.
3. High-strength concrete successfully controls both short-term and long-term deflections by increasing the modulus of elasticity and reducing creep.
4. The long-term durability of structures is significantly improved, addressing a critical aspect for the sustainable utilization of construction materials.[19].
5. High-strength concrete is a useful material for high-rise buildings, long-span bridges, heavy-duty industrial floors, pre-stressed concrete, etc.

1.10 High Performance Concrete

High-performance concrete (HPC) is a type of concrete made by blending specific materials in accordance with a carefully chosen mix design. The components are thoroughly mixed, transported, placed, consolidated, and cured to ensure that the resulting concrete exhibits outstanding performance within the structure where it is utilized [17, 20]. High-performance concrete (HPC) is designed to withstand the environmental conditions and loads it will encounter in its designated application. Its focus on durability is crucial in ensuring the concrete's long-term performance. Various methods are employed to measure concrete durability, with resistance to chloride, water, and air penetration being some of the straightforward indicators.

Over the past 15 years or so, high-performance concrete has seen gradual development, primarily driven by the production of concrete with ever-increasing strengths, such as 80, 90, 100, 120 MPa, and occasionally even higher. In some regions today, it is common to routinely produce concrete with strengths reaching 140 MPa [20].

1.11 Supplementary Cementitious Materials

1.11.1 Industrial Waste

Numerous industrial byproducts are generated, and their utilization has become a compelling due to increased environmental awareness and worries about potential hazardous impacts, an alternative to conventional disposal techniques[21, 22].

1.11.2 Silica Fume

Silica fume (SF) is acquired as a secondary product in the course of the smelting procedure within the silicon and ferrosilicon sector. Construction and production of high-strength, high-performance concrete both benefit greatly from it. During the reduction of high-purity quartz to silicon at temperatures up to 2000 ◦C, SiO_2 vapor is produced, which subsequently oxidizes and condenses in the low-temperature zone, forming small particles composed of non-crystalline silica, commonly known as silica fume (SF)[23].The residual products that emerge from the manufacturing of silicon metal and ferrosilicon alloys, possessing silicon concentrations of 75% or higher, generally encompass 85–95% non-crystalline silica. In contrast, the by-product from the production of ferrosilicon alloys containing 50% silicon has a lower silica content and exhibits less pozzolanic properties. Hence, the SiO_2 content of silica fume is directly linked to the type of alloy produced [1, 23].

1.11.3 Fly Ash

Fly ash (FA) is a byproduct of coal combustion used for energy production. It has been observed that fly ash possesses the capability to eliminate diverse environmental pollutants. Fly ash can be chemically and physically activated to increase its adsorption ability. Fly ash has also demonstrated significant potential for use in the construction sector. Fly ash is transformed into zeolites, overcoming the problem of disposal while creating a useful and advantageous product [17, 24].

1.12 Agricultural Wastes

1.12.1 Corn cob Ash

The fine waste product known as corn cob ash (CCA) is produced when maize and corn are burned. Around 139 million ha of land were used to produce 589 million tons of maize by the year 2000.With 8.04 million tons produced in 2001, South Africa led all African nations, followed by Nigeria with 4.62 million tones [25]. According to earlier research, the maize cob ash comprises an oxygen-deficient combination of $Al2O3$ and $SiO2$ that is between 70–75 percent and more than 65% $SiO2$ [4, 25].

1.12.2 Rice husk Ash

Rice husk is the naturally occurring outer layer that forms around rice grains as they mature. In nations with substantial rice cultivation, such as China, India, Indonesia, Malaysia, and Bangladesh, where thriving rice milling sectors exist, rice husk is regarded as a form of agricultural solid waste. By the conclusion of 2013, the worldwide annual harvest of rice husk exceeded 742 million metric tons, constituting over 20% of this total harvest. In the context of India, the rice milling procedure results in approximately 78% of the overall weight as rice, broken rice, and bran, while the remaining 22% corresponds to the weight of rice husk extracted from the paddy [4, 16].

1.12.3 Bagasse Ash

Bagasse ash (BA) is generated as a byproduct when sugar cane bagasse is cogenerated and incinerated at specific temperatures. Nations such as India, Thailand, Brazil, Pakistan, Columbia, the Philippines, Indonesia, and Malaysia experience notable yearly generation of bagasse ash, which is frequently disposed of into the environment without appropriate utilization. However, research has shown that this mineral holds great potential as a pozzolanic material and can effectively serve as an additive to Portland cement in both mortar and concrete applications [4].When sugar cane bagasse ash undergoes air calcination at 600°C with a heating rate of 10°C/min, it showcases supplementary attributes including amorphous silica, an elevated surface area, and minimal carbon content. Incorporating bagasse ash (BA) into a concrete mix not only adds value to waste materials but also contributes to the global reduction of CO2 emissions. The presence of pozzolan minerals in bagasse ash is significantly influenced by its chemical and physical attributes [4, 7].

1.12.4 Wheat Straw Ash

Wheat straw is a byproduct of agriculture that has significant SiO2 content: When burned, it produces pozzolanic ash that is highly silica rich.[26]. In Turkey, wheat is a significant agricultural product. In this study, wheat straws are pre burned after being milled to a size of 1 to 5 mm. Later, the pre-burned material is burned under controlled circumstances for 5 hours at 570 and 670 degrees Celsius. The ash is abruptly cooled and crushed to a size of 90–200 m. Ash is used to create the standard test specimens, which are then mechanically, chemically, and physically examined to determine their pozzolanic qualities [26].

1.12.5 Saw dust Ash

Sawdust is a waste product generated during the mechanical processing of wood into various sizes and shapes. Often, this dust is burned for home heating, resulting in sawdust ash (SDA), which exhibits pozzolanic properties. Dry sawdust concrete possesses insulation characteristics similar to wood and is significantly lighter, weighing only 30% of regular concrete. When the correct cement to sawdust ratios are employed, sawdust concrete is non-flammable. Due to its attributes, sawdust concrete finds applications as a fundamental building material[27].

1.13 Mechanical Properties of Concrete

1.13.1 Stress-Strain behavior

As per the investigation, the stress-strain formula for confined high-strength concrete offers fairly precise forecasts of the empirical performance observed in circular and square samples featuring diverse configurations of normal- or ultra-high-yield strength confinement. The longitudinal strain at which the initial hoop or spiral fracture occurs in confined high-strength concrete is detailed, alongside a suggested empirical equation for its computation[18]. Four distinct variations of high-strength concrete (HSC) underwent stress-strain curve examinations at varying temperatures (20, 100, 200, 400, 600, and 800°C). Factors such as concrete strength, aggregate type and steel fiber inclusion were considered in the experimental study. Derived from the stress-strain curve test outcomes, unadorned HSC demonstrates brittle characteristics at temperatures below 600°C and a shift to ductile attributes beyond 600°C. On the other hand, steel-fiber HSC exhibits ductility at temperatures above 400°C.Within the temperature interval of 100–400°C, the compressive strength of HSC experiences a decline of approximately 25% when contrasted with its strength at ambient conditions. As temperature rises, the strength consistently diminishes, dwindling to around a quarter of its initial potency at 800°C. Temperature also impacts the strain observed at maximum loading, elevating from 0.003 at room temperature to 0.02 at 800°C [28].

1.13.2 Compressive Strength

High strength concrete (HSC), an innovative construction material, stands out for its superior compressive strength. Its exceptional durability and load-bearing capacity make it suitable for constructing slender and long-lasting structures using modern engineering and building techniques. Previous research studies have demonstrated that incorporating sugarcane bagasse ash (BA) into the concrete results in increased compressive strength.

The study compared control concrete (CT) mixed with 100% Portland cement (PC) to mixtures combined with BA. The CT concrete exhibited relatively high strength development, with compressive strengths of 60.5 MPa at 7 days, 65.6 MPa at 28 days, and 75.2 MPa at 90 days. In contrast, the normalized compressive strengths of concrete combined with 10% BA and 20% BA (at the same ages) were found to be in the range of 102-107% and 101-104%, respectively. Both of these measurements surpassed those recorded in the CT concrete, signifying the favorable influence of integrating BA on augmenting the compressive strength of high-strength concrete.[12].

1.13.3 Flexural Strength

The ability of concrete to resist bending without fracturing is evaluated through its flexural strength. It is essential for designing bending-stress-prone structures like beams, slabs, and bridges. Commonly used to increase flexural strength is reinforced concrete, which combines the compressive strength of concrete with the tensile strength of steel [4, 15].

1.14 Bricks

Since they have been around for thousands of years, bricks are among the most traditional and often used building materials. In order to give them strength and longevity, they are often created by molding clay or other materials into rectangular blocks and then burning them in a kiln or sun dried. Bricks are available in a variety of shapes, hues, and textures, giving architects and builders the freedom to produce aesthetically beautiful designs[29]. They are ideal for various climates and safety standards because of their high thermal insulation and fire resistance. Bricks are widely used in both conventional and modern building because of their uniformity and simplicity of placement. Their attractiveness as an eco-friendly choice in building materials is further enhanced by the fact that they are sustainable and recyclable[29, 30].

1.15 Unburnt Bricks

Burnt bricks are a form of building material made from natural clay without going through the kiln firing process. They are often referred to as "sun-dried" or "air-dried" bricks. The clay for these bricks is molded into the desired shape, which is then allowed to dry naturally in the sun. Unfired bricks have lower compressive strength and a more rustic appearance than fired bricks, but are still an economical and environmentally friendly option for some construction projects [13]. They often work in kilns or areas with limited access to fuel. Burnt bricks generally provide structural strength, but because they are prone to water damage, adequate moisture management during construction and after completion is critical. Despite their drawbacks, fired bricks are nevertheless valuable in sustainable construction methods because they consume less energy to produce and emit fewer greenhouse emissions than fired bricks [14, 31].

1.16 Mechanical Properties of Unburnt Bricks

1.16.1 Compressive Strength

Unfired bricks have a lower compressive strength than fired bricks, often between 1 and 5 megapascals (MPa). Their weaker bonding from natural drying without kiln firing makes them more suited for non-load-bearing structures like walls and partitions. For them to be durable, proper curing and moisture protection are crucial. Previous research showed the effect of intrusion of other cementitious material to unburnt bricks [32].

1.16.2 Modulus of Rupture

The modulus of rupture (MOR) of a material is a measure of its capacity to withstand bending or flexural forces without shattering. It denotes the highest tensile stress that a material can sustain before breaking under bending force. Because concrete and other brittle materials are stronger under compression than tension, the MOR is lower than compressive strength. MOR is an important metric for planning and evaluating the performance of bending-stressed structural elements such as beams, slabs, and bridges [32].

1.17 Summary

Drawing from the preceding discussions, it can be deduced that the incorporation of bagasse ash into concrete markedly enhances its compressive strength. However, existing literature also establishes that this practice diminishes the flexural strength of concrete, attributed to the dilution impact caused by cement. On the other hand, if we talk about the infiltration of cementitious materials in unburnt bricks we conclude that it increases the compressive strength of unburnt bricks, although the modulus of rupture of burnt bricks is less than the compressive strength.

Experimental Program

1.18 General

Studying the behavior of high strength concrete using bagasse ash needs detailed test programs with various concrete mix regimes. The test program includes basic mechanical testing of concrete specimens including compressive strength test. Different concrete specimens are casted with different percentage of cement replacement with bagasse ash. The stress strain response and elastic modulus is also analyzed after testing.

1.19 Preparation of Specimens

1.20 Materials

The following materials are used in this study. They are described below:

1.20.1 Cement

Ordinary Portland Cement (OPC) was used as a binder for making controlled high strength concrete samples and bagasse ash modified high strength concrete samples in this study. Its chemical composition

Obtained is shown in Table:

3.3 1 Properties of Portland cement

Constituents	Mass Percentage (%)	
	O.P.C	Silica Fume
CaO	79	1.8
$Al2O_3$	13.82	--
SiO_2	5.8	96.98
Fe_2O_3	1.16	0.2
$ZnO+MnO+TiO_2$	0.22	--
K_2O	--	1

1.20.2 Fine Aggregates

In this study natural sand was used. This sand was obtained from Qibla Bandi. Most of the sands of Pakistan have Fineness Modulus less than 2.4. This is because the sands of Pakistan are quite finer. At the similar workability value finer sand require more Superplasticizer than coarse sand. In this study coarser sand having fineness modulus of 2.5 was used to prevent the usage of larger volumes of superplasticizer. The results of sand gradation and its comparison with ASTMC33/C33M-13 limits is given in Table:

3.3 2 Sieve analysis of fine aggregate

Sieve Number	Sieve Size (mm)	Weight Retained (grams)	Percent Retained (%)	Cumulative Percent Retained (%)	Percent Passing (%)

#4	4.75	0.027	2.7	2.65	97.35
#8	2.36	0.0305	3.05	5.70	94.30
#16	1.18	0.121	12.1	17.80	82.02
#30	0.6	0.238	23.8	41.60	58.40
#50	0.3	0.367	36.7	78.35	21.65
#100	0.15	0.153	15.3	93.65	6.35
Pan	0	0.0165	1.65		
Fineness Modulus				2.41	

1.20.3 Coarse Aggregates

In this study limestone based coarse aggregates were used which were obtained from Taxila. The maximum size aggregate was 12.7 mm. The gradation of aggregate in its natural state was not according to ASTM C-33, so a blend of different sizes was prepared to bring the gradation in between the ASTMC33/C33M-13 bounds [24, 33].

1.20.4 Properties of aggregates

3.3 3 Properties of aggregates

Sr No.	**Property**	**Results**
1	Bulk Specific Gravity of Sand	**2.77**

2	Absorption Value of Sand	**1.52%**
3	Fineness Modulus of Sand	**2.711**
4	Bulk Specific Gravity of Coarse Aggregate	**2.65**
5	Absorption of Coarse Aggregate	**1.14%**
6	Maximum Aggregate Size of Coarse Aggregate	**9.43mm**
7	Dry-Rodded Bulk Density	**1486kg/m^3**

1.20.5 Water

Potable water was used for mixing and curing of concrete.

1.20.6 Chemical and Mineral Admixtures:

The densified silica fume was used as mineral admixture. The bulk specific gravity of silica fume was 2.241. It was chosen from the commercially available silica fume products. One was from BASF Chemicals (PVT) LTD and the other was from Sika Chemicals (PVT) LTD. Based on the quantity of SiO2, which is the main pozzolanic agent, Silica Fume 1 obtained from BASF Chemicals was chosen from two.

1.20.7

1.20.8 Mix Proportions:

1:1.18:1.28

3.3 4Mix Ratio Calculations

Samples	Cement (kg/m^3)	Water to Cement Ratio	Sand(kg/m^3)	Coarse Aggregate(kg/m^3)	Bagasse Ash(kg/m^3)	Water(kg/m^3)	Superplasticizer9ml) (1% of cement,kg)	Silica Fume(kg) (10% of cement,kg)	No of samples
HSC	14.20	0.3	16.87	18.936	0	4.26	0.142	1.42	4
O5 SCBA-HSC	12.24	0.3	16.86	18.936	1.954	3.672	0.1224	1.214	4
10 SCBA-HSC	10.29	0.3	16.87	18.936	3.9057	3.087	0.1029	1.029	4
15 SCBA-HSC	8.342	0.3	16.87	18.936	5.85	2.502	0.0834	0.834	4

1.20.9 Mixing of Concrete Ingredients:

A horizontal drum mixer (Fig 3.4) was used to carry out the mixing of concrete ingredients. First the coarse aggregate and sand were measured on weight balance according to the calculations were added in the mixer. After this cement was added[34]. For bagasse modified high strength concrete the amount of calculated bagasse ash was added to the mixer. The silica fume was added according to the 10% amount of cement.

1.20.10Concrete Specimen Preparation:

The freshly prepared concrete was placed into the steel cylinder molds in three layers with 25 blows per layer as given in (ASTM C192/C192M-16a 2016). The steel cylinders were oiled before concrete placing. The size of specimen was 300mm x 150mm (300mm height and 150 mm diameter). The top surface of freshly prepared concrete was finished by trowel. All the specimens were kept in the molds for 24 hours. Following a 24-hour period, the specimens were removed from the molds and subsequently positioned within a curing tank for 28 days, maintaining a humidity level of 95% and a temperature of 23°C [35].

1.21 Material property test:

Comprehensive material property tests, including flexural, split tensile, and compressive tests, were performed in this section at room temperature. Detailed information about the testing procedures, techniques, equipment used, and testing variables is thoroughly discussed..

1.21.1 Test specimens:

1.22 Test procedures:

1.23 General procedure:

1.23.1 Compressive strength test:

This is the most important test for high-strength concrete. It measures the maximum compressive load a concrete specimen can withstand before it fails. Concrete cylinders after 7 and 28 days curing were tested with a compression testing machine. Compressive tests on concrete cylinders were performed according to ASTM C39/C39M. The loading rate was 0.2 Mpa/s.

3.3 5 Test Results of three mix ratios

Sr. No	**Mix proportion**	**7 days test(psi)**	**28 days test(psi)**	**No. of samples**
1	**1:1.29:1.83**	6100	8250	**3**
2	1:1.18:1.28	7700	9031	**3**
3	1:1.04:2.21	6900	8465	**3**

Mix Proportion: 1:1.18:1.28

3.3 6 Test Results of BAHSC

Samples	Bagasse ash replacement	7 days strength in Mpa	7 days Strength in Psi	28 days strength in Mpa	28 days strength in Mpa
1	5%	62.99	9133	78.13	11328
2	5%	65.76	9535	78.68	11411
3	5%	64.21	9311	79.51	11531
4	10%	62.03	8995	80.13	11621
5	10%	60.15	8721	80.90	11733
6	10%	61.75	8954	81.79	11863
7	15%	61.45	8910	80.02	11605
8	15%	64.15	9302	73.65	10682
9	15%	63.32	9182	84.03	12187

1.23.2 Split tensile strength test:

The split tensile test, often denoted as the Brazilian test, is a commonly utilized laboratory method for evaluating the tensile strength of concrete, rocks, and other materials with brittle characteristics. It proves especially valuable for materials that are challenging or not suitable for conventional direct tension testing methods.[36]. In the split tensile test, a cylindrical or disc-shaped specimen is subjected to diametric compressive loading. The test is performed as follows:

1. Sample Preparation: A cylindrical or disc shaped sample is cast or prepared from the material under investigation. For concrete, a cylindrical specimen is commonly used. The specimen should have smooth, flat and parallel ends to ensure accurate loading and failure.

2. Loading setup: The prepared specimen is placed on the testing machine, and a compressive force is applied diametrically to the specimen. The force is applied perpendicular to the axis of the cylinder, causing the specimen to experience tensile stress along the direction of the applied load.

3. Failure Mechanism: As the load increases, the specimen will eventually fail along the diametric plane. This failure is caused by tensile stresses acting perpendicular to the applied compressive load. The failure plane usually develops as a curved crack that propagates through the center of the specimen, splitting it in two.

4. Measurement: The tensile strength is determined by utilizing the load at the point of failure and the cross-sectional area of the specimen.The formula for split tensile strength (T) is given by:

$$T = 2P / (\pi * D * d)$$

Where:

T = Split tensile strength

P = Failure load (force applied to the specimen until failure)

D = Diameter of the specimen

d = Thickness of the specimen (for disc-shaped specimens)

The split tensile strength is denoted in terms of force per unit area, such as MPa or psi (pounds per square inch), contingent upon the system of measurement employed[36].

The split tensile test was conducted on the concrete cylinder following the guidelines of ASTM C496/C496M. The loading rate for the split tensile test was maintained as stipulated by ASTM C496/C496M during the assessment of the concrete cylinder. The loading rate was kept to 0.2 Mpa/s. Three tests were carried out for each mix and average was taken.

1.23.3 Flexural Strength Test:

Flexural strength test is carried out on reinforced concrete beams for analyzing the flexural strength of high strength concrete using bagasse ash. The ASTM C78/C78M is used for testing concrete beams [37].

Results and Discussion

This section includes the evaluation of the mechanical properties of the tested material through three basic tests: compressive test, split tensile test and flexural test. Compressive testing provides critical insight into a material's ability to withstand axial loads, revealing an impressive compressive strength value. Meanwhile, split tensile test evaluates the tensile strength of a material by subjecting it to indirect tension, which gives a significant tensile strength value. Finally, the flexural test examines the bending behavior of the material, indicating its ability to withstand external loads without fracture. The results obtained from all three tests collectively indicate that the material exhibits excellent mechanical performance, making it a promising candidate for various structural applications.

1.24 Compressive strength

3 cylinders were tested for control sample concrete cylinders. 3 concrete cylinders were tested for 5%, 10%, 15% replacement of cement with SCBA. Results of these test are presented in figure:

Table 4. 1 Compressive strength of BAHSC

sample	BA replacement %	7 days strength Mpa	7 days strength Psi	28 days strength Mpa	28 days strength Psi
1	5	62.99	9133	78.13	11328
2	5	65.76	9535	78.68	11411
3	5	64.21	9311	79.51	11531
4	10	62.03	8995	80.13	11621
5	10	60.15	8721	80.9	11733
6	10	61.75	8954	81.79	11862
7	15	61.45	8910	80.02	11605
8	15	64.15	9302	73.65	10682
9	15	63.32	9182	84.03	11555

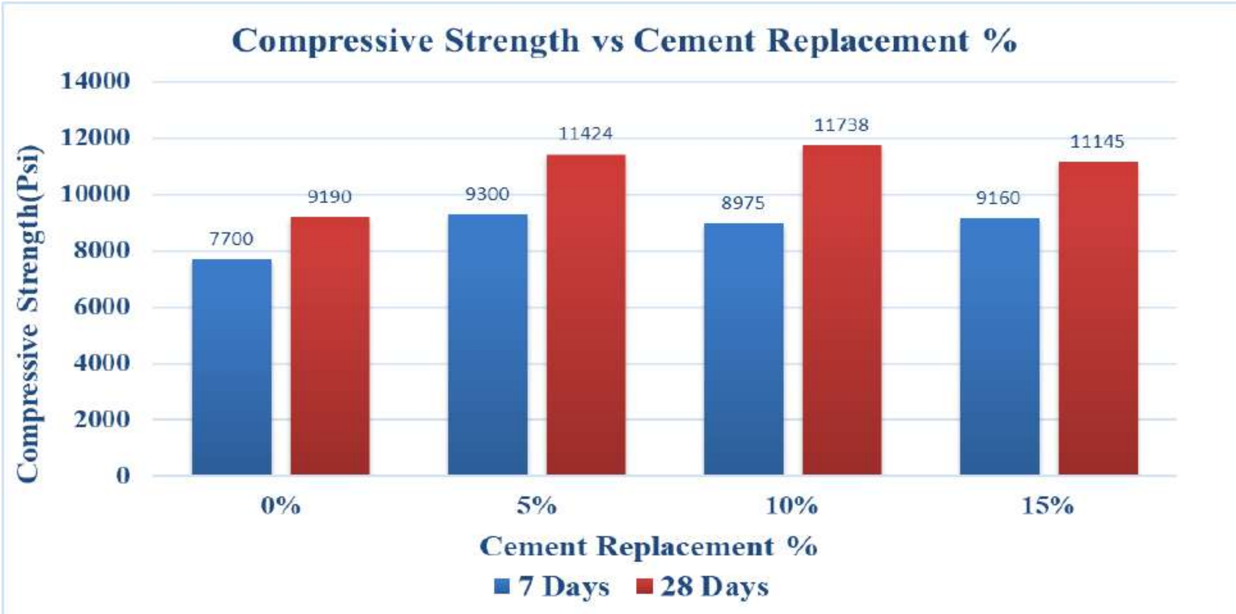

Figure 4. 1 Compressive strength VS Cement Replacement

The analysis of compressive strength in concrete samples indicated that the blend featuring a 10% cement replacement showcased the greatest compressive strength in comparison to the samples with 5% and 15% cement replacements. This finding indicates that a 10% cement replacement provides the optimal balance between cement and the replacement material, resulting in improved compressive strength performance. However, as the cement replacement was further increased to 15%, we observed a decrease in compressive strength, suggesting that higher replacement percentages may negatively impact the overall strength of the concrete.

1.25 Split tensile test

Three concrete cylinders were cast for each percentage of cement replacement (5%, 10%, and 15%) and subjected to a standard 28-day curing process. After the curing period split tensile strength tests were performed on each set of cylinders to evaluate the mechanical properties. This approach ensured that the results were statistically representative and allowed for a comprehensive comparison of the effects of different cement replacement levels on the concrete's performance.

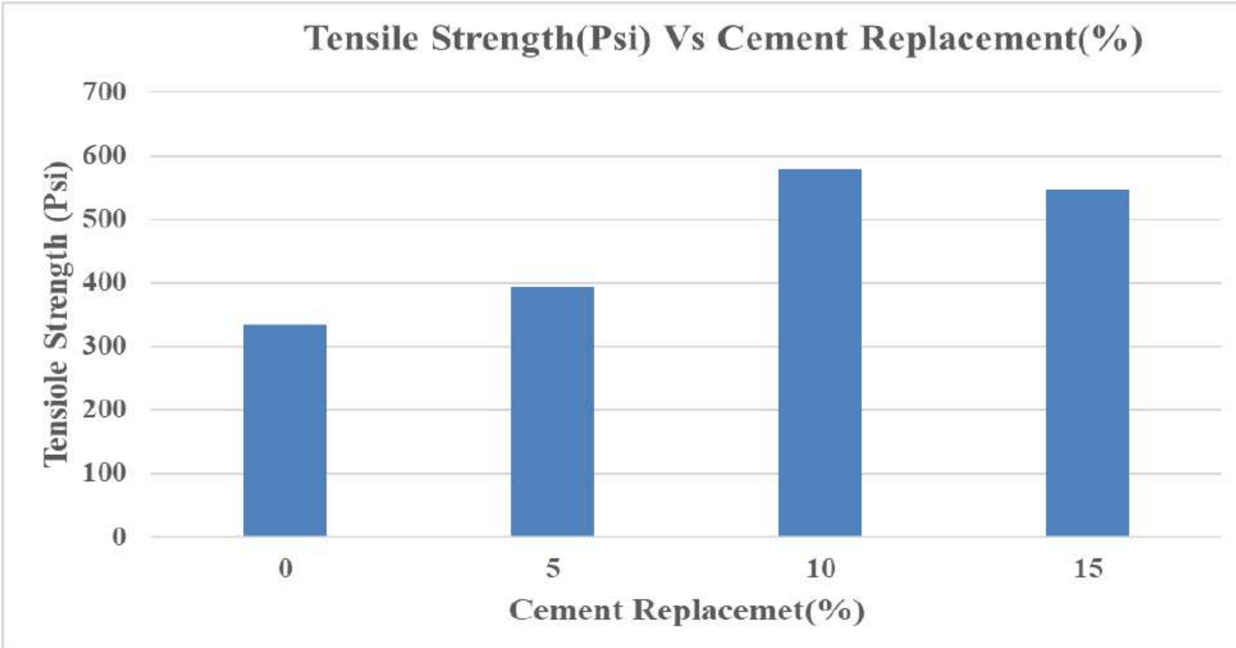

Figure 4. 2 Tensile strength Vs cement replacement (BAHSC)

After a 28-day curing period, concrete cylinders with varying percentages of cement replacement (5%, 10%, and 15%) underwent split tensile testing. The findings unveiled that among the three percentages, the concrete cylinders with a 10% cement replacement displayed the utmost split tensile strength. This outcome suggests that a 10% cement replacement positively impacted the concrete's tensile strength, enhancing its resistance to indirect tension forces. However, when the cement replacement percentage was increased to 15%, a decrease in split tensile strength was observed, indicating that higher replacement percentages might negatively affect the material's ability to withstand indirect tension. These outcomes provide valuable insights into the impact of cement replacement on the concrete's tensile properties and aid in determining the most suitable replacement level for achieving the desired mechanical performance.

1.26 Flexural test

After a 28-day curing period, the concrete beams were subjected to a flexural test to evaluate their bending behavior. Each beam presents a different mix with cement replacement of 5%, 10% and 15%. On applying load and measuring deflection it became clear that concrete beams with 10% cement replacement showed the highest flexural strength among the three cases. This result shows a positive effect of 10% cement replacement on the ability of concrete to withstand external loads without fracturing. However, upon closer inspection, we observed a reduction in flexural strength for beams with 15% cement replacement, which underscores the importance of maintaining an optimal balance between cement and replacement material. While our strength values were not as high as desired, these results provide valuable insight into the impact of various cement replacement percentages on concrete's ability to flex, prompting us to explore ways to enhance the mechanical properties of the material for future applications.

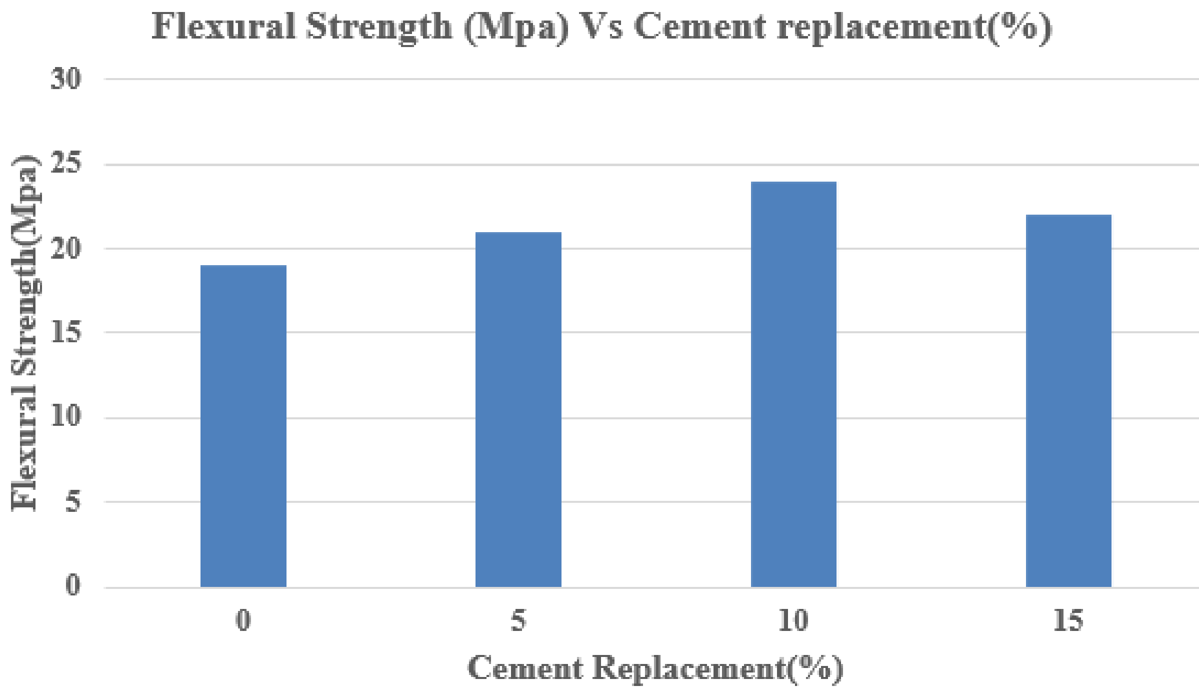

Figure 4. 3 Flexural strength Vs cement replacement

1.27 Unburnt bricks

The primary objective of this study is to investigate the impacts of introducing sugar cane bagasse ash into unburnt bricks and assess their compressive strength. The compressive test serves as a fundamental evaluation method to determine the bricks' ability to withstand axial loads, making it crucial for assessing their structural performance. Our aim is to conduct compressive tests on unfired bricks containing different proportions of sugar cane bagasse ash, aiming to identify the optimal blend that enhances strength while preserving the environmentally friendly attributes of unfired bricks. To achieve this, we carefully incorporated varying proportions of sugar cane bagasse ash into the brick-making process, creating distinct mixtures. Each mix proportion was meticulously used to cast three separate bricks, ensuring consistency and precision in the experimental setup. The compressive tests were then carried out on these individual bricks to assess their strength and structural behavior. Through the implementation of numerous tests for each mixture ratio, our intention was to mitigate discrepancies and acquire dependable data, thereby facilitating a comprehensive exploration of the influence of sugar cane bagasse ash on the compressive strength of unfired bricks.

Table 4.4 1 Compressive strength Unburnt bricks

Sample	Strength (Mpa)
Control sample	2.26
10% SCBA replacement	2.6
20% SCBA replacement	2.65
30% SCBA replacement	3.25
40% SCBA replacement	5.3
50% SCBA replacement	6.8

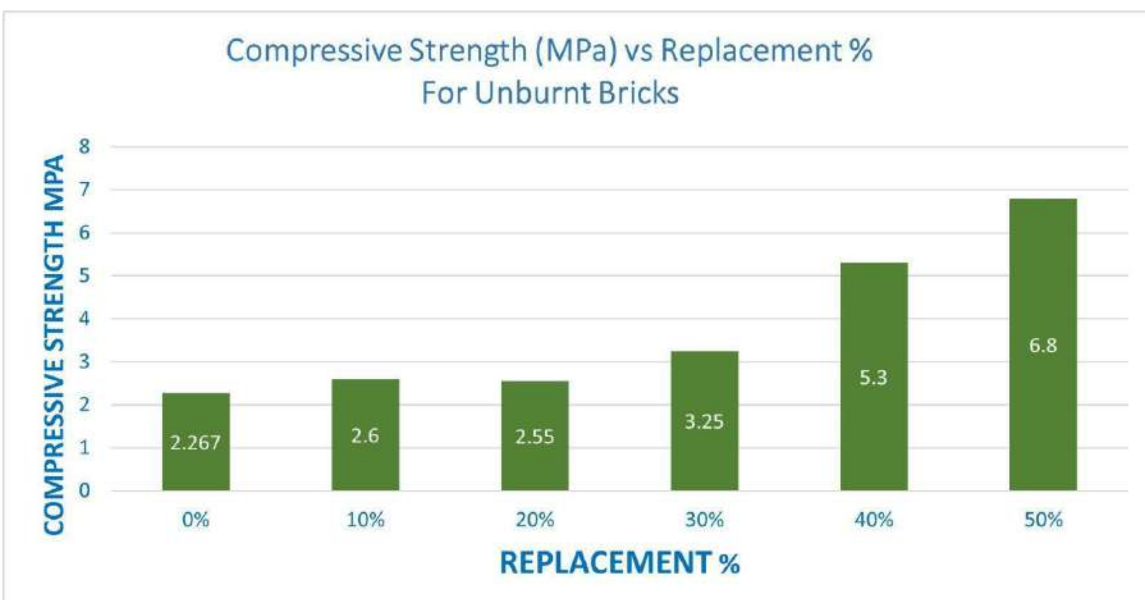

Figure 4.4 1 Compressive strength Vs Replacements

Conclusion

Based on the results of all tests conducted on concrete and bricks, the following key conclusions can be drawn:

1.28 For Concrete

1. Compressive Strength: Among the various replacement percentages (5%, 10%, and 15%), the concrete specimens with a 10% cement replacement demonstrated the greatest compressive strength. This suggests that a 10% cement replacement positively influenced the material's ability to withstand axial loads.

2. Split Tensile Strength: Similar to compressive strength, the concrete cylinders with 10% cement replacement displayed the highest split tensile strength, indicating improved resistance to indirect tension forces.

3. Flexural Strength: The concrete beams with 10% cement replacement demonstrated the most remarkable flexural strength among the three percentages. This finding underscores the importance of finding the right balance between cement and replacement material for optimal bending behavior.

4. Overall Impact: While 10% cement replacement yielded favorable results across all tests, higher replacement percentages (15%) led to decreased strength values. This highlights the need to carefully consider the cement replacement level to achieve the desired mechanical properties.

1.29 For Unburnt Bricks with Sugar Cane Bagasse Ash:

1. Compressive Strength: The incorporation of sugar cane bagasse ash into unburnt bricks positively influenced their compressive strength. A specific mix proportion (to be mentioned in the results section) exhibited the highest compressive strength, showing potential for producing stronger and eco-friendly bricks.

2. Environmental Benefit: The utilization of sugar cane bagasse ash as a partial substitute for conventional brick-making constituents showcases a sustainable strategy for waste management and contributes to mitigating environmental repercussions.

3. Research Implications: The study's conclusions offer insightful information about the practicality of employing sugar cane bagasse ash in unburned bricks, opening the door to more investigation and advancement in the field of environmentally friendly building materials.

Overall, the results of both concrete and unburnt bricks tests emphasize the significance of carefully selecting replacement materials to optimize the mechanical performance of construction materials while promoting environmentally responsible practices. These findings encourage further exploration and innovation in sustainable construction practices for a greener and more resilient future.

Recommendations:

1. **Further Investigation of Optimal Mix Proportions:** Based on the results obtained from the tests conducted on concrete and unburnt bricks with sugar cane bagasse ash, it is recommended to conduct further research to explore the optimal mix proportions for both materials. Fine-tuning the mix designs could potentially lead to even higher strength and improved sustainability.

2. **Durability Testing**: In order to evaluate the enduring performance and resilience of both the concrete and unfired bricks over the long term, it is recommended to carry out supplementary assessments including evaluations of freeze-thaw resistance, sulfate resistance, and alkali-silica reaction (ASR) potential. Understanding the materials'

behavior under various exposure conditions will provide valuable insights for real-world applications.

3. **Microstructural Analysis:**Examine the interfacial bond between cementitious materials and aggregates using microstructural investigation techniques including scanning electron microscopy (SEM) and X-ray diffraction (XRD), as well as the reaction products formed in the presence of sugar cane bagasse ash. This analysis can provide valuable information on the mechanisms responsible for the observed strength improvements.

4. **Environmental Impact Assessment**: Conduct a life cycle assessment (LCA) to evaluate the overall environmental impact of using concrete with various cement replacement percentages and unburnt bricks with sugar cane bagasse ash. This assessment will help quantify the environmental benefits and guide sustainable decision-making in construction practices.

5. **Economic Analysis**: Perform a cost-benefit analysis to compare the production costs of the novel concrete and unburnt bricks against conventional materials. Assessing the economic viability of adopting these sustainable materials will be crucial for their acceptance in the construction industry.

8**. Educational and Awareness Initiatives**: Promote the benefits of using eco-friendly construction materials by organizing workshops, seminars, or educational campaigns for construction professionals, builders, and policymakers. Raising awareness about sustainable construction practices can encourage broader adoption.

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Originality Certificate

We, the undersigned members of the capstone design project group, hereby confirm that the group project titled "**[Optimizing the mechanical performance of eco-friendly high strength concrete and unburnt bricks using sugarcane bagasse ash]**" has been undertaken and completed by us as a collaborative effort. The project report is prepared by the undersigned group members. Any external sources, including published or unpublished works, have been appropriately acknowledged and referenced in accordance with the guidelines provided by NUTECH University.

As a group, we understand the severity of plagiarism and its consequences, and we assure you that the level of plagiarism in this project report is below 20 percent. To ensure the originality of our project report, we have utilized anti-plagiarism (Turnitin) software to verify the uniqueness of the content.

By signing this undertaking certificate, we affirm that our project work adheres to the principles of academic integrity. We are committed to upholding the values and standards of NUTECH University.

Signatures of Group Members:

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[Usama Ihsan Pracha - Group Member 1]

2. 

[Muhammad Hassan Gul - Group Member 2]

3.

[Saddam Afsar - Group Member 3]

4.

[Muhammad Mahad - Group Member 4]

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Date: September 4, 2023