Experimental Study on Rubberized Geopolymer Concrete with Sugarcane Bagasse Ash

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Abstract. The purpose of this experimental investigation is to determine whether it is feasible and effective to use sugarcane bagasse ash (SCBA) in place of some of the cement in rubberized geopolymer concrete. Rubber particles are added to the concrete to improve its ductility and energy absorption capability, while SBA is added as an additional cementitious material to lessen its environmental impact. Sugarcane bagasse ash, a byproduct of the sugarcane industry, has the potential to be utilized as an extra cementitious element due to its pozzolanic properties. To improve the concrete mix's ductility and ability to absorb energy, waste rubber particles are added. Rubberized geopolymer concrete is evaluated in numerous curing circumstances through extensive laboratory testing, which includes compressive strength, flexural strength, and split tensile strength. The study's findings shed light on whether using SCBA in rubberized geopolymer concrete is feasible and present environmentally friendly options for building applications. The study helps to promote circular economy concepts and environmental sustainability in the building industry by lowering cement usage and utilizing waste rubber resources. The design and optimization of rubberized geopolymer concrete mixes for improved mechanical qualities and durability are among the practical implications that may be applied to promote the use of environmentally friendly building materials. The mechanical characteristics of rubberized geopolymer concrete were assessed through experimental research. This paper is a scientific approach for complying the performance evaluation of strength studies such as Flexural strength, Compressive strength, Split tensile Strength, effect of NaOH molarities and the effect of curing method in rubberized geopolymer concrete that contains SCBA.

Keywords: Fly Ash, Sugarcane bagasse Ash, Rubberized Geopolymer Concrete, Alkaline Activator Solution

1 Introduction

The demand for concrete is rising as a result of the increased infrastructure and building development worldwide. Portland cement, a vital component of conventional concrete, is a major contributor to atmospheric carbon dioxide emissions. The majority of the energy and carbon dioxide emissions related to ordinary ready-mixed concrete are caused by Portland cement [1, 2]. The environmental impact of cement production and the high demand for
concrete make it crucial to address the environmental degradation caused by this material. It is therefore necessary to explore alternatives that promote sustainable development. By using activated pozzolanic binders as replacements for ordinary Portland cement (OPC), eco-friendly concrete allows us to use less OPC and reduce CO2 emissions [3]. In the field of building materials, the pursuit of sustainability and innovation has prompted the investigation of substitute approaches that reduce environmental effect while preserving structural soundness. The eco-friendly composition and durability of geopolymer concrete have made it a viable alternative to traditional Portland cement-based concrete. This has special importance as the building sector looks for methods to lower its carbon footprint and lessen its need on non-renewable resources. The use of rubber tyres is increasing, leading to a growing amount of waste rubber. Old and irreparable tyres are often discarded in landfills. To tackle this issue, the construction industry can effectively utilize this waste in large quantities. However, the consumption of cement-based concrete is also rapidly increasing, resulting in increased CO2 emissions. Fly ash (FA), sugarcane bagasse ash (SCBA), and used rubber tyres are significant environmental concerns. Rather than discarding them, it is necessary to address the quantity of their production to avoid landfill problems. Researchers have been working on replacing cement in concrete with environmentally acceptable alternatives for many years. FA and SCBA are materials that can partially or fully replace cement in concrete, depending on specific requirements. Waste rubber tyre utilization and reduction of cement consumption can be achieved by developing geopolymer concrete, which incorporates fly ash and sugarcane bagasse ash as cement replacements and waste rubber crumbs as a substitute for natural aggregates [4]. Overall, the conclusion of the previous journal article likely summarized the key findings of the experimental study and provided insights into the potential of rubberized geopolymer concrete with SCBA as a sustainable and durable construction material.

Building materials made of geopolymeric material present a viable answer to these problems. As an alternative to conventional concrete, which normally uses Portland cement as its binder, geopolymer concrete is a creative and sustainable option. This emerging construction material is gaining recognition in the industry due to its unique characteristics, sustainable qualities, and potential to reduce carbon emissions. Instead of using Portland cement, geopolymer concrete utilizes geopolymer binders that are created through a chemical reaction between source materials rich in silicon (Si) and aluminum (Al), such as fly ash, slag, or other industrial by-products, and alkali activators like sodium hydroxide (NaOH) [4, 3]. By activating these source materials with alkali solutions, geopolymer concrete forms a strong three-dimensional network of geopolymer chains, which provide the necessary strength and binding properties for the concrete. geopolymers are inorganic materials produced through a synthesis process called geo-polymerization. Geopolymerization plays a crucial role in creating geopolymer concrete. It involves a chemical reaction between source materials containing silicon (Si) and aluminum (Al) and alkaline activators. This reaction results in the formation of a geopolymer binder. During geopolymerization, the source materials' silica (Si) and alumina (Al) compounds undergo polycondensation reactions when exposed to an alkaline solution. Typically, solutions of sodium hydroxide (NaOH) and Sodium Silicate are used as alkaline activators [5]. The interaction between the source materials and the alkaline activators leads to the creation of three-dimensional polymer chains. These chains unite and solidify, forming a geopolymer matrix that acts as the binder in geopolymer concrete. The geopolymer binder provides the necessary strength and binding properties for the concrete to set and harden. Geopolymer concrete provides an economical solution by utilizing various waste materials that would otherwise fill landfills and pose health hazards. Therefore, researchers are increasingly inclined towards this user-friendly and environmentally friendly construction technology. The rubber crumb can be used as a
partial replacement for fine aggregate in geopolymer composites [3, 6]. Also investigating the potential utilization of sugarcane bagasse ash (SCBA) as a safe and sustainable material. Bagasse ash mainly consists of SiO$_2$, making it a suitable candidate for Geopolymer. Its pozzolanic nature allows the amorphous silica to react with calcium hydroxide, enhancing the binding properties. SCBA, an agricultural waste, has been recognized as a pozzolanic material after calcination. Geopolymer technology provides an effective method for reusing pozzolanic waste materials. Unlike conventional Portland cements, geopolymers rely on the polycondensation of silica and alumina precursors for structural strength. Geopolymers consist of source materials and alkaline liquids, with high silicon (Si) and aluminum (Al) content. By-product materials such as fly ash, slag, silica fume, red mud, and rice-husk ash can be utilized [7]. Geopolymer concrete (GPC) technology has gained momentum in the construction industry, offering a lower global warming effect compared to conventional OPC concrete. To ensure sustainable growth, it is crucial to avoid excessive use of natural resources and adopt eco-friendly materials or end-products to minimize waste. The buildup of old tires can result in a number of problems, including the release of harmful gasses upon combustion, which can harm the environment and pose health risks [8]. Therefore, in order to limit environmental effects and reduce raw material consumption, it is vital to investigate options that permit the recycling or reuse of waste tires. Rubber waste can be substituted for natural fine and/or coarse aggregates in the production of geopolymer concrete (GPC), producing rubberized geopolymer concrete (RGPC) while maintaining the natural sand content [9]. Using scrap rubber to create geopolymer composites is an eco-friendly way to handle the millions of tires that are made annually. In order to evaluate the performance of the rubberized geopolymer concrete with SCBA, a variety of strength tests will be conducted, including split tensile strength, compressive strength, flexural strength, and the impact of different NaOH molarities on the material's strength. We'll also examine the effects of curative methods.

The primary goal of this is to reduce waste by making use of old rubber tires and SCBAs that have been discarded. Additionally to determine the ideal proportion of rubber crumbs to use in place of fine aggregate.

**2 Materials & Methodology**

**2.1 Materials**

Fly ash, sugarcane bagasse ash, sodium hydroxide, sodium silicate, and fine and coarse aggregates are the ingredients required to make rubberized geopolymer concrete. Since thermal power facilities may be found in practically every Indian state, fly ash is easily accessible. The jaggery mill yields the sugarcane bagasse ash. The alkaline activator solution is made from sodium hydroxide and silicate, both of which are readily available and reasonably priced. Lastly, the waste tire grinding mills are used to gather the rubber crumbs.

**2.1.1 Fly Ash**

A byproduct of burning pulverized coal in coal-fired steam and power facilities is called fly ash (FA). During the combustion process, the pulverized coal is produced into the boiler's combustion chamber and burns instantly to form a molten mineral residue. Ash is formed when the heat generated is absorbed by the boiler tubes, which cool the flue gas and solidify the molten mineral waste. Because of this, the ash's larger particles settle at the bottom of the combustion chamber. We call this slag or bottom ash. Fly ash, on the other hand, is the finer
particle that is suspended in the flue gas. Fly ash is still dumped as a waste product in massive quantities across vast tracts of land. It is indisputable that employing fly ash to replace cement is important. With a high silica and alumina concentration, the FA is a pozzolanic material that has cementitious qualities. In extremely alkaline conditions, fly ash produces an inorganic alumino-silicate polymer product that results in the polymeric Si–O–Al–O linkages known as Geopolymer [4]. Fly ash fineness and quantity are crucial factors in the activation of geopolymer.

2.1.2 Sugarcane bagasse ash

A byproduct of the sugarcane industry, sugarcane bagasse ash (SCBA) is produced when the fibrous waste left over after juice extraction is burned in boilers to produce energy. In the process of making concrete, this ash can partially substitute cement. In the process of making concrete, SCBA can be used in place of cement due to its special chemical characteristics. Calcium silicate hydrate is a cementitious substance that is formed when high concentrations of silicon dioxide and aluminum oxide react with calcium hydroxide in cement. The percentage of silica in bagasse ash is 68.82.

2.1.3 Alkaline Activator solution

Geopolymer concrete is activated using an alkaline activator solution, which is a mixture of sodium hydroxide and sodium silicate solutions. According to recent research and investigations, the compressive strength of geopolymer concrete rises as the concentration of sodium hydroxide or sodium silicate solution increases and the viscosity of the fresh mix increases. Additionally, more brittle concrete with higher compressive strength results from an increase in the molarity (M) of sodium hydroxide solution concentration [10, 11].

2.1.4 Sodium hydroxide

Sodium hydroxide, commonly referred to as caustic soda, has a caustic metallic base with the chemical formula NaOH. It is a white solid that can be found as a 50% saturated solution, flakes, pellets, and granules. One of the alkaline activators used in the manufacturing of geopolymer concrete is sodium hydroxide, which starts the geo polymerization reaction. Geopolymer concrete gets its strength and endurance from a three-dimensional network of covalent connections that are formed when it combines with alumino-silicate elements like fly ash or slag.

2.1.5 Sodium silicate

Sodium silicate is a chemical that combines silica (SiO2) and sodium oxide (Na2O). Sodium silicate is also called water glass. They are easily soluble in water, generating alkaline solutions, except for those that are the most silicon-rich. It is a clear, viscous liquid that is soluble in water and has a wide range of industrial and commercial applications. One of the primary applications of sodium silicate is as an alkaline activator in the production of geopolymer concrete. Geopolymer concrete is made of a three-dimensional network of covalent connections that are formed when it is mixed with aluminosilicate materials like fly ash or slag. This reaction starts the geo polymerization reaction.

2.1.6 Fine Aggregate
This experiment uses manufactured sand, which is created by breaking hard granite stone, as the fine aggregate. The crushed sand has a cube-like form. It has no silt, biological contaminants, clay matter, etc. According to IS requirements, the sand is evaluated for specific gravity and fineness modulus.

2.1.7 Coarse Aggregate

75% of the concrete volume is by the coarse aggregate, making it as a very important constituent. They should have certain requirement with respect to shape, grading, strength and size, though they are considered very inert, they exhibit certain reactivity which is popularly known as alkali aggregate reactivity. Since our geopolymer concrete highly alkaline due to sodium hydroxide Hence alkali aggregates reactivity marks significant important. The coarse aggregates retained in a 12.5 mm I.S. sieve and passed through a 20 mm I.S. sieve were employed in this experimental investigation. In accordance with IS requirements, the coarse aggregate is assessed for specific gravity and fineness modulus.

2.1.8 Rubber Crumbs

Rubber crumbs are small pieces of rubber that are derived from discarded rubber tyres. In concrete, these crumbs can partially replace the sand [6]. Rubber crumbs are a sustainable way to solve the problem of waste disposal and lessen the need for natural resources in concrete. The rubber crumbs reduce the amount of sand required for concrete production, which is an important natural resource. Secondly, it provides a beneficial use for discarded rubber tyres, which would otherwise end up in landfills, taking up valuable space and posing a threat to the environment [2]. Mechanical cutting and grinding were used to develop the rubber crumbs. Test specimens are produced with various percentages of Tyre rubber crumbs in fine aggregates, ranging from, 10%, 20%, and 30% [12].

2.2 Methodology

It covers the mix design of geopolymer concrete, outlining the manufacturing process and the specific curing method employed for the test specimens. Subsequently, it delves into the various types of specimens utilized, the relevant test parameters, and the detailed procedures.

2.2.1 Mix Design

In the case of geopolymer concrete, the mix design follows a similar approach to conventional concrete with some necessary modifications. While established IS regulations can be used to calculate the proportions of a conventional concrete mix, there is no set procedure or set of rules for constructing a mix for geopolymer concrete. As a result, it takes trial and error to arrive at an optimal blend. Prior research was considered in order to determine the final mix design for geopolymer concrete. With a constant NaOH molarity of 8 M, a number of experimental mixes containing fly ash and sugarcane bagasse ash were made by varying the alkaline liquid to fly ash ratio [7], concentration of NaOH, and alkaline liquid to fly ash ratio [13, 14].

<table>
<thead>
<tr>
<th>Mix</th>
<th>SCBA</th>
<th>FA</th>
<th>CA</th>
<th>NaOH Solution</th>
</tr>
</thead>
</table>

Table 1. Mix Design
The specimens for Rubberized geopolymer concrete were prepared and subjected to curing under two conditions: ambient temperature curing and oven curing. In these specimens, the fine aggregates were partially replaced with Rotted tyre rubber crumbs at various percentages, such as 10%, 20% and 30% [15]. Several kinds of specimens were cast in order to assess the mechanical qualities: 15 x 15 x 15 cm cubes (for compressive strength tests conducted over 7 and 28 days), 15 cm diameter and 30 cm height cylinders (for tensile strength tests conducted over 7 and 28 days), and 10 x 10 x 50 cm beams (for flexural strength tests conducted over 7 and 28 days). Testing is carried out using the proper testing apparatus and procedures following the completion of the curing period.

3 Results and Discussions

3.1 Compressive Strength

Rubberized geopolymer concrete's compressive strength is evaluated after seven and twenty-eight days. It is evident that the compressive strength increases as the percentage of rubber crumbs rises from 0% to 20% and then decreases [2]. In geopolymer concrete without addition of SCBA, weak bonding between the tiny aggregates causes voids to form as the rubber content increases, leading to the decrease in the compressive strength. Rubberized geopolymer concrete with SCBA experiences a rapid geopolymerization process as a result of the alkaline activator solution and source material reacting, gaining 85% of its compressive strength in just 7 days. Rubberized geopolymer concrete with SCBA compressive strength is determined by the geopolymeric process that was established there. Additionally, it is evident that raising these contents raises the compressive strength; nevertheless, this depends on the alkaline activator solution concentration and the curing circumstances [16-21]. For the 8M rubberized geopolymer concrete with SCBA, the maximum compressive strength measured is 41.27N/mm². Additionally, the concrete's strength is influenced by the curing process. It is evident that oven curing a specimen yields higher compressive strength than ambient curing.

Table 2. Compressive strength of Rubberized Geopolymer Concrete with SCBA

<table>
<thead>
<tr>
<th>Mix</th>
<th>SCBA Kg/m³</th>
<th>Molarity of NaOH solution</th>
<th>% of Rubber crumbs</th>
<th>Compressive strength in N/mm²</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>7days</td>
</tr>
<tr>
<td>A1</td>
<td>0</td>
<td>8M</td>
<td>0%</td>
<td>30.22</td>
</tr>
<tr>
<td>A2</td>
<td>0</td>
<td>8M</td>
<td>10%</td>
<td>32.04</td>
</tr>
<tr>
<td>A3</td>
<td>153.9</td>
<td>8M</td>
<td>20%</td>
<td>34.22</td>
</tr>
<tr>
<td>A4</td>
<td>153.9</td>
<td>8M</td>
<td>30%</td>
<td>32.03</td>
</tr>
</tbody>
</table>

Table 2. Compressive strength of Rubberized Geopolymer Concrete with SCBA
3.2 Flexural Strength

The flexural strength of rubberized geopolymer concrete with SCBA is measured at 7 days and 28 days and is shown in Table. The flexural strength varies from 5.79 N/mm² to 7.81 N/mm² for 8M molarity and various percentages of rubber crumbs. When the percentage of rubber crumbs rises to 20%, the flexural strength increases; after that, the strength falls. The 8 M mix of 20% rubber crumbs yields the highest flexural strength of 7.81 N/mm², whereas the 8 M mix of 0% rubber crumbs yields the minimum of 5.79 N/mm². The rubberized geopolymer concrete's flexural strength is increased by the addition of rubber crumbs.

Table 3. Flexural strength of Rubberized Geopolymer Concrete with SCBA

<table>
<thead>
<tr>
<th>Mix</th>
<th>SCBA Kg/m³</th>
<th>Molarity of NaOH solution</th>
<th>%of Rubber crumbs</th>
<th>Flexural strength in N/mm²</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>7 days</td>
</tr>
<tr>
<td>A1</td>
<td>0</td>
<td>8M</td>
<td>0%</td>
<td>5.79</td>
</tr>
<tr>
<td>A2</td>
<td>0</td>
<td>8M</td>
<td>10%</td>
<td>5.94</td>
</tr>
<tr>
<td>A3</td>
<td>153.9</td>
<td>8M</td>
<td>20%</td>
<td>6.3</td>
</tr>
<tr>
<td>A4</td>
<td>153.9</td>
<td>8M</td>
<td>30%</td>
<td>6</td>
</tr>
</tbody>
</table>
Additionally, we compare the flexural strength of geopolymer concrete that has been rubberized with SCBA to that of geopolymer concrete that has been cured for 28 days. The addition of SCBA has got significant advantage over Normal geopolymer concrete mix. From the bar graph given below, it is evident that the geopolymer concrete with SCBA has higher flexural strength than that of geopolymer concrete with same percentage of rubber crumbs.

![Bar chart showing variation of flexural strength with % of Rubber crumbs for 8M concentration of NaOH](chart1)

**Fig 2.** Variation of flexural strength with % of Rubber crumbs for 8M concentration of NaOH

The rubberized geopolymer concrete's split tensile strength after seven and twenty-eight days is displayed in the table. Between 2.9 and 3.69 N/mm² for 8M molarity and different percentages of rubber crumbs, the split tensile strength varies. Up to a 20% rise in the percentage of rubber crumbs, the split strength increases; after that, the strength falls. The 20% rubber crumbs mix yields the highest split tensile strength of 3.69 N/mm², while the 0% rubber crumbs mix yields the lowest split tensile strength of 2.9 N/mm².

**3.3 Split Tensile Strength**

![Bar chart showing variation of flexural strength with % of Rubber crumbs for 8M concentration of NaOH in geopolymer concrete with & without SCBA](chart2)

**Fig 3.** Variation of flexural strength with % of Rubber crumbs for 8M concentration of NaOH in geopolymer concrete with & without SCBA

<table>
<thead>
<tr>
<th>% of Rubber crumbs</th>
<th>Geopolymer concrete with SCBA</th>
<th>Geopolymer Concrete</th>
</tr>
</thead>
<tbody>
<tr>
<td>0%</td>
<td>7.29</td>
<td>6.45</td>
</tr>
<tr>
<td>10%</td>
<td>7.5</td>
<td>6.52</td>
</tr>
<tr>
<td>20%</td>
<td>7.81</td>
<td>6.66</td>
</tr>
<tr>
<td>30%</td>
<td>7.65</td>
<td>6.8</td>
</tr>
</tbody>
</table>
### Table 4. Split Tensile strength of Rubberized Geopolymer Concrete with SCBA

<table>
<thead>
<tr>
<th>Mix</th>
<th>SCBA Kg/m³</th>
<th>Molarity of NaOH solution</th>
<th>% of Rubber crumbs</th>
<th>Split Tensile strength in N/mm²</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>7days</td>
</tr>
<tr>
<td>A1</td>
<td>0</td>
<td>8M</td>
<td>0%</td>
<td>2.9</td>
</tr>
<tr>
<td>A2</td>
<td>0</td>
<td>8M</td>
<td>10%</td>
<td>2.98</td>
</tr>
<tr>
<td>A3</td>
<td>153.9</td>
<td>8M</td>
<td>20%</td>
<td>3.06</td>
</tr>
<tr>
<td>A4</td>
<td>153.9</td>
<td>8M</td>
<td>30%</td>
<td>3.02</td>
</tr>
</tbody>
</table>

#### Fig 4. Variation of split tensile strength with % of Rubber crumbs for 8M concentration of NaOH

### 4 Conclusion

In this study, rubberized geopolymer concrete is made by combining agricultural waste, such as sugarcane bagasse ash and discarded rotting tires, with industrial waste from thermal power plants, notably fly ash. NaOH and Na₂SiO₃, two alkaline activators, were used to start the geopolymerization process. In terms of environmental and health considerations, SCBA is often disposed of in landfills or utilized as fertilizer, neither of which is sustainable. For better recycling and waste management of SCBA, using SCBA in building materials presents a viable option. The objective of the experimental studies was to investigate the novel characteristics and mechanical properties of Rubberized geopolymer concrete, such as its compressive strength, splitting tensile strength, and flexural strength. The study's findings allow for the following conclusions to be made:

1. The fresh Rubberized geopolymer concrete has a good consistency, when the concrete mix becomes less workable after the inclusion of rubber crumbs. This characteristic could be improved by adding super plasticizers so that the concrete becomes workable.

2. When rubber fragments go from 0% to 20% of the total, the compressive strength rises and subsequently falls. Without the inclusion of SCBA, the compressive strength of...
geopolymer concrete decreases as a result of voids forming from weak bonding between the small particles and rising rubber content. For the 8M rubberized geopolymer concrete with SCBA, the maximum compressive strength measured is 41.27N/mm².

3. The tensile properties of rubberized geopolymer concrete with SCBA, such as split and flexural tensile strength, increase with the amount of rubber crumbs in the presence of SCBA due to its pozzolanic properties. The greatest flexural strength was seen for 20% of the rubber crumbs; after that, the strength gradually decreased.

4. The concrete's strength is influenced by the curing process. When the specimen is compared to ambient curing, it is evident that oven curing increases the compressive strength.

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