International Journal of Mechanical and
Sustainability Engineering Technology

Journal homepage:
https://uniexpertsacademy.com/index.php/IJMSET/index
ISSN: 3083-8363

Recent Research on Aluminium/SCBA Composites: A Review

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ARTICLE INFO

Article history:
Received 1 September 2025
Received in revised form 10 December 2025
Accepted 31 December 2025
Available online 4 April 2026

Keywords:
Sugarcane Bagasse, Reinforcement Material, Compositional Variation, Sustainable Resource, Aluminium Matrix Composites

ABSTRACT

Sugarcane bagasse ash (SCBA) is an abundant agricultural waste generated from the sugar industry, and its utilization as a reinforcement material in composite systems has attracted increasing research attention due to its sustainability and potential engineering benefits. This review paper presents a comprehensive overview of the properties, processing methods, and applications of SCBA as a reinforcement in aluminium matrix composites (AMCs). The chemical composition, physical characteristics, and microstructural features of SCBA are discussed to highlight its suitability as a low-cost reinforcement material. Various fabrication techniques used for SCBA-reinforced composites, including stir casting, powder metallurgy, and other manufacturing approaches, are also examined. In addition, the influence of SCBA incorporation on mechanical properties such as hardness, tensile strength, compressive strength, and impact resistance is reviewed based on previous experimental studies. The advantages of SCBA, including its high silica content, lightweight nature, and environmental benefits, are also compared with its limitations such as compositional variability, moisture sensitivity, and dispersion challenges within the aluminium matrix. The findings from the literature indicate that SCBA has promising potential to enhance the performance of aluminium composites while contributing to sustainable material development through the valorization of agricultural waste. However, further studies are required to optimize particle dispersion, interfacial bonding, and processing parameters in order to achieve consistent composite performance for industrial applications.

1. Introduction

Sugarcane is a tall, sturdy perennial grass with fibrous stalks rich in sucrose that is used to make sugar. Sugarcane is frequently employed in the manufacture of sugar, ethanol, and other bioactive chemicals. It is grown in tropical and subtropical regions around the world, mainly for its sugar content [1]. The cultivation of sugarcane and the extraction of sugar from its sap have played an important role in human civilization. Sugarcane cultivation has a rich history of spreading globally, reaching countries such as Brazil, India, China, Egypt, and the Americas through European colonization [2] Today, sugarcane is a major commercial crop grown in over 200 countries, producing

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approximately 1332.2 million tonnes annually. The primary producers of sugarcane are Brazil, India, China, and Thailand, with Brazil being the largest producer [3], [4].

Sugarcane is a C4 plant known for its rapid growth and efficient photosynthetic process. It typically grows in tropical or subtropical climates and requires a warm climate, plenty of sunlight, and a well-distributed water supply. The plant consists of stalks, called stems, which can reach a height of 2 to 6 meters and a diameter of 2 to 6 centimeters. These sticks are characterized by their thick fibrous outer shell and juicy inner core.

Sugarcane bagasse (SCB) is the dry, pulpy, fibrous residue that remains after crushing and extracting juice from sugarcane or sorghum stalks. SCB is widely recognized as a valuable by-product with diverse applications. Its primary use is in energy generation, where it is burned in boilers to produce heat and electricity. SCB also serves as a feedstock for renewable energy, including biofuels and biogas [5].Due to its high cellulose content, it has become an important material in the development of sustainable packaging, offering an eco-friendly alternative to conventional plastics. In addition, SCB is used in the construction sector to manufacture products such as cement mixtures, asbestos substitutes, and brake pads [6], [7]. These varied applications highlight SCB's potential as a sustainable resource that contributes to both energy production and material innovation.

The chemical composition of SCB is 32% - 45% cellulose, 20% - 32% hemicellulose, 17% - 32% lignin, 1% - 9% extractives and 0.68% - 9% ash [8]. In general, raw bagasse ash is composed primarily of silica (60-75%), potassium oxide, calcium oxide, and other minor oxides [9], as shown in Table 1 below [10], [11], [12].

Table 1: Chemical composition of SCB

SiO_2	Al_2O_3	Fe_2O_3	CaO	Na_2O	K_2O	SO_3	MnO	MgO	LOI	Ref.
54.10	5.69	3.54	15.37	-	-	0.03	-	1.41	19.36	[13]
78.34	8.55	3.61	2.15	0.12	3.46	-	0.13	1.65	0.42	[11]
78.05	3.81	2.01	3.98	0.21	0.42	-	-	2.24	-	[14]
77.55	6.48	4.71	2.85	-	2.36	0.82	-	4.19	-	[15]
78.89	7.27	3.85	1.28	0.69	1.41	1.55	-	1.28	-	[16]

The main purpose of growing sugarcane is to obtain sucrose, which is converted into various forms of sugar. Sugar is found in the sap of the plant's stems. After harvesting, the sugarcanes are crushed to extract the juice. This goes through several processes to separate the sugar from the impurities. These processes include clarification, evaporation, crystallization, and centrifugation, resulting in the production of unrefined sugar or refined white sugar. This review article aims to analyse different conditions and processes on the reinforcement of SCB in aluminium matrix composite (AMC).

1.1 Aluminium Matrix Composites (AMC) in Various Applications

Aluminium metal matrix composites are used in engineering applications such as automotive, aerospace, defense and space components. Aluminium matrix composites exhibit improved properties such as good strength, improved stiffness, reduced density, high thermal properties, controlled thermal expansion, and improved wear resistance that cannot be achieved with existing conventional materials. The main component of MMC aluminium is aluminium or aluminium alloys such as Al-Si, Al-Cu, Al-Si-Mg.

The mechanical and physical behavior of metal matrix composites (MMCs) varies significantly depending on whether they are in a liquid, solid, or solid-liquid state. This variation is largely influenced by the dislocation mechanisms and the interaction between the matrix and the reinforcement materials [17], [18]. Studies indicate that the microstructural behavior of composite materials is strongly influenced by the interface energy between different phases. The interface plays a decisive role in shaping the mechanical properties and overall performance of the composite. To evaluate these characteristics, molecular dynamics and microstructure simulations are commonly employed to estimate parameters such as elastic modulus and Poisson's ratio, which are essential for understanding composite behavior [19], [20], [21].

Porosity in cast composites is another critical factor that directly affects mechanical performance. High porosity typically results in reduced tensile and impact strength, whereas low porosity enhances these properties. Techniques such as squeeze casting and extrusion have proven effective in minimizing porosity, thereby improving the mechanical reliability of composites [22], [23].In addition, a suitable mould design is vital for controlling wettability between substances in composite materials. Proper mould design not only facilitates stronger interfacial bonding but also reduces porosity. Specific moulding approaches, including bladder moulding and the use of silicone moulds, have demonstrated promising results in achieving low porosity and improved mechanical properties [24], [25].

Hence, it can be concluded that microstructural behavior of composite materials is governed by both interface energy and porosity. Effective mould design and interface modification strategies are therefore essential for achieving strong interfacial bonding and low porosity, which collectively enhance the mechanical performance of composites. Figure 1 describes the fabrication routes for AMCs.

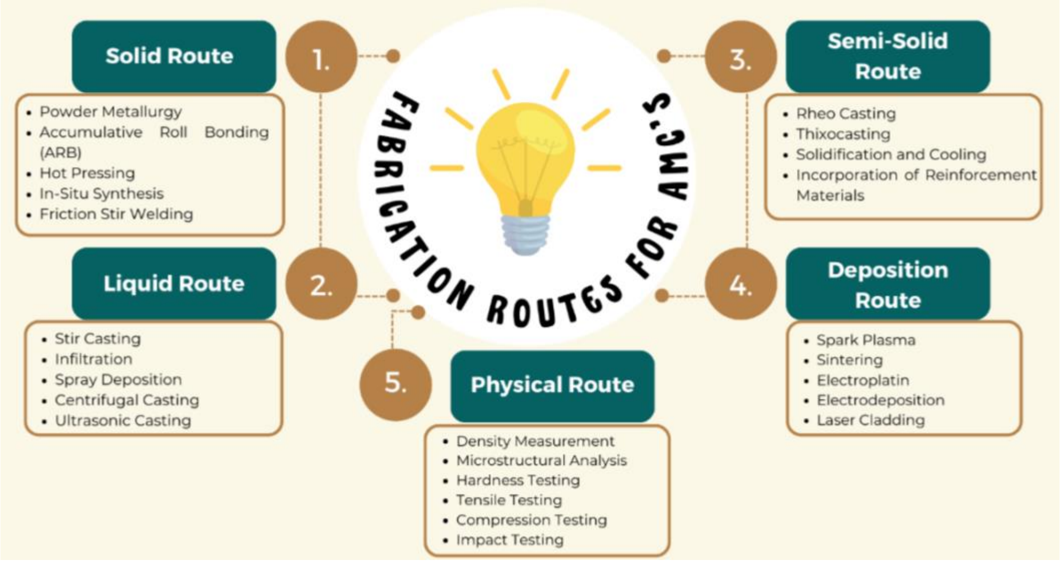

Figure 1: Fabrication routes for AMC's

2. Characteristics of SCBA

Sugarcane bagasse ash (SCBA) exhibits several distinct properties that make it suitable for various applications. It is a renewable and sustainable resource, as sugar cane is a high-yielding crop with a relatively short growing cycle. Bagasse is lightweight, with low density and high porosity. It has good thermal insulation properties, low thermal conductivity, and moderate tensile strength. On the other hand, the sugar cane bagasse ash has several distinctive features.

SCBA is widely recognized for its high silica content, which imparts strong pozzolanic properties and makes it suitable for use as a supplementary cementitious material (SCM) in cementitious materials. SCBA is primarily composed of silica, present in both amorphous and crystalline forms such as quartz [26]. The amorphous silica fraction is significant because it readily reacts with calcium hydroxide in cement to form additional cementitious compounds, thereby enhancing performance [27], [28]. The pozzolanic activity of SCBA is closely linked to its silica content and is influenced by factors such as particle size, fineness, and impurity content. Finer particles and higher amorphous silica content generally improve reactivity, thereby strengthening the mechanical properties and durability of concrete [27], [29].

SCBA has been successfully incorporated into various concrete applications, including self-compacting concrete and mortars, where it improves compressive and tensile strengths and long-term durability [30]. Its inclusion also reduces shrinkage, lowers chloride penetration, and produces denser microstructures, all of which enhance the overall performance of concrete [31], [32]. Therefore, SCBA’s high silica content and pozzolanic properties establish it as a valuable SCM, offering both performance benefits in concrete applications and environmental advantages through waste utilization. However, its effectiveness depends on careful processing and characterization to optimize reactivity and ensure consistent results.

The fine particle size and large surface area of SCBA further enhance its reactivity and pozzolanic potential, reinforcing its effectiveness as a supplementary cementitious material (SCM). Research has shown that the optimal replacement level of bagasse ashes in cement lies between 10% and 20% by weight, a range that balances improvements in mechanical properties and durability without significantly affecting workability [33]. Within this range, concrete incorporating SCBA demonstrates notable gains in compressive, splitting tensile, and flexural strengths, largely due to improved particle packing and denser microstructure [34].

In addition to mechanical performance, SCBA enhances durability by reducing chloride-ion penetration, lowering water permeability, and increasing resistance to acid and sulfate attacks. These benefits are attributed to the pozzolanic reactions that refine the pore structure and strengthen the matrix [31], [35]. Collectively, these findings highlight the potential of bagasse ash as a reliable SCM, particularly when applied at replacement levels of 10–20%, where both performance and durability are maximized.

The high porosity of SCBA significantly influences its water absorption capacity, thereby affecting the performance of concrete mixtures. Pavement concrete containing bagasse ash has been reported to exhibit porosities of 6.74% to 10.21% and water absorption rates of 15.00% to 20.82% [36]. Studies have shown that incorporating SCBA reduces concrete slump, indicating decreased workability. This is due to the increased water demand to achieve the desired consistency [37], [38].

Despite these challenges, controlled replacement of cement with SCBA at 10–15% has been shown to improve compressive, tensile, and flexural strength [39]. These enhancements are attributed to the formation of additional calcium-silicate-hydrate (C-S-H) gel, which densifies the concrete microstructure and strengthens its matrix [40]. Thus, while the porous nature of SCBA can negatively affect workability, its contribution to strength and durability at optimal replacement levels underscores the importance of carefully balancing its incorporation into concrete design.

The composition of SCBA is highly variable and depends on several factors, including combustion temperature, burning duration, and the properties of the original bagasse feedstock. These variations directly influence the ash's physical and chemical characteristics, thereby affecting its suitability for different applications. Combustion temperature plays an important role in determining the silica phase present in SCBA. Higher combustion temperatures tend to increase the ash's crystallinity. For instance, amorphous silica forms at temperatures below 600°C, whereas higher temperatures lead to the formation of crystalline phases such as cristobalite [41]. Additionally, calcination at 800°C and 1000°C has shown high pozzolanic activity [42]. Prolonged burning at lower temperatures (600-650°C for up to 3 hours) can produce ash with a high content of amorphous silica, which is beneficial for pozzolanic activity [43].

The chemical composition of the original feedstock also plays a decisive role. For instance, elevated potassium oxide levels can lower the melting point of the ash, leading to operational issues such as slagging and fouling in boilers [44]. In addition, particle size influences reactivity, with smaller particles generally exhibiting greater pozzolanic potential [45]. Therefore, the variability in SCBA composition underscores the importance of careful control and characterization. Understanding how combustion conditions and feedstock properties affect the ash is crucial for optimizing its performance, particularly in construction applications where consistent quality and reactivity are essential.

The color of SCBA can vary considerably, ranging from gray to light brown, and this variation is influenced by both combustion conditions and the presence of impurities in the feedstock. Calcination temperature plays a key role, where higher temperatures generally produce lighter ash due to more complete combustion, while lower temperatures often result in darker ash from incomplete combustion and residual organic matter [46].

Impurities such as mineral residues and other contaminants also contribute to color differences. Elevated levels of these impurities tend to darken the ash, indicating a greater presence of unburned residues and minerals [47]. Hence, the color variation of SCBA is determined by a combination of combustion efficiency and feedstock purity. Higher combustion temperatures and cleaner combustion processes yield lighter ash, whereas incomplete combustion and impurities lead to darker ash. Understanding these variations is important, as they can serve as indicators of ash quality and consistency for its intended applications.

2.1 SCBA as Reinforcement

Sugarcane bagasse (SCB) is the fibrous residue that remains after squeezing the juice from the sugarcane stalks. Due to its wide availability, renewability, low cost, and favorable mechanical properties, bagasse has attracted attention as a potential reinforcement material in a variety of applications. Composed of cellulose, hemicellulose, and lignin, bagasse has a fibrous structure that can transform into various forms, such as fibers or chopped particles.

These properties make it suitable for enhancing the performance of composite materials. Sugar cane fibers, particularly from SCB, have been extensively studied for their potential as reinforcements in polymer composites. These fibers are abundant, low-cost, and environmentally friendly, making them attractive for a range of applications, including automotive components, building materials, packaging, and consumer products [48], [49]. Table 2 below shows the chemical composition and physical properties of the raw material.

Table 1: Chemical composition and physical properties of raw material (%) [50]

	QS	QP	Cement	SF	SCBA
SiO_2	94.548	98.11	18.347	95.14	82.37
Al_2O_3	1.181	0.61	4.225	0.919	4.24
Fe_2O_3	0.166	0.23	3.794	0.149	5.06
MgO	0.126	0.16	1.808	0.339	0.86
Na_2O	0.049	0.35	-	0.072	/
TiO_2	0.005	-	0.299	0.003	0.38
SO_3	2.747	0.02	3.605	1.288	/

Table 1: Chemical composition and physical properties of raw material (%) [50] (Cont.)

	QS	QP	Cement	SF	SCBA
MnO	0.126	0.01	0.066	0.005	0.33
Total	99.99	99.70	99.49	99.97	99.57
Mean size (μm)	-	20.91	50	0.89	21.26
Specific surface area (m^2/kg)	-	6.53	0.89	22.34	6.49

Sugarcane fortification has been widely studied over the years, with niche applications in the sugar industry and bioenergy production. Silicon dioxide (SiO2), also called silicic acid, is a useful multifunctional inorganic compound that is one of the basic materials. Silicon occurs naturally in the form of quartz, sand or flint. Gelled and amorphous forms are also possible, both crystalline and amorphous in the earth's crust. Silicic acid comes from the soil in the form of silicic acid, which is absorbed by the sugar cane plant and enriched with cellulose micronutrients. The silicon content of the soil influences the silica concentration.

In addition to other metallic impurities, amorphous silicon dioxide predominates in sugar cane ash. In sugar cane ash, amorphous silica dominates, along with other metallic impurities. Production of high-purity silicon nanoparticles (SiNPs) from SCBA will be an important synthetic route to reduce production costs and provide low-cost polysilicon semiconductors for niche technology applications. SCBA is approximately 73% rich in silica and is economically viable due to the conversion of the raw material to produce silica gel and powders [51]. Sugarcane bagasse has been studied as a potential raw material and source of sugar, juice and fuel in the ethanol industry, as well as a valuable material in the cement industry [29]. Figure 2 shows the flow process of SCBA.

Figure 2: Flow process of SCBA

2.2 Constraints of SCBA in Various Applications

The increasing sugar consumption requires increased sugar cane cultivation. At the same time, increasing sugar cane cultivation increases the burden on the sugar cane processing industry, leading to increased waste disposal. In this sense, the waste generated by the sugar industry must be dealt with using sustainable methods to avoid further pollution. The presence of fiber, wax and protein makes sugarcane bagasse the unruliest in nature, limiting its degradability and conversion efficiency.

Therefore, it cannot be easily separated into easily usable components and the available pre-treatment techniques are the most expensive and least technologically advanced steps for converting biomass into fermentable sugars. Liquid residues from pre-treatment processes are rich in pentose, soluble and insoluble lignin [7].

This offers great potential for increasing efficiency and reducing costs through further research and development. Currently, cane molasses is widely used as a resource to produce bioethanol, leaving other secondary materials such as pentose, vinasse, and effluents. The best use of pentose in the pre-treatment liquor is to produce ethanol. However, current processes using existing microorganisms result in extremely low waste yields. This multi-product approach, using sugar cane waste as a resource in the context of the bio refinery, facilitates the sustainability of existing sugar cane industries [7].

This issue covers the limits of sugarcane bagasse, such as moisture content variability, poor energy density, composition variations, and the impact of storage conditions on bagasse quality. It also discusses the effects of these limits on essential applications like bioenergy, biofuels, and value-added products. The issue also emphasizes continuing research efforts and novel approaches to overcoming these constraints, including drying processes, pretreatment procedures, and process optimization tactics. The limitations associated with sugarcane bagasse arise from several factors that limit its widespread use and potential applications. There are 4 key limitations.

Firstly, moisture content variations. Sugar cane bagasse has an inherent moisture content of 45%-52% after sugarcane crushing, which can create challenges in various applications [52]. A high moisture content can lead to difficulties in storage, transport and processing. For example, in bioenergy applications, high moisture content reduces the energy density of bagasse and requires additional drying processes to achieve efficient combustion. In other applications, such as pulp and paper production, moisture content affects the quality and properties of the end product. Management and control of moisture content is critical to ensure consistency and optimize performance in various applications.

Next is limited energy density. Sugarcane bagasse has a relatively low energy density compared to fossil fuels such as coal or natural gas. Its low energy density may limit its direct use as a primary fuel source in certain industrial processes [53]. To overcome this limitation, bagasse is often used in combination with other fuels or subjected to densification processes such as pelletizing or briquetting to increase energy density [54], [55]. Technological advances are also being sought in combustion and gasification systems to improve energy conversion efficiency and maximize the use of bagasse as a renewable energy source.

The composition of sugarcane bagasse can vary due to factors such as sugarcane variety, harvest time, and processing methods. Differences in the composition of bagasse can affect its suitability for different applications. For example, the presence of contaminants such as alkali or chlorine can affect combustion efficiency and equipment corrosion in bioenergy applications. When manufacturing value-added products such as bioplastics or biochemicals, variations in the composition of bagasse can affect the quality and yield of the end product. Thorough characterization and understanding of bagasse composition are critical to selecting appropriate processing methods and optimizing their use in various applications.

Lastly, sugarcane bagasse presents handling and storage challenges due to its bulkiness, fibrous nature, and potential for microbial degradation. Bagasse can be difficult to handle and transport efficiently, particularly in large quantities, resulting in higher operating costs and logistical challenges. Additionally, bagasse is susceptible to microbial growth, especially if not properly stored or processed. To maintain bagasse quality, prevent spoilage, and minimize safety risks, storage techniques such as covering, ventilation, and proper stacking practices must be implemented.

2.3 Pros and Cons of SCBA

These general pros and cons provide an overview of the benefits and limitations of sugar cane ash. However, when using sugar cane ash in different industries and contexts, it is important to consider specific applications, local regulations and quality control measures. Because of its affordable production cost and excellent eco-friendly end product, SCBA waste is one of the preferred smart raw materials in the manufacture of innovative products [56]. Pros and cons of the Sugarcane Bagasse Ash (SCBA) are shown in Figure 3 and 4.

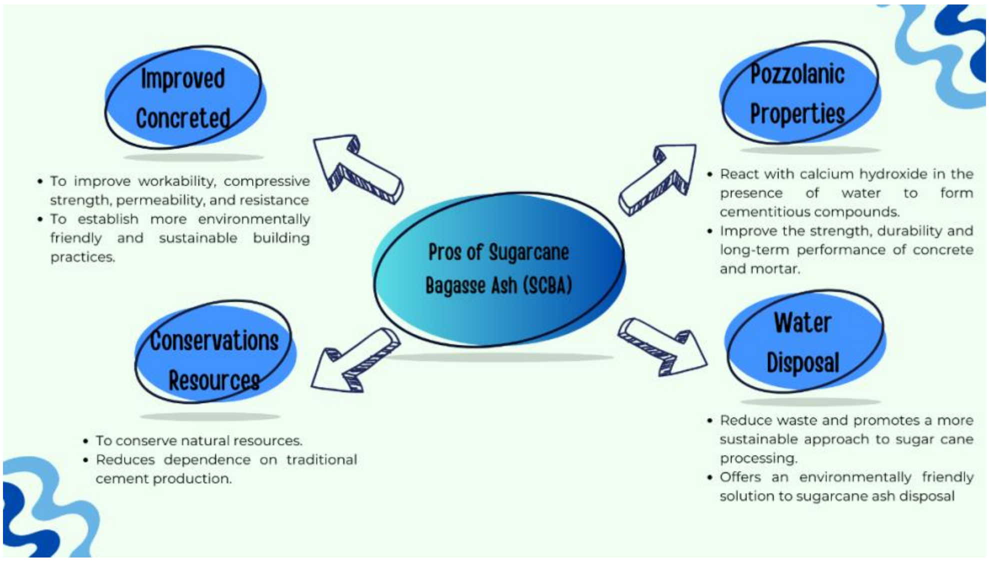

Figure 3: Pros of SCBA

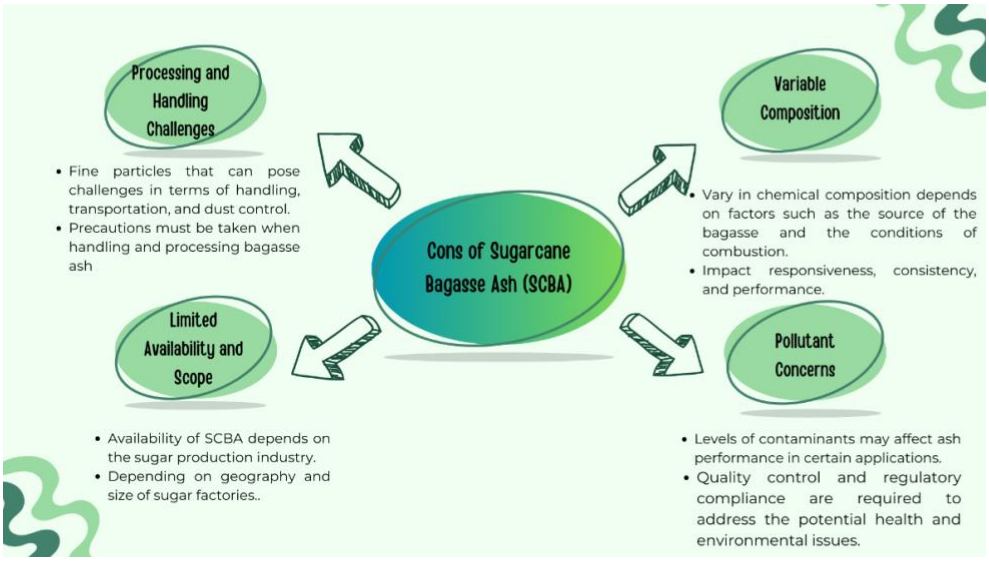

Figure 4: Cons of sugarcane bagasse ash (SCBA)

2.4 Composition, Mechanical Properties and Structures of SCBA

SCBA is composed of several components and has unique mechanical properties and architecture. Sugar cane bagasse is a fibrous waste collected after juice extraction from sugar cane for sugar manufacture. It is mostly composed of cellulose, hemicellulose, and lignin, which are the primary components of plant cell walls. The most frequent element is cellulose, which accounts for

40-45% of the bagasse composition. Bagasse contains approximately 25-35% hemicellulose and approximately 20-30% lignin. Extractive, ash, and trace amounts of proteins and minerals are also secondary components [57].

The mechanical properties of sugarcane bagasse are influenced by several factors, including sugarcane maturity, processing method, and treatment. It has low rigidity, as indicated by its modulus of elasticity. Bagasse also has high compressive strength, making it suitable for load-bearing applications. Changes in color, chemical characteristics, wettability, aesthetic appearance, and mechanical properties are also caused by weathering [58].

Sugar cane bagasse is organized in a hierarchical system with varying degrees of organization. Macroscopically, it appears as a fibrous substance composed of individual fibers. These fibers are made up of bundles of smaller fibrils of cellulosic microfibers. The arrangement and orientation of the fibers and fibrils contribute to the overall strength and rigidity of the rod structure [59].

3. SCBA as Reinforcement in Aluminium Matrix Composites (AMC)

Sugarcane bagasse ash as reinforcement in Aluminium Matrix Composites (AMC) can be a promising approach. Bagasse ash is a byproduct of the sugarcane industry, and its incorporation in composites can lead to several benefits, as illustrated in Figure 5.

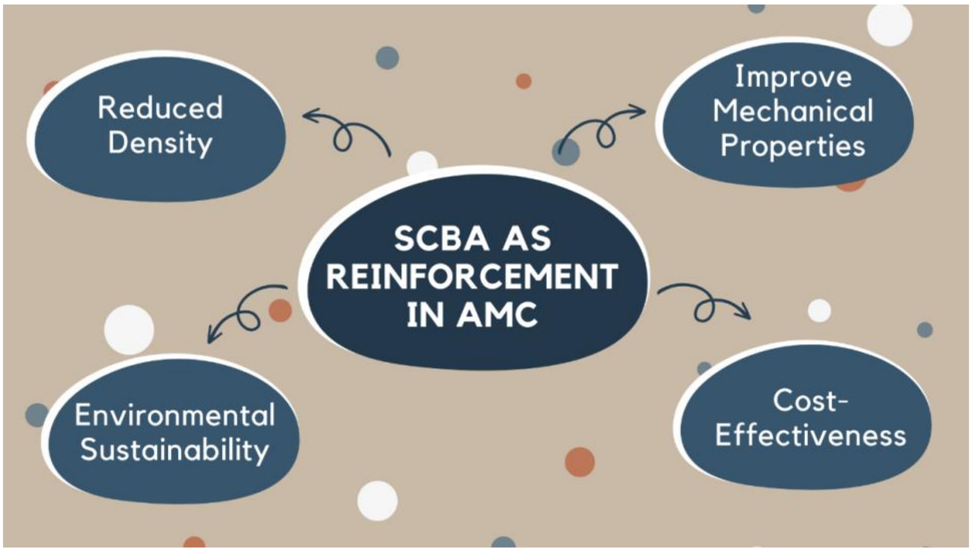

Figure 5: SCBA as reinforcement in AMC

However, successful implementation requires careful processing and optimization to ensure proper dispersion and bonding between the ash and aluminium matrix. Moreover, the composite’s properties may vary depending on the ash’s quality, particle size, and processing techniques. As with any new composite material, research and testing and necessary to understand its full potential, address challenges, and validate its sustainability for specific applications in various industries. Nonetheless, sugarcane bagasse ash shows promise as a sustainable and cost-effective reinforcement for AMC.

3.1 Application of SCBA’s Waste

SCBA can be used as a reinforcement material in Aluminium Matrix Composite (AMC). AMCs are composite materials in which aluminium or its alloys serve as the matrix, while other materials such as SCBA act as reinforcement to improve the specific properties of the composite. The combination of the lightweight aluminium matrix with the additional reinforcement results in connections with better mechanical, thermal and other performance properties [60]. Figure 6 shows a few applications SCBA waste.

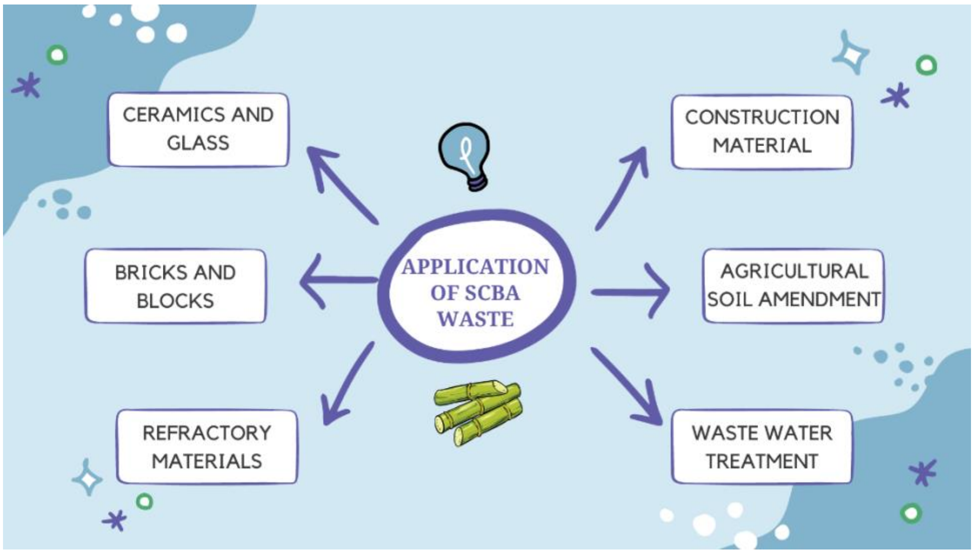

Figure 6: Application of SCBA's waste

3.2 Manufacturing Techniques for SCBA Reinforced Composites

In the manufacture of SCBA (sugar cane bagasse ash) reinforced composites, SCBA is incorporated into a matrix material such as a polymer, cement or metal to improve the properties of the composite. Different techniques can be used depending on the type of matrix and the desired properties of the final composite material. Some common fabrication techniques for SCBA reinforced composites are illustrated in Figure 7.

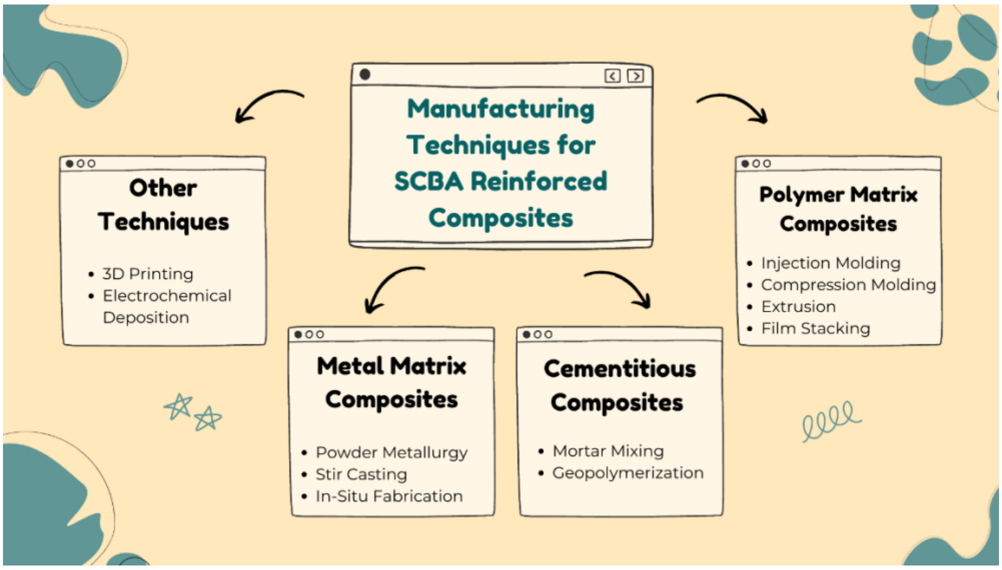

Figure 7: Manufacturing techniques for SCBA reinforced composites

Each of these techniques offers its advantages and challenges in terms of achieving good dispersion, binding, and orientation of the SCBA particles within the matrix, which ultimately affects the properties of SCBA-reinforced composites. The choice of fabrication technique depends on the specific application, the matrix material, and the desired properties of the final composite. Extensive testing and optimization are required to achieve the desired performance of SCBA-reinforced composites in various industrial applications.

4. Physical, Mechanical and Microstructure of SCBA

Spherical particles are formed by melting at high temperature. It was found that these spherical particles contain oxides of Mg, P, K. Also in a previous study, spherical particles were observed in the microstructure of bagasse ash and these particles were reported to have a similar elemental composition (Si, Mg, Na and O) and very small amounts of P and Fe [61]. The physical, mechanical, and microstructural properties of SCBA are essential considerations when evaluating its potential use as a reinforcement material. Here is an overview of each aspect:

4.1 Physical Properties

SCBAs manufactured by power plants range in color from dark black to light black. Due to incomplete combustion, dark black indicates a higher concentration of carbon. There were unburned carbon particles that reduced specific gravity. Sieving can remove fibrous particles, and ball milling further reduces the size and shape of the fine particles, thereby increasing their pozzolanic [62]. Here is an overview of each aspect in physical properties:

- Particle Size: Sugarcane bagasse ash (SCBA) particles can vary in size, and their distribution may influence how they interact with the matrix material. Smaller particles sizes may lead to better dispersion and binding in the composites.
- Density: Sugarcane bagasse ash (SCBA) is typically lightweight which is advantageous for reducing the overall density of the composite material.
- Porosity: the presence of pores or voids in SCBA particles can affect the composite's mechanical properties and structural integrity.
- Surface Area: A higher surface area of SCBA can promote improved interactions and bonding with the matrix.

4.2 Mechanical Properties

4.2.1 Hardness

Hardness testing was performed using a Vickers Durometer according to ASTM E10 standards at room temperature. The dimensions of five samples were 5mm x 10mm x 5mm individually. The samples were individually tested three times, and their average hardness number value was used as the hardness number of each sample. The parameters used in the Vickers hardness test are force = 4900 N, dwell time = 10 s and load = 500 g. The HV number is then determined by the F/A ratio, where F is the force exerted on the diamond in kilograms and A is the surface area of the resulting notch in square millimeters [63].

4.2.2 Strength

SCBA is typically used as a reinforcing material in composite materials or as an additive in building materials where its strength properties are important to improving the overall performance of the end product. The specific strength requirements for SCBAs vary depending on the application and the desired properties of the end product. Different industries and applications may have different standards and specifications for acceptable resistor values. Therefore, it is important to consider the intended use and service conditions of the material or composite when assessing the appropriate strength of the SCBA.

In order to determine the resistance properties of the respirator, extensive mechanical tests are carried out, including tensile, compression, bending and impact tests according to applicable standards (e.g. ASTM or ISO) to ensure accurate and reliable results. The test results help in evaluating the potential applications of SCBA and its effectiveness as a reinforcement or additive in various materials.

Tensile strength is the maximum stress that a material can withstand before it breaks under stress. For SCBA reinforced composites, the tensile strength is reasonable, which effectively improves the tensile properties of the composite.

Compressive strength is the maximum load that a material can withstand before bursting under pressure. For building materials such as concrete or mortar containing SCBAs, sufficient compressive strength is important to ensure the material can support loads and provide structural stability [64].

Flexural strength measures a material's ability to withstand bending or flexing. For composites used in applications where bending forces are prevalent, such as beams or structural members, adequate flexural strength is essential for structural integrity. In SCBA-reinforced composites, good interfacial bond strength of the SCBA matrix is critical. A strong bond ensures efficient load transfer between the reinforcement and the matrix, resulting in better mechanical properties [64].

Impact resistance is the ability of a material to withstand sudden dynamic loads without tearing. In some applications, such as automotive components or sporting goods, adequate impact strength in respirator-reinforced composites can improve their durability.

4.2.3 Microstructure

Microstructure in the context of SCBA (sugar cane bagasse ash) refers to the small-scale structure and arrangement of its constituent particles and phases. It examines material at a microscopic level to understand the distribution, size, shape and interaction of the various components present in the SCBA [65]. The microstructure of SCBA can vary depending on factors such as the combustion process, the source of the bagasse, the processing conditions, and the after-treatment methods used. Key aspects of SCBA microstructure include:

- Morphology: The shape and morphology of SCBA particles, such as their aspect ratio, can impact the composite’s microstructure and mechanical properties.
- Particle Size and Distribution: SCBA particles can range in size from nanometers to microns. Microstructure analysis consists of studying the distribution and packing of these particles in the ash.
- Homogeneity: A uniform and homogeneous distribution of SCBA within the matrix is crucial for achieving consistent and predictable composite behavior.
- Interface: The interface between SCBA and the matrix influences load transfer and bonding strength, which affects the overall mechanical performance of the composites.

5. Conclusion

This review article discusses the potential of sugar cane bagasse, a fibrous residue from sugar production, as a valuable resource for various applications. However, there are several limitations, including variations in moisture content, low energy density, variations in composition, and storage conditions that affect bagasse quality. These limitations affect key applications such as bioenergy, biofuels and value-added products. The document highlights ongoing research efforts and innovative approaches to overcome these limitations, including drying techniques, pretreatment methods, and process optimization strategies. Sugarcane is a tall, hardy perennial grass with fibrous stems rich in sucrose and used to make sugar, ethanol, and other bioactive chemicals.

5.1 Recommendation

Technology transfer and industrial adoption**:** Encourage efforts to bridge the research-industry gap by facilitating the transfer of successful technology and innovation from sugar cane bagasse research. This could involve building partnerships between research institutes and relevant industries to implement efficient processing techniques and applications.

Standardization and Quality Control: Emphasize the importance of establishing standardized methods for characterizing and assessing the quality of sugar cane bagasse and its derivative products. Standardization can ensure consistency and reliability across different applications, making it easier for industry to adopt these materials.

Acknowledgement

The author would like to thank to Faculty of Mechanical Engineering and Manufacturing, Faculty of Technical and Vocational Education, Faculty of Computer Science and Information, Universiti Tun Hussein Onn Malaysia, and Intec Precision Engineering Sdn. Bhd. For providing necessary research facilities for this study.

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