DOI: https://doi.org/10.24425/amm.2025.155496

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SILICA EXTRACTION FROM RICE HUSK: A REVIEW ON THE EFFECT OF COMBUSTION TEMPERATURE

Combustion significantly contributes to pollution, releasing harmful pollutants that can have detrimental effects on environmental and human health. Rice husk (RH), a by-product of rice milling, makes up about 20-22% of the weight of harvested rice. It primarily consists of cellulose, hemicellulose, lignin, and a significant amount of silica. Traditionally seen as agricultural waste and often burned or discarded, rice husks have recently gained attention for their potential in industrial applications, especially for extracting silica. This review studies the effect of the chemical composition and properties of rice husks, focusing on the combustion used to obtain high-purity silica. It reviews how the combustion temperature, heating rate, and cooling rate influence the purity and phase of silica, highlighting the delicate balance required to produce either highly reactive amorphous silica or crystalline forms of silica. Additionally, will discuss the applications of both amorphous and crystalline silica across various industries, including construction, electronics, and agriculture, showing the sustainability and economic benefits of utilising rice husk-derived silica. By optimising the combustion process, we can improve the quality and functionality of the extracted silica, thus contributing to waste reduction and environmental sustainability.

Keywords: Combustion; Rice husk (RH); Rice husk ash (RHA); Extraction; Silica

1. Introduction

Rice husk (RH), also known as a byproduct of rice milling, is the protective outer layer of rice grains [1,2]. It is made up of harvested rice and is produced in large quantities, especially in countries like Malaysia, India, and Southeast Asia. Rice husk consists mainly of cellulose, hemicellulose, lignin, and a significant amount of silica, which accounts for about 20-22% of its weight [3,4]. This high silica content makes rice husk valuable for various industrial uses, particularly for extracting silica and silicon. However, due to the low density of rice husks, it will be difficult for disposal and transportation, raising environmental concerns if not managed properly [5]. In general, rice husk ash has a density of about 180-200 kg/m^3, which is evident by its high porosity, lightweight, and fine nature [6].

In the past, rice husks were often considered agricultural waste and were either burned or discarded, contributing to air pollution and environmental harm. Nowadays, with an increasing focus on sustainability and technological advances, rice husks are being put to better use. They are used as biofuel, in the production of building materials, and as a source for high-value products like activated carbon and silica nanoparticles [7]. The silica extracted from rice husks is especially valuable for making high-quality

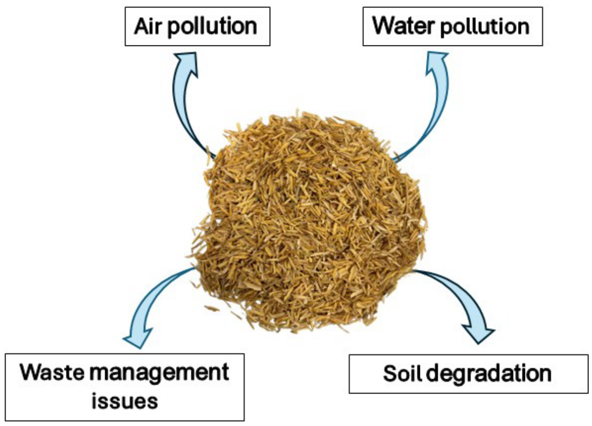

Fig. 1. Problems caused by rice husk

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silicon, which is essential in electronics, solar energy, and ceramics. By finding innovative ways to use rice husks, we can reduce waste, minimize environmental impact, and add value to this previously underutilized resource. Furthermore, using rice husks as a raw material for silica production not only reduces agricultural waste but also avoids the environmental damage caused by sand mining. Additionally, adopting organic acids like citric acid for the leaching process offers a greener alternative to traditional strong acids, further lowering the environmental footprint of silica production.

The combustion process of rice husk is undertaken primarily to extract silica [8]. It is a valuable material with numerous industrial applications. During combustion, the organic components of the rice husk are burned away, leaving behind a residue rich in silica, which is also known as rice husk ash (RHA). This process not only facilitates the isolation of silica but also helps in reducing the volume of agricultural waste. The outcome of the combustion process is largely dependent on the temperature at which it is carried out [9]. RHA produced by combustion at various temperatures, displays different colours. At lower temperatures, the combustion may be incomplete, resulting in black ash with lower silica content and higher carbon residues. Higher temperatures make combustion more efficient, resulting in grey or white ash as shown in Fig. 2 with high-purity amorphous silica, which is valuable for many industrial applications [10]. Therefore, controlling the combustion temperature is crucial to review so that we can optimize the quality and characteristics of the silica extracted from rice husk.

2. Composition of silica in rice husk

Rice husk-derived silica possesses a distinctive blend of high purity, amorphous structure, and excellent adsorption properties, making it a significant and sustainable resource in various sectors. There is a significant amount of variation in the chemical composition of rice husk, which is the protective outer layer of rice grains, depending on the country of origin [11]. There are several factors that contribute to this difference, including the composition of the soil, climate, agricultural practices, and the types of rice [12]. Silica (SiO_2) is the most abundant component of rice husk, but it also contains some other minerals, including alumina (Al_2O_3), sodium oxide (Na_2O), calcium oxide (CaO), potassium oxide (K_2O), iron oxide (Fe_2O_3), magnesium oxide (MgO), and sulphur trioxide (SO_3).

From Fig. 3, it is clearly shown that rice husks from nations such as India, Japan, Brazil, and Malaysia often have high quantities of silica, frequently surpassing 90 percent [13]. This

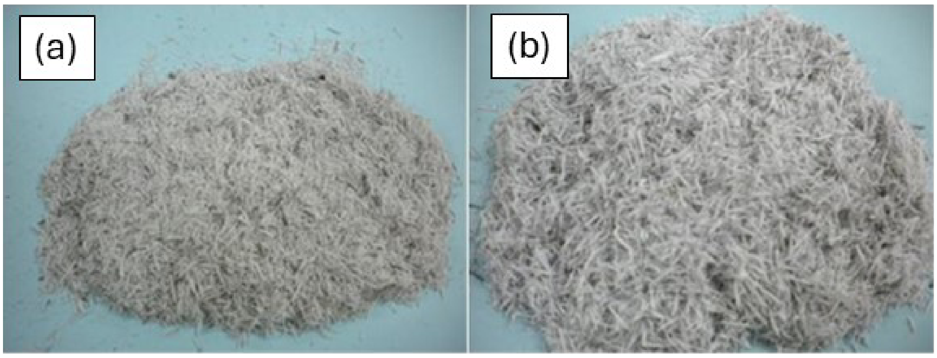

Fig. 2. (a) Greyish rice husk ash; (b) White rice husk ash

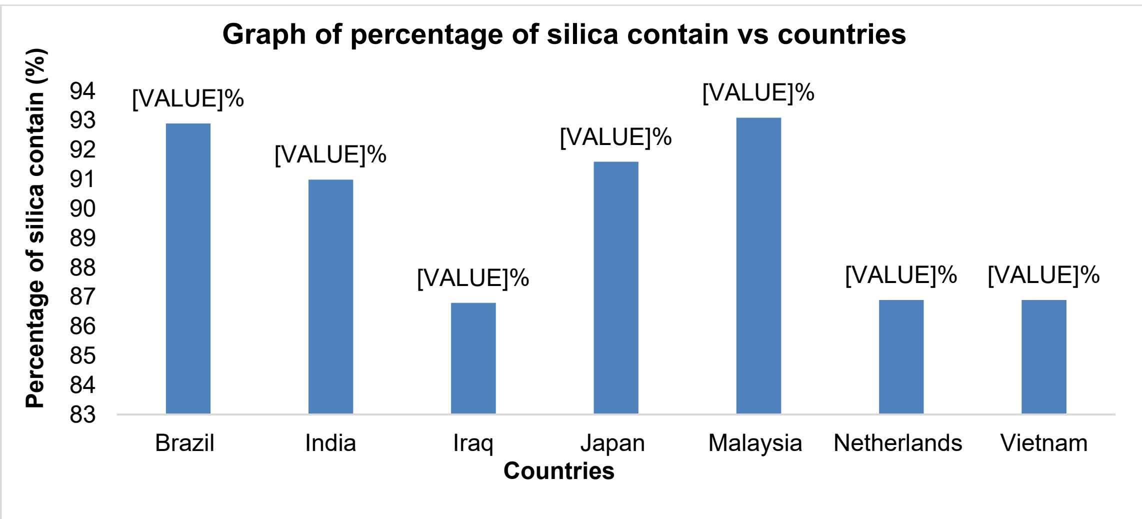

Fig. 3. Graph of percentage of silica contained in different countries [13]

high silica concentration is advantageous for the production of high-purity rice husk ash (RHA), which is utilised extensively in a variety of industries such as ceramics and construction. On the other hand, rice husk from countries such as Vietnam may have a slightly lower silica content, but it may include higher levels of potassium oxide (K_2O) and calcium oxide (CaO). In this case, the ash is suitable for uses that require greater alkaline qualities, such as fertilisers and soil conditioners, because it contains more oxides, which contribute to the ash's compatibility for these applications [14-16].

Silica is commonly found in raw rice husk (RH) and rice husk ash (RHA) that has various significant characteristics. The silica is primarily amorphous, which increases its reactivity and makes it highly desirable for industrial applications like rubber industry as a reinforcing filler to enhance its mechanical properties. Other than that, it also can apply in construction materials as a pozzolanic material in cement and concrete. Besides that, rice husk ash exhibits notable attributes such as a substantial surface area and porosity, enabling it to efficiently absorb chemicals and enhance material characteristics. Furthermore, the silica content in both RH and RHA is typically high, frequently exceeding 90% which offers a pure and consistent supply of silica [17]. These properties of rice husk-derived silica through Energy Dispersive X-ray Spectroscopy (EDS) analysis, which helps identify the elemental composition of the material [18,19]. As temperatures keep on increasing around 800-850°C, the silica can start to crystallize, forming cristobalite or tridymite phases, which may reduce its reactivity and usefulness for certain applications [20,21].

3. Combustion process

The method of rice husk combustion was designed to efficiently eliminate unwanted impurities and produce high-purity silica [17]. During the combustion process, the minerals content present in the rice husk is burned at controlled temperatures, usually ranging from 600°C to 1000°C based on previous study shown in Table 1 to ensure full oxidation [22-26]. This procedure converts the rice husk into rice husk ash (RHA), which is primarily composed of amorphous silica. By precisely controlling the combustion temperature, the presence of impurities such as carbon residues and other metal oxides (including Al_2O_3, Na_2O, CaO, K_2O, Fe_2O_3, MgO, and SO_3) is significantly reduced or even completely eliminated thus determined by X-ray fluorescence (XRF). The high-purity silica product is known for its exceptional reactivity and suitability for a wide range of industrial applications. The process of purifying silica through combustion not only enhances its purity but also optimizes its commercial value and functionality.

During the combustion of rice husk to extract high-purity silica, several factors such as heating temperature, heating rate, and cooling rate have significant influences [27]. This temperature range guarantees the full oxidation of organic components while maintaining the silica content. Based on TABLE 1, the heating rate typically ranging from 1°C/min to 20°C/min, plays an important role in determining the thermal degradation of rice husk. Controlling the rate of heating and gradually increasing the temperature can minimize the sticking together of silica particles and preserve their structural integrity. Next, the rate at which the temperature decreases are equally significant. Typically, it is advisable to employ a gradual cooling rate, such as 2°C/min to 20°C/min, to prevent thermal shocks that may lead to structural flaws or impurities in the silica.

Past study from TABLE 1 clearly shows that the temperature at which combustion occurs is very important in the process of converting rice husk into silica. At combustion temperatures of 600-800°C, the resultant ash maintains a black ash. The dark colour signifies the existence of remaining carbon and other contaminants in the rice husk ash. Although there is some partial oxidation happening at these temperatures, it is not enough to entirely remove all undesired components [28]. However, when the temperature of combustion increases to 1000°C, a notable shift takes place. At this high temperature, the rice husk ash undergoes a colour change to white ash, indicating that the carbon and other impurities have been nearly eliminated. The presence of white ash signifies the effective elimination of almost all impurities, resulting in the presence of highly pure silica [29]. This highlights the need to attain and sustain elevated combustion temperatures to guarantee the creation of uncontaminated, responsive silica that is appropriate for diverse industrial uses. The change from black to white ash demonstrates the efficacy of elevated temperatures in refining rice husk ash and improving its quality and marketability.

Other than that, these studies also highlighted the importance of the heating and cooling rates in the combustion process of rice husk to produce high-purity silica. One key finding is that the most suitable heating rate is 5°C/min. This specific rate strikes a balance that allows for the complete combustion of the rice husk, ensuring the transformation into high-purity silica.

TABLE 1

Comparison of past studies about the combustion temperature, heating rate, and cooling rate of rice husk

Authors	Parameters		
	Temperature (°C)	**Heating rate (°C/min)**	**Cooling rate (°C/min)**
Hirose Carlsen & Saito, 2024	650-1100	20	0-20
Fernandes et al., 2024	800	10	Slowly till room temperature
Daulay et al., 2021	600-1000	1	—
Grimm et al., 2021	600	1	2
Ma et al., 2023	600-800	10	20

If the heating rate is too fast, the rice husk does not have sufficient time to undergo full combustion, resulting in incomplete oxidation and lower-purity silica. On the other hand, if the heating rate is too slow, the process becomes inefficient, significantly extending the time required to achieve the desired outcome. Similarly, the cooling rate is also significant in preserving the quality of the silica produced. Research has found that a cooling rate of 2°C/min is most suitable. Cooling down too quickly can lead to thermal shocks, which might damage the ash structure and adversely affect the purity of the silica. A gradual cooling rate of 2°C/min helps maintain the structural integrity of the ash, ensuring that the final silica product is of high purity and free from structural flaws.

3.1. Temperature range

3.1.1. Low-temperature range

Low-temperature combustion, occurring between 500-700°C, tends to produce high-purity, amorphous silica [30]. This process effectively removes organic matter without significantly crystallizing the silica. One major advantage of maintaining the amorphous structure is its high reactivity, which is beneficial for many industrial applications. However, a drawback is that incomplete combustion may leave some carbon residues, potentially affecting the final product's purity. Additionally, the rice husk ash produced is often pink in colour [31].

3.2.2. Medium-temperature range

When conducting medium-temperature combustion between 700-900°C, the silica content and purity are significantly influenced by the combustion process. As the temperature rises, more organic matter is completely burned off, leading to higher-purity silica. At these temperatures, the silica structure remains predominantly amorphous [30]. One advantage of this method is that it strikes a balance between achieving efficient combustion and preserving the amorphous structure of silica. However, a disadvantage is that the risk of forming crystalline phases begins to increase slightly as the temperature approaches the higher end of this range. In this range, the rice husk ash will be at grey in colour because there are still some impurities inside it [31].

3.1.3. High-temperature range

Next, high-temperature combustion ranging from 900 to 1000°C, significantly impacts the silica content and purity in materials like rice husk ash. At these elevated temperatures, silica transitions from an amorphous form to crystalline structures, specifically forming cristobalite or tridymite phases [32]. This transformation has its advantages, such as the near-complete removal of organic matter and other impurities, resulting in a pure white rice husk ash [31]. However, this crystallization process also has its drawbacks, as it reduces the reactivity of silica, limiting its applicability in certain industrial processes.

4. Application

The combustion temperature of rice husk significantly influences the phase of silica produced. When rice husk is combusted at temperatures low range and medium range, the silica obtained is predominantly in an amorphous form [33]. This is because the lower temperatures prevent the crystallization process, allowing the silica to retain a disordered and non-crystalline structure. Conversely, when the combustion temperature gets higher in the high-temperature range, the silica tends to become crystalline and often in the form of cristobalite or tridymite [32]. This transformation occurs due to the higher energy environment, which provides the necessary conditions for the silica atoms to arrange into a more ordered, crystalline lattice. The intermediate high-temperature range can result in a mixture of both amorphous and crystalline phases, depending on the specific conditions and duration of the combustion process.

The amorphous silica is characterized by its high surface area and reactivity has a wide range of industrial applications. In the area of material science, it is commonly used as a filler in rubber and plastic composites to enhance strength and durability. Its high reactivity also makes it an excellent additive in cement and concrete [34], thus improving the mechanical properties and durability of the concrete. Additionally, amorphous silica is utilized in the production of high-performance ceramics and refractory materials due to its ability to withstand high temperatures and thermal shocks. In the agricultural sector, it serves as a beneficial soil amendment, improving soil structure and plant health. Thus, amorphous silica can be applied across a wide range of industries and applications.

On the other hand, crystalline silica with its well-defined structure is extensively used in the manufacturing of glass and ceramics [35], where it provides clarity and strength. Its high thermal stability makes it ideal for use in the production of refractory bricks and moulds used in metal casting. Furthermore, crystalline silica is a key component in the electronics industry, where it is used to produce silicon wafers for semiconductors and solar panels [36]. Despite its versatile applications, the handling of crystalline silica requires caution due to its potential health risks, such as silicosis, when inhaled as fine dust [37]. Therefore, appropriate safety measures are essential during its processing and use. Thus, both amorphous and crystalline silica each have distinct value and specialized applications across various industries.

5. Conclusion

Rice husk (RH) and its derivative, rice husk ash (RHA), offer significant value due to their high silica content, which constitutes about 20-22% of the husk's weight. The effective utilization of rice husks, which were previously considered agricultural waste, addresses both environmental and economic concerns. The combustion process of rice husks, aimed at extracting silica, is crucial for transforming this agricultural waste into a high-value resource. The efficiency of this process is highly dependent on the combustion temperature. At lower temperatures (500-700°C), the combustion may result in incomplete oxidation, producing black ash with residual carbon. However, as the temperature increases (700-900°C), more organic matter is oxidized, resulting in grey ash with higher purity silica. At temperatures above 900°C, the silica begins to undergo complete combustion, and the impurities are eliminated and produce white ash. Other than that, the chemical composition of rice husk varies depending on its country of origin, influenced by factors such as soil composition, climate, and agricultural practices. This variation affects the quality and suitability of the silica for different industrial applications.

In conclusion, the controlled combustion of rice husks to extract silica not only reduces agricultural waste and minimizes environmental impact but also produces a valuable material with wide-ranging industrial applications. The ability to produce both amorphous and crystalline silica, depending on the combustion conditions, further enhances the versatility and economic potential of rice husk-derived silica. By optimizing the combustion process, high-purity silica which can meet the specific needs of various industries, contributing to sustainability and the efficient use of agricultural by-products can be produced.

Acknowledgement

This research was supported by the [Name of Research Grant] under Grant Number. I would like to express their gratitude for the financial and technical support provided, which significantly contributed to the successful completion of this study.

REFERENCES

[1] D. Carlevaris, M. Leonardi, G. Straffelini, S. Gialanella, Design of a friction material for brake pads based on rice husk and its derivatives. Wear **526-527** (2023). DOI: https://doi.org/10.1016/j.wear.2023.204893

[2] C.A.M. Moraes et al., Review of the rice production cycle: By-products and the main applications focusing on rice husk combustion and ash recycling. Nov. 20, 2014, SAGE Publications Ltd. DOI: https://doi.org/10.1177/0734242X14557379

[3] R. Pode, Potential applications of rice husk ash waste from rice husk biomass power plant. Jan. 01, 2016, Elsevier Ltd. DOI: https://doi.org/10.1016/j.rser.2015.09.051

[4] N.T. Nguyen et al., The extraction of lignocelluloses and silica from rice husk using a single biorefinery process and their characteristics. Journal of Industrial and Engineering Chemistry **108**, (2022). DOI: https://doi.org/10.1016/j.jiec.2021.12.032

[5] B.A. Tayeh, R. Alyousef, H. Alabduljabbar, A. Alaskar, Recycling of rice husk waste for a sustainable concrete: A critical review. Aug. 20, (2021). Elsevier Ltd. DOI: https://doi.org/10.1016/j.jclepro.2021.127734

[6] Y. Zou, T. Yang, Rice husk, rice husk ash and their applications. in Rice Bran and Rice Bran Oil: Chemistry, Processing and Utilization. Elsevier 207-246 (2019). DOI: https://doi.org/10.1016/B978-0-12-812828-2.00009-3

[7] G. Ramalingam, A.K. Priya, L. Gnanasekaran, S. Rajendran, T.K.A. Hoang, Biomass and waste derived silica, activated carbon and ammonia-based materials for energy-related applications – A review. Fuel **355**, (2024). DOI: https://doi.org/10.1016/j.fuel.2023.129490

[8] R.A. Bakar, R. Yahya, S.N. Gan, Production of High Purity Amorphous Silica from Rice Husk. Procedia Chem. **19**, (2016). DOI: https://doi.org/10.1016/j.proche.2016.03.092

[9] S. Steven et al., Thermodynamics Simulation Performance of Rice Husk Combustion with a Realistic Decomposition Approach on the Devolatilization Stage. Waste Biomass Valorization **13**, 5, (2022). DOI: https://doi.org/10.1007/s12649-021-01657-x

[10] R. Sigalingging, E. Susanto, S. Panggabean, The effect of rice husk mass on temperature and characteristics of its ash using a pyrolysis equipment organic-inorganic waste. In IOP Conference Series: Earth and Environmental Science, Institute of Physics Publishing, Apr. 2020. DOI: https://doi.org/10.1088/1755-1315/454/1/012043

[11] N. A. Mohidem, N. Hashim, R. Shamsudin, H. C. Man, Rice for Food Security: Revisiting Its Production, Diversity, Rice Milling Process and Nutrient Content. Jun. 01, 2022, MDPI. DOI: https://doi.org/10.3390/agriculture12060741

[12] D. Singh Karam et al., An overview on the preparation of rice husk biochar, factors affecting its properties, and its agriculture application. 2022. doi: 10.1016/j.jssas.2021.07.005

[13] M. A. Salam, K. Ahmed, T. Hossain, Md. S. Habib, Md. S. Uddin, N. Papri, Prospect of Molecular Sieves Production using Rice Husk in Bangladesh: A Review. International Journal of Chemistry, Mathematics and Physics **3**, 6, 105-134 (2019). DOI: https://doi.org/10.22161/ijcmp.3.6.2

[14] H. Moayedi, B. Aghel, M.M. Abdullahi, H. Nguyen, A. Safuan A Rashid, Applications of rice husk ash as green and sustainable biomass. Nov. 10, (2019). Elsevier Ltd. DOI: https://doi.org/10.1016/j.jclepro.2019.117851

[15] A. Kumar, B. Sengupta, D. Dasgupta, T. Mandal, S. Datta, Recovery of value added products from rice husk ash to explore an economic way for recycle and reuse of agricultural waste. Mar. 01, (2016). Springer Netherlands. DOI: https://doi.org/10.1007/s11157-015-9388-0

[16] A. Geethakarthi, Novel Approaches towards Sustainable Management of an Agricultural Residue-The Rice Husk. Nature Environment and Pollution Technology **20**, 1, 349-355 (2021). DOI: https://doi.org/10.46488/nept.2021.v20I01.040

[17] P.U. Nzereogu, A.D. Omah, F.I. Ezema, E.I. Iwuoha, A.C. Nwanya, Silica extraction from rice husk: Comprehensive review and applications. Hybrid Advances **4**, 100111 (2023). DOI: https://doi.org/10.1016/j.hybadv.2023.100111

[18] R. Suryana, Y. Iriani, F. Nurosyid, D. Fasquelle, Characteristics of silica rice husk ash from Mojogedang Karanganyar Indonesia. in IOP Conference Series: Materials Science and Engineering, Institute of Physics Publishing, Jun. 2018. DOI: https://doi.org/10.1088/1757-899X/367/1/012008

[19] R. Vijayan, G.S. Kumar, G. Karunakaran, N. Surumbarkuzhali, S. Prabhu, R. Ramesh, Microwave combustion synthesis of tin oxide-decorated silica nanostructure using rice husk template for supercapacitor applications. Journal of Materials Science: Materials in Electronics **31**, 7, 5738-5745 (2020). DOI: https://doi.org/10.1007/s10854-020-03142-y

[20] M.M. Hirose Carlsen,Y. Saito, Phase diagram of SiO2 crystallization upon rice husk combustion to control silica ash quality. Waste Management **182**, 55-62 (2024). DOI: https://doi.org/10.1016/j.wasman.2024.04.009

[21] M. Amran et al., Rice husk ash-based concrete composites: A critical review of their properties and applications. Feb. 01, 2021, MDPI AG. DOI: https://doi.org/10.3390/cryst11020168

[22] M.M. Hirose Carlsen, Y. Saito, Phase diagram of SiO2 crystallization upon rice husk combustion to control silica ash quality. Waste Management **182**, 55-62 (2024). DOI: https://doi.org/10.1016/j.wasman.2024.04.009

[23] I.J. Fernandes, C.A.M. Moraes, J.R.J. Egea, V.C. Sousa, Production and characterization of silica materials from rice husk ash by different combustion processes. Powder Technol. **436**, (2024). DOI: https://doi.org/10.1016/j.powtec.2024.119473

[24] A. Daulay, Andriayani, Marpongahtun, S. Gea, Effect of variation temperature at burning rice husk to obtain silica. In AIP Conference Proceedings, American Institute of Physics Inc., Apr. 2021. DOI: https://doi.org/10.1063/5.0046151

[25] A.M. Grimm, L.Y. Dorsch, G.H. Kloess, D. Enke, A. Roppertz, Transition metal promoted combustion of rice husk and rice straw towards an energy optimized synthesis of biogenic silica. Biomass Bioenergy **155**, (2021). DOI: https://doi.org/10.1016/j.biombioe.2021.106282

[26] Y. Ma et al., Comparative Study of Different Pretreatment and Combustion Methods on the Grindability of Rice-Husk-Based SiO2. Nanomaterials **13**, 22 (2023). DOI: https://doi.org/10.3390/nano13222951

[27] S. El-Sayed, Thermal decomposition, kinetics and combustion parameters determination for two different sizes of rice husk using TGA. Engineering in Agriculture, Environment and Food **12**, 4 (2019). DOI: https://doi.org/10.1016/j.eaef.2019.08.002

[28] E. Aprianti S, A huge number of artificial waste material can be supplementary cementitious material (SCM) for concrete production – a review part II. Jan. 20, 2017, Elsevier Ltd. DOI: https://doi.org/10.1016/j.jclepro.2015.12.115

[29] M. Haziq, A. M. Hisham, S. Ahmad, S. Sufi, Effect of Burning Temperature on Rice Husk from Pasir Puteh and Pasir Tumboh Areas, Kelantan. Research Progress in Mechanical and Manufacturing Engineering **4**, 1, 258-264 (2023). DOI: https://doi.org/10.30880/rpmme.2023.04.01.028

[30] N.F.M. Joharudin, N.A. Latif, M.S. Mustapa, N.A. Badarulzaman, M.F. Mahmod, Effect of burning temperature on rice husk silica as reinforcement of recycled aluminium chip AA7075. Journal of Advanced Research in Fluid Mechanics and Thermal Sciences **68**, 1, 125-132 (2020). DOI: https://doi.org/10.37934/arfmts.68.1.125132

[31] R.P. Jaya, M.A.A. Muhamad Nor, Z.A. Ahmad, Z. Mohd Amin, Properties of mortar containing rice husk ash at different temperature and exposed to aggressive environment. In Advanced Materials Research, pp. 87-93 (2013). DOI: https://doi.org/10.4028/www.scientific.net/amr.620.87

[32] Md.T. Islam, Md.F. Hossen, Md.A. Asraf, Md. Kudrat-E-Zahan, C.M. Zakaria, Production and Characterization of Silica from Rice Husk: An Updated Review. Asian Journal of Chemical Sciences **14**, 2, 83-96 (2024). DOI: https://doi.org/10.9734/ajocs/2024/v14i2296

[33] S. Steven, E. Restiawaty, Y. Bindar, Routes for energy and biosilica production from rice husk: A comprehensive review and emerging prospect. Renewable and Sustainable Energy Reviews **149**, (2021). DOI: https://doi.org/10.1016/j.rser.2021.111329

[34] M. Seifan, S. Mendoza, A. Berenjian, Mechanical properties and durability performance of fly ash based mortar containing nano- and micro-silica additives. Constr. Build. Mater. **252**, (2020). DOI: https://doi.org/10.1016/j.conbuildmat.2020.119121

[35] P. Patra, K. Annapurna, Transparent tellurite glass-ceramics for photonics applications: A comprehensive review on crystalline phases and crystallization mechanisms. Progress in Materials Science **125**, 100890 (2022). DOI: https://doi.org/10.1016/j.pmatsci.2021.100890

[36] M. Fan, Z. Yu, W. Ma, L. Li, Life Cycle Assessment of Crystalline Silicon Wafers for Photovoltaic Power Generation. Silicon **13**, 9, (2021). DOI: https://doi.org/10.1007/s12633-020-00670-4

[37] T.P. Souza, M. van Tongeren, I. Monteiro, Respiratory health and silicosis in artisanal mine workers in southern Brazil. Am. J. Ind. Med. **64**, 6 (2021). DOI: https://doi.org/10.1002/ajim.23242