

A REVIEW OF PADDY STRAW, COTTON STALK, FLY ASH AND GGBS-BASED BIO-BRICKS FOR LOW-COST RURAL HOUSING

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ABSTRACT

As people look for ways to make building materials more sustainable, there's a growing interest in using agricultural waste and industrial by-products. This is because traditional bricks are not very eco-friendly. Researchers have been studying how to make bricks from things like rice straw, cotton stalks, and other waste materials. They've also been looking at using fly ash and slag, which are leftovers from industrial processes, as binding agents. These new bricks are not only better for the environment, but they're also lighter and can help keep buildings cool or warm. One way to make these bricks is by using a special kind of activator that makes them easier to handle. However, there's still a lot to learn about how to mix these materials together to create strong, durable bricks that are affordable for people in rural areas. For example, we need to figure out the best proportions of each material to use, and how they'll hold up to things like water and extreme temperatures. If we can get this right, it could be a game-changer for sustainable building.

Keywords: Bio-bricks, Paddy Straw, Cotton Stalk, Fly Ash, GGBS, Geopolymer, One-Part Geopolymer, Rural Housing, Sustainable Construction

1. INTRODUCTION

Building materials are really important when it comes to making homes affordable, using resources wisely, and being kind to the environment. Traditional bricks are made from clay and need to be fired at high temperatures. This process can hurt the environment and use up a lot of resources, depending on how it's done. So, people are looking for new ways to make bricks that use recycled materials and don't need to be fired in a kiln. These new bricks still need to be strong and affordable, though - just being good for the environment isn't enough. They have to meet certain standards to make sure they're safe. Researchers have looked into using paddy straw in its raw or processed form to make building products that are lightweight and good at keeping heat in. They've also talked about rice-straw ash and rice-husk ash, but these are different from regular paddy straw because burning them changes what they're made of and how they work. On the other hand, not as much attention has been given to cotton stalks when it comes to making bricks. While there has been some research on using lignocellulosic materials and composites that contain cotton stalks, this doesn't directly tell us how well a mix of paddy straw and cotton stalk would work in a special kind of concrete made with fly ash and GGBS.

Farming activities produce a lot of leftover materials, like the straw from rice fields and the stalks from cotton plants. Using these leftovers to make building materials could help reduce our need for new resources. But there's a catch - these materials are made of lignocellulose, which means their shape, moisture levels, and ability to absorb and interact with other substances can affect how well they hold together. Just adding more of these fibers to a mixture doesn't necessarily make it better. To create a good building material, we need to find a balance between making it lighter or more energy-efficient, and keeping it strong, stable, and resistant to moisture. This is important because if we get it right, we can make bricks that are not only good for the environment but also durable and long-lasting.

Industrial waste products like fly ash and ground granulated blast-furnace slag can be used to create special kinds of binding systems, such as alkali-activated or geopolymer-type systems. Fly ash is particularly useful because it contains reactive aluminosilicate components. On the other hand, many GGBS materials are rich in calcium, which can help improve strength. However, the performance

of these binding systems depends on several factors, including the type of feedstock used, the proportions of the precursors, the amount of water, the dosage of the activator, and the curing conditions. Some research has shown that these binding systems can achieve high strengths when used on their own, but this does not necessarily mean that they will perform equally well when used to make bricks that contain agricultural fibers. In fact, the strength of such bricks can be quite different from that of the binding system alone.

When it comes to making bricks, people are looking for simpler ways to do it. One way to do this is to use a system that only needs one part, like a dry mix that you add water to. This mix can include a special helper called anhydrous sodium metasilicate. The good thing about this approach is that you don't need to make a separate liquid solution, which can be a hassle. However, the helper itself can be expensive and you have to handle it carefully. In areas where people are building homes in the countryside, using local materials and letting the bricks dry in the air might be a good idea. But to know for sure if this is a good idea, you need to compare the costs of the materials, how they are made, how they are dried, and how they are transported. This way, you can figure out what works best.

This study looks at a new idea for a building material that combines four different things: paddy straw, cotton stalk, fly ash, and ground granulated blast furnace slag. We're comparing how these different materials work on their own, and looking at how they're different from each other - like how fibre-based materials are different from ash-based ones. We're also trying to figure out if using just one part to activate the material is a good idea. The goal here isn't to say that this new material is already better than traditional bricks in terms of strength or cost - it's more about creating a plan to test it and see how it does in terms of things like how strong how much water it absorbs, how dense it is, how it behaves in different temperatures, how durable it is, and how much it costs.



Fig.1 Conceptual Illustration of Hybrid Bio-Brick Production Using Agricultural Waste and Industrial By-Products for Sustainable Rural Housing.

2. LITERATURE SURVEY

Oli et al. (2026) – Performance Evaluation and Application Framework for Sustainable Brick Manufacturing Using Rice Husk Ash

Researchers recently looked into making bricks in a more environmentally friendly way by using ash from rice husks. They tried different amounts of ash to see how it affected the bricks. The study checked things like how strong the bricks were, how much water they absorbed, how much they shrank, and if they got a weird white coating on them. What they found was that the amount of rice husk ash used really matters for the brick's quality. There's a sweet spot for how much ash to use to get good results. This study suggests that using ash from farms can be a good way to make bricks that are better for the planet.

Prabhu Gurunathappa Sheelavantar et al. (2026) – Performance Evaluation and TiGRA-Based MultiResponse Optimization of Sustainable Fly AshSlag-Based One-Part Alkali-Activated Concrete Mix Design

Researchers have been looking into creating a more sustainable type of concrete called one-part alkali-activated concrete, or OPAAC for short. This new concrete uses fly ash and ground granulated blast furnace slag as alternative materials to traditional cement. The goal was to see how well this new concrete would perform in terms of strength, durability, and resistance to water and salt damage. To achieve this, the researchers used a special method called Taguchi L9 orthogonal array and Grey Relational Analysis to find the perfect mix of ingredients. They made nine different batches of concrete and let them cure for 28 days at room temperature. What they found was that adding more ground granulated blast furnace slag made the concrete stronger and more durable. This is because it creates a denser network of tiny particles that makes the concrete more resistant to damage. The best mix they found was one that used 70% fly ash and 30% ground granulated blast furnace slag, with a certain amount of water and activator added. This mix was able to achieve a compressive strength of 48.30 MPa, which is a measure of how much pressure the concrete can withstand. Overall, the study showed that OPAAC can

be a practical and sustainable alternative to traditional concrete, which is better for the environment. By using waste materials like fly ash and ground granulated blast furnace slag, we can reduce the amount of waste sent to landfills and decrease the carbon footprint of the construction industry. This new type of concrete has the potential to make buildings and infrastructure more sustainable and environmentally friendly.

Ansari and Kumar (2025) – Geopolymerization of Fly Ash and GGBS for Sustainable Industrial Waste Utilization

Researchers looked at how to make geopolymer using fly ash and GGBS. They tried different amounts of alkaline activator and GGBS, and cured the mixtures at different temperatures and times. The study found that the right amount of GGBS and the right conditions can make the geopolymer stronger. But using too much activator and controlling the curing conditions can be expensive and complicated. This means we need to find a simpler and cheaper way to make sustainable geopolymer systems. The team, led by Ansari and Kumar, published their findings in 2025, and their work can help us understand how to use fly ash and GGBS to create stronger and more sustainable materials. By changing the amount of GGBS and the curing conditions, we can improve the strength of the geopolymer, but we also need to think about the cost and how easy it is to make.

Kavitha et al. (2024) – Development of Sustainable Masonry Solid Blocks by the Incorporation of Industrial and Agro Waste

Researchers like Kavitha and her team looked into making sustainable masonry blocks using industrial and agricultural waste in 2024. They wanted to see if they could create alternative construction blocks by mixing different waste materials, which would reduce our need for traditional building materials. The study showed that using industrial and agricultural waste in masonry products is a great idea. But what's interesting is that no one has really explored combining paddy straw, cotton stalk, fly ash, and GGBS in the same way that's being proposed now.

Singh, Maiti and Mohanty (2024) – Development of Filler-Free and Ambient Cured Fly Ash Based Geopolymer Brick Utilizing Low Molar Concentration of Activating Solution

Researchers looked into using a special kind of brick made from fly ash, which is a type of waste material, and a small amount of activating solution. They wanted to see if they could make a good brick without using too much of the activating solution. The team tested the brick's strength and how much water it could absorb. They found out that using a small amount of activating solution and letting the brick dry naturally could be a good way to make affordable bricks. But they didn't try adding any natural fibers like straw or cotton to the mix, which could have made the bricks even better. This study is important because it could help us find new ways to use waste materials and make construction more sustainable. The researchers, led by Singh, published their findings in 2024, and their work could have a big impact on the building industry.

Faridmehr et al. (2023)-studied the optimization of fly ash–GGBS-based one part geopolymers with improved properties.

Researchers looked at 80 different mixtures of fly ash and GGBS to see how they affected the strength of a special kind of concrete called geopolymer. They wanted to know how different ingredients and conditions, like the amount of fly ash, GGBS, and water, and the temperature, impacted the strength of the concrete after 28 days. They used a simple system with a solid activator that only needed water to work. The results showed that the strength of the concrete varied widely, from 2 to 102.1 MPa, with an average of about 46 MPa. The study found that adding more GGBS made the concrete stronger, probably because of its calcium content. However, adding too much activator didn't always make it stronger - there was an optimal amount, around 12% by weight of fly ash, that worked best. This optimal amount is equivalent to about 6% Na₂O. The researchers concluded that using fly ash and GGBS together could be a more sustainable alternative to traditional cement-based concrete. But they didn't look at adding other materials, like paddy straw or cotton stalk, to create a new kind of hybrid bio-brick that incorporates all these materials. They mainly focused on making the best possible binder, rather than exploring new ways to use these materials together.

AgataIwanCandra et al. (2022) – Increasing Compressive Strength of the Red Brick with Fly Ash and Rice Husk Ash

Researchers found a way to make regular bricks stronger by adding fly ash and rice husk ash to the mix. They used a type of soil called sandy clay and added different amounts of fly ash and rice husk ash - 4%, 8%, and 12% of the soil's weight. Then, they made brick samples and tested how strong they were using a special machine. The results showed that adding 12% fly ash made the bricks the strongest, with a strength of 75.07 kgf/cm², which is even stronger than normal bricks. However, adding rice husk ash didn't make the bricks as strong. The study found that using fly ash can help reduce the amount of soil needed to make bricks and make them stronger, which is a more environmentally friendly way to produce bricks. This is a big deal because it could help make brick production more sustainable. The team's findings suggest that fly ash can be a useful addition to brick production, and it's worth exploring further.

Rautray et al. (2021) – Bio-Bricks: Circular Economy and New Products

Researchers have been looking into ways to turn agricultural waste into useful building materials, rather than just throwing it away. A study by Rautray et al. in 2021 explored how bio-bricks can help reduce waste and promote sustainable development. They found that using agricultural waste to make building products can really make a difference in reducing waste and conserving resources. This approach supports the idea of a circular economy, where waste is minimized and resources are used efficiently. The study showed that products made from agricultural waste can be a great alternative to traditional construction materials, and are better for the environment. By using

these bio-bricks, we can reduce the amount of waste we produce and create more sustainable buildings. This is a step towards a more circular economy, where we make the most of the resources we have and reduce our impact on the planet.

Xiyao Zheng and Jun Wu (2021) – Early Strength Development of Soft Clay Stabilized by One-Part Ground Granulated Blast Furnace Slag and Fly Ash Based Geopolymer

Researchers looked into using a special kind of binder to stabilize soft clay. This binder was made from a mix of Ground Granulated Blast Furnace Slag and Fly Ash. They wanted to find an alternative to the usual cement used to make weak clay stronger. The study checked how different ratios of these materials affected the clay's strength. They found that the best mix was 90% Ground Granulated Blast Furnace Slag and 10% Fly Ash, with a specific amount of activator and water. This mix made the clay much stronger after just 14 days. The team used various tests to understand how this mix worked. They saw that it formed special gels that connected and filled the gaps between clay particles, making it stronger. Fly Ash also helped make the binder easier to mix and more consistent. But adding too much Fly Ash actually made the clay weaker, because it filled the pores instead of connecting the particles. This study shows that using the right mix of these materials can be a good way to stabilize soft clay.

Zhou et al. (2020) – Preparation and Properties of Bio-Geopolymer Composites with Waste Cotton Stalk Materials

Researchers looked into using old cotton stalks to make a new kind of building material. They took the stalks and turned them into fibers and powder to see how they would work in this new material. What they found was that the stalks, even when not treated, could affect how dense and strong the material was. But when they treated the stalks, they worked even better with the rest of the material. This study is really important for our current research because it shows that old cotton stalks can be used to make stronger and more sustainable building materials. The idea is to use these stalks to create a new kind of material that is good for the environment. This could be a big step forward in making construction more sustainable. By using waste cotton stalks, we can reduce waste and create something new and useful. The study by Zhou et al. in 2020 is a great example of how we can take old materials and turn them into something new and exciting.

p. Lavanya et al. (2020) – Properties of Geopolymer Bricks Made with Fly Ash and GGBS

Researchers found that using fly ash and GGBS to make geopolymer bricks is a good idea. They studied how strong these bricks are, how much water they absorb, how well they resist acid, and if they produce any efflorescence. To make the bricks, they mixed fly ash and GGBS with a special solution that helps them bond together. The results showed that adding GGBS to the mix can greatly affect the strength and other properties of the bricks. This study confirms that fly ash and GGBS can be used as binder materials, which is a great way to reuse industrial waste. The bricks made with these materials have a lot of potential for use in construction. By using fly ash and GGBS, we can reduce waste and create strong, durable bricks. This is a significant finding, as it could lead to more sustainable building practices. The study's results are promising, and further research could explore the possibilities of using geopolymer bricks in different applications.

Garas, Bakhom and Allam (2015) – Rice Straw-Cementitious Bricks: Analytical Study on Mechanical Properties and Sustainability Measures

Researchers looked into using rice straw to make bricks, and they found some interesting things. They added different amounts of rice straw to the brick mixture and checked how strong it was. What they discovered was that the amount of rice straw used really affects how well the bricks hold up. Using rice straw is also good for the environment because it uses up waste from farms. However, they realized that you need to find the right balance of straw and other materials to make the bricks strong and sustainable. This is important because it can help reduce waste and make construction more eco-friendly. The study showed that using rice straw in bricks can be a good idea, but you need to get the mix just right. By using the right amount of straw, we can make bricks that are both strong and good for the planet. This can be a big step forward in making construction more sustainable and reducing our impact on the environment.

3. REVIEW METHODOLOGY

Researchers looked at a collection of studies on using waste materials to make building blocks. They focused on studies that used agricultural waste, like straw from rice paddies or cotton stalks, to make bricks. They also looked at studies on using fly ash and special cement called GGBS geopolymer. The team organized the information by the year it was published, the type of material used, and how it was made. They also looked at what properties were tested, what the studies found, and what the limitations were. This review is based on the information they gathered from these studies. The team wanted to see how these alternative materials could be used in construction, and what benefits and drawbacks they might have. By looking at all these different studies, they hoped to get a better understanding of how to use waste materials to build more sustainable buildings.

4. THEMATIC LITERATURE SYNTHESIS

Researchers have been exploring the potential of using agricultural waste to create lightweight and efficient building materials. They've been looking into using residues from paddy straw, rice straw, and rice husks to make bricks. These studies show that these materials have promise, but it's crucial to get the right balance between the amount of residue used and the strength and water absorption of the final product. For instance, research on rice straw has examined its raw form, ash, and materials related to rice husks, assessing factors like

compressive strength, density, and thermal behavior. However, one area that hasn't received much attention is the use of cotton stalks. While some studies suggest that cotton stalk particles or fibers can be used in construction, there's limited research on combining untreated cotton stalk with paddy straw, fly ash, and ground granulated blast furnace slag. Other studies have investigated the use of fly ash and ground granulated blast furnace slag in geopolymer binders, finding that factors like the binder composition, activator amount, water-to-binder ratio, and curing conditions all impact strength and durability. In many cases, ground granulated blast furnace slag improves strength development, although it can affect cost and handling due to its activator requirements. One-part geopolymer systems using anhydrous sodium metasilicate are also being explored, as they may simplify the preparation process compared to using separate liquid sodium hydroxide and sodium silicate solutions. Nevertheless, their suitability for use in fiber-containing bricks needs to be determined through experimentation. Overall, these studies highlight the potential of agricultural waste in construction, but also emphasize the need for further research to optimize the use of these materials.

5. CRITICAL COMPARISON

So, when it comes to performance, there are a few key things to consider: how strong the material is, how much water it absorbs, its density, how it behaves in different temperatures, and how durable it is. Using leftover agricultural materials can actually make the material less dense and better at insulating, but if you use too much of it, the material might not be as strong. Even when you're using a mix of industrial waste and other materials, the performance still depends on how you mix it and the conditions you use to activate it. Just because you're using recycled materials doesn't mean the final product is cheap - the cost of the activators, processing, drying, and other factors all add up. And let's not forget about the cost of labor and materials in your local area. So, if someone claims that their eco-friendly brick is low-cost, they should be able to back it up with some solid comparisons to traditional building materials.

6. RESEARCH GAPS

1. Not much research has been done on mixing paddy straw, cotton stalk, fly ash, and GGBS to create a new kind of bio-brick that can be used for building houses in rural areas.
2. When it comes to construction materials, rice and paddy-residue have been studied a lot, but not as much attention has been given to materials made from cotton stalks.
3. When it comes to making FA-GGBS geopolymer bricks, most research uses liquid alkaline activators, but some studies take a different approach with a one-part dry mix, often adding agricultural fibers to the blend.
4. We still haven't found a way to balance all the important factors like strength, how much water something absorbs, density, how well it keeps heat, how long it lasts, and cost.
5. We need to test what happens when we use untreated agricultural leftovers in a controlled environment to see how they work.
6. We need to check if using anhydrous sodium metasilicate as an activator makes economic sense by looking at the real costs of the materials and the process.

7. PROPOSED RESEARCH FRAMEWORK

We can use paddy straw and cotton stalks without any special treatment. Just clean, dry, and cut them to size. Fly ash and GGBS can work together as a binder. We need to see if a simple activator can be used. To find the best mix, we have to try different combinations and test them in a controlled environment. The most important tests are for strength, water absorption, and density. If possible, we can also check for heat performance, durability, and cost. The goal is to find a mix that balances strength, absorption, density, sustainability, and cost. We can't assume it's better than regular bricks until we've tested it. We need to prepare many samples and test them carefully. This will help us understand how the different ingredients work together. By doing this, we can create a new material that is strong, sustainable, and affordable. The tests will show us if we're on the right track. If the results are good, we can use this new material for building. It's a simple idea, but it could make a big difference. We just need to take the time to get it right. The key is to find the right balance. We don't want a material that is too weak or too expensive. We need something that works well and is good for the environment. This is a challenge, but it's also an opportunity. If we can create a sustainable building material, it could help reduce waste and pollution. So, let's get started and see what we can achieve. We'll test and retest until we find the perfect mix. Then, we can share our discovery with others and make a positive impact.

8. EXPECTED CONTRIBUTION

The review points out a potential experimental approach at the point where the use of agricultural waste meets FA-GGBS geopolymer technology; the proposed research could supply comparative mix-design data for a hybrid system consisting of paddy straw and cotton stalk and examine whether one-part activation can support a viable low-cost method of producing bricks.

9. FUTURE RESEARCH DIRECTIONS

To take things forward, researchers should explore how different mix proportions, fibre shapes and amounts, and curing conditions in various temperatures affect the outcome. They should also consider how well these materials last over time, how stable they are, and

how well they conduct heat. When it comes to costs, it's essential to think about what materials are available locally, how much energy is needed to process them, and how much activator is used. Additionally, the costs of moulding and curing should be factored in and compared to those of traditional red and fly-ash bricks to get a better understanding of the overall economics. This will help paint a clearer picture of the practicality and potential of these materials.

10. CONCLUSION

Using everyday materials like farm waste and industrial leftovers can be a great way to build houses in a more sustainable way. For example, researchers have been looking into using rice straw to make lightweight and insulating materials. But they haven't really explored using cotton stalks yet. Some studies have found that using special binders like FA and GGBS can be a good idea, and making them is pretty straightforward. What's really interesting is that nobody has properly looked into combining rice straw, cotton stalks, FA, and GGBS to make cheap and eco-friendly bricks for houses in rural areas. This shows that we need to do more experiments to figure out the best mix of materials and see how they perform in terms of strength, durability, and cost. By doing this, we can make building materials that are better for the environment and more affordable for people

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