UNIVERSITI PUTRA MALAYSIA

EFFECT OF RICE HUSK ASH ADDITION ON THE PHYSICAL PROPERTIES OF SODA-LIME-SILICA GLASS FOR BUILDING GLASS AND WINDOW

MOHAMMAD F F S ALAZEMI

EFFECT OF RICE HUSK ASH ADDITION ON THE PHYSICAL PROPERTIES OF SODA-LIME-SILICA GLASS FOR BUILDING GLASS AND WINDOW

By

MOHAMMAD F F S ALAZEMI

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Doctor of Philosophy

September 2021

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Doctor of Philosophy

EFFECT OF RICE HUSK ASH ADDITION ON THE PHYSICAL PROPERTIES OF SODA-LIME-SILICA GLASS FOR BUILDING GLASS AND WINDOW

By

MOHAMMAD F F S ALAZEMI

September 2021

Chairman : Mohd Khairol Anuar bin Ariffin, PhD, PEng
Faculty : Engineering

One of the promising raw materials in producing glass is rice husk (RH), which contains about 90% of silica and is usually burnt in an open area which contributed to serious air pollution problems. The environmental issues of RH could be resolved by utilizing rice husk ash (RHA) as a silica source in the glass manufacturing process. The main objective of this research is to develop an eco-friendly Soda-Lime-Silica - Rice Husk Ash (SLS-RHA) glass for the application of building glass and window. Three main experiments were conducted; morphology test, ultrasonic velocities testing and Rockwell hardness test to assess the microstructure, elastic and mechanical behaviour of the developed SLS-RHA glass. Response surface methodology (RSM) was used to design the experiments incorporating two factors; such as the ratio of SLS to RHA and their interrelationship; and the effect on glass hardness properties were analysed using analysis of variance (ANOVA). From the morphology analysis, the addition of RHA to the glass former matrix increased the porosity of the glass which influenced the elastic properties of the newly developed glass. It was observed that sample two with 5% RHA wt. addition performed the finest under elastic properties test and the longitudinal and shear modulus of RHA glass decrease with the increased of RHA content. Sample with 5% of RHA possessed high and medium elastic properties, which make it easier to bend rather than elongate, less stiff, tough at a certain direction, and has low rigidity. The value of the longitudinal modulus decreased 7.12% with the addition of 10% RHA wt. Finally, for the hardness test, based on the observation from HRF, HRB and HRG contour plots which showed that the hardness values for each sample decreased as the RHA percentage increased in the SLS glass system. The hardness of the glass decreased with an increase in the addition of RHA content due to elastic deformation. The optimal solution obtained from ANOVA for the combination of RHA and SLS is SLS (A) 29.589% wt. and RHA (B) 0.031% wt. This formulation provided the results of 130.588 for HRF, 124.844 for HRB and 120.098 for HRG. It can be summarized that the use of silica from RHA efficiently improved the bulk modulus while maintaining a lower Young's modulus value of the glass. This

resulted in improved impact resistance of the glass due to a slower decelerated in smaller stress acting on the glass even though the glasses are less stiff. In this research, RHA proved to be a good silica source alternative for the glass manufacturing process, which can potentially improve the melting process temperature indirectly helps to reduce the cost of the manufacturing process.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

KESAN TAMBAHAN ABU SEKAM PADI TERHADAP SIFAT FIZIKAL KACA SODA-LIME-SILIKA UNTUK KACA BANGUNAN DAN JENDELA

Oleh

MOHAMMAD F F S ALAZEMI

September 2021

Pengerusi : Mohd Khairol Anuar bin Ariffin, PhD, PEng
Fakulti : Kejuruteraan

Salah satu bahan mentah yang mempunyai potensi yang tinggi dalam penghasilan kaca ialah sekam padi (RH), yang mengandungi kira-kira 90% silika dan biasanya dibakar di kawasan terbuka dan merupakan penyumbang kepada masalah pencemaran udara yang serius. Isu alam sekitar ini boleh diselesaikan dengan menggunakan abu sekam padi (RHA) sebagai sumber silika dalam proses pembuatan kaca. Objektif utama penyelidikan ini adalah untuk membangunkan kaca Soda-Lime-Silica - Rice Husk Ash (SLS-RHA) yang mesra alam untuk aplikasi kaca dan tingkap bangunan. Tiga eksperimen utama telah dijalankan; iaitu ujian morfologi, ujian halaju ultrasonik dan ujian kekerasan Rockwell untuk menilai struktur mikro, keanjalan dan tingkah laku mekanikal kaca SLS-RHA yang dibangunkan. Kaedah tindak balas permukaan (RSM) telah digunakan untuk mereka bentuk eksperimen yang menggabungkan dua faktor; iaitu nisbah SLS kepada RHA dan kesalinghubungan serta kesannya terhadap sifat kekerasan kaca telah dianalisis menggunakan analisis varians (ANOVA). Daripada analisis morfologi, penambahan RHA pada bekas matriks kaca meningkatkan keliangan kaca yang mempengaruhi sifat keanjalan kaca yang baru dibangunkan. Dari pemerhatian juga didapati bahawa sampel dua dengan penambahan 5% berat RHA mempunyai sifat keanjalan terbaik manakala modulus memanjang dan ricih kaca RHA berkurangan dengan peningkatan kandungan RHA. Sampel dengan 5% RHA mempunyai sifat keanjalan tinggi dan sederhana, yang menjadikannya lebih mudah dibengkokkan daripada memanjang, kurang kaku, lasak pada arah tertentu, dan mempunyai ketegaran yang rendah. Nilai modulus memanjang berkurangan 7.12% dengan penambahan 10% RHA wt. Akhir sekali bagi ujian kekerasan, berdasarkan pemerhatian dari plot kontur HRF, HRB dan HRG menunjukkan bahawa nilai kekerasan bagi setiap sampel menurun apabila peratusan RHA meningkat dalam sistem kaca SLS. Kekerasan kaca menurun dengan peningkatan dalam penambahan kandungan abu sekam padi akibat ubah bentuk elastik. Penyelesaian optimum yang diperoleh daripada ANOVA untuk gabungan RHA dan SLS ialah SLS (A) 29.589% berat. dan RHA (B) 0.031% berat. Formulasi ini

memberikan keputusan 130.588 untuk HRF, 124.844 untuk HRB dan 120.098 untuk HRG. Ia boleh dirumuskan bahawa penggunaan silika daripada abu sekam padi secara cekap meningkatkan modulus pukal sambil mengekalkan nilai modulus Young yang lebih rendah bagi kaca, yang menyebablan rintangan hentaman kaca yang lebih baik disebabkan oleh nyahpecutan yang lebih perlahan dalam tegasan yang lebih kecil bertindak ke atas. kaca walaupun gelas itu kurang kaku. Dalam penyelidikan ini, RHA terbukti sebagai alternatif sumber silika yang baik untuk proses pembuatan kaca dan berpotensi meningkatkan suhu proses lebur yang secara tidak langsung membantu mengurangkan kos proses pembuatan.

ACKNOWLEDGEMENTS

"Firstly, all thanks and praise to **Allah** that he bless me to complete my higher education and I dedicate my greatest love to all my family including my **mother** who always supplicates and asks **Allah** to help and bless me to fulfil the requirements of the thesis and gain the degree, my **wife** who encourages me to gather the PhD award and my **kids** who make me smile during my study, finally, my thanks to my **government** for providing me the opportunity and support to obtain this degree."

I take this opportunity to sincerely express my gratitude to Prof. Ir. Dr. Mohd Khairol Anuar Mohd Ariffin for chairing my committee and advising this research. I am grateful to him for spending time with me and helping me. I am indebted to him for his whole-hearted support, enthusiasm and inspiration throughout my graduated study.

I am grateful to Associate Professor. Ir. Ts. Dr. Faieza Binti Abdul Aziz and Dr. Eris Elianddy Supeni for the valuable advice and suggestions provided to me during the progression of my study and for their participation in my committee.
I also thank all other faculty members who helped me prepare this thesis.

THANK YOU

This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Doctor of Philosophy. The members of the Supervisory Committee were as follows:

Mohd Khairol Anuar bin Mohd Ariffin, PhD, PEng
Professor Ir.
Faculty of Engineering
Universiti Putra Malaysia
(Chairman)

Faieza binti Abdul Aziz, PhD
Associate Professor, Ir. Ts.
Faculty of Engineering
Universiti Putra Malaysia
(Member)

Eris Elianddy bin Supeni, PhD
Associate Professor
Faculty of Engineering
Universiti Putra Malaysia
(Member)

ZALILAH MOHD SHARIFF, PhD
Professor and Dean
School of Graduate Studies
Universiti Putra Malaysia

Date: 9 March 2022

Declaration by graduate student

I hereby confirm that:

- this thesis is my original work;
- quotations, illustrations and citations have been duly referenced;
- this thesis has not been submitted previously or concurrently for any other degree at any other institutions;
- intellectual property from the thesis and copyright of thesis are fully-owned by Universiti Putra Malaysia, as according to the Universiti Putra Malaysia (Research) Rules 2012;
- written permission must be obtained from supervisor and the office of Deputy Vice-Chancellor (Research and Innovation) before thesis is published (in the form of written, printed or in electronic form) including books, journals, modules, proceedings, popular writings, seminar papers, manuscripts, posters, reports, lecture notes, learning modules or any other materials as stated in the Universiti Putra Malaysia (Research) Rules 2012;
- there is no plagiarism or data falsification/fabrication in the thesis, and scholarly integrity is upheld as according to the Universiti Putra Malaysia (Graduate Studies) Rules 2003 (Revision 2012-2013) and the Universiti Putra Malaysia (Research) Rules 2012. The thesis has undergone plagiarism detection software.

Signature: ________________________ Date: __________________

Name and Matric No.: ____

Declaration by Members of Supervisory Committee

This is to confirm that:

- the research conducted and the writing of this thesis was under our supervision;
- supervision responsibilities as stated in the Universiti Putra Malaysia (Graduate Studies) Rules 2003 (Revision 2012-2013) are adhered to.

Signature: ______________________________
Name of Chairman of Supervisory Committee: ______________________________

Signature: ______________________________
Name of Member of Supervisory Committee: ______________________________

Signature: ______________________________
Name of Member of Supervisory Committee: ______________________________

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

2D	Two Dimensional
3D	Three Dimensional
ANOVA	Analysis of Variance
CCD	Central Composite Design
CFD	Computational Fluid Dynamic
CI	Confidence Interval
DF	Degrees of freedom
EPDM	Ethylene-Propylene-Diene Terpolymer
FEM	Finite Element Method
FFD	Full Factorial Design
HCL	Hydrochloric Acid
HRB	Rockwell B-Scale
HRF	Rockwell F-Scale
HRG	Rockwell G-Scale
NBO	Non-Bridging Oxygen
PC	Personal Computer
RH	Rice Husk
RHA	Rice Husk Ash
RHV	Rockwell Hardness Value
RSM	Response Surface Method
R&D	Research and Development
SEM	Scanning Electron Microscope
SLS	Soda Lime Silicate
WRHA	White Rice Husk Ash

XRD	X-Ray Diffraction
XRF	X-Ray Fluorescence
VIF	Variance Inflation Factors

CHAPTER 1

INTRODUCTION

This chapter describes the research background, problem statement, objectives, scope of the research work and the importance of the study to the engineering community in general and researchers perspectives in particular.

1.1 Research Background

Waste management is one of the foremost topics of study that is vastly developing in the scientific fields. The global markets are currently working on minimizing the necessity for extracting raw materials and maximizing the material life by promoting the reuse and recycling program. This idea is driven by the need to turn waste into a valuable resource by designing products that can be easily recovered and reused as a raw material for a similar, industry (Borek et al., 2020). Activities like these are compelling methods to avoid pollution and reduce waste emissions (Dales, 2002).

As industrial production keep on increasing day by day, domestic wastes increases, as well as their disposal management continued to pose a serious threat to society and environment. Waste Reduction Group Environmental Protection Department reported that about 83000 tonnes of glass waste were generated and only 3% of these was recovered (Borek et al., 2020).

Glass recycling offers a series of advantages such as preserve raw materials sources and help to reduce energy consumption. The soda-lime silicate (SLS) glass waste usage has been widely initiated due to the awareness of environmentally friendly products and the unique behaviour of the SLS glass itself. SLS glass can be recycled several times without loosening its strength and adaptability in different techniques and shapes of fabrication (Shamsudin et al., 2016). The use of recycled SLS glass in the fabrication of glass-ceramic or green glass-ceramics composite has attracted numerous studies due to its quartz phase content (Juoi et al., 2013).

In the past few years, numerous researchers have shown interest in applying rice husk (RH) silica in several fields. Due to its low thermal conductivity (κ), rice husk ash (RHA) is used as an ingredient in the manufacture of insulation refractories. RHA also has been widely used in several areas for the manufacture of various silicates, zeolites, catalysts, nanocomposites, cement, lightweight building materials, insulators, and adsorbents over the past two decades. For countless reasons, present-day glass is one of the most commonly used materials in human daily life, and the number is rising tremendously. Glass is known as a non-crystalline supercooled liquid and the major element in glass making which acted as a “network-former” in glass networks is silica (SiO_2). Huge silica resources are therefore required for glass industries.

For this reason, researchers are trying to find alternative sources of silica. RHA has tremendous potential to fulfil this requirement because it contains more than 90 wt. % of amorphous silica. In this work, RHA is incorporated into the glass matrix to produce a porous glass composite. The idea of utilizing the RHA came out since RH is considered an agro-waste and has been posed as an environmental threat due to its abundance. RH is commonly burnt in the open air, which causes an enormous carbon monoxide emission to the atmosphere (Kartini, 2011). RH mainly contains about 75-90% of organic materials. One of the main advantages of RHA is its high content of silica, which has the potential to be the replacement of quartz sand in glassmaking. SLS glass is obtained from urban waste (used glass bottles and household glass containers). Through recycling SLS waste glass, the raw material consumption is reduced yielding economical and environmental benefits. This approach is a low investment method. The properties of the composite also can be tailored to the application by controlling the materials composition such as powder size, volume fractions and sintering temperature.

1.2 Problem Statement

Glass industries are investing large resources in extensive research and development activities to find new methods to use glass, to make new products available, to improve recyclability and effective recycling, and to improve manufacturing site energy efficiency. As a result, glass goods' environmental performance should be improved throughout their entire cycles. Glassmaking necessitates the use of raw materials. Sand and recycled glass are the most common raw materials used in glassmaking. Glass recycling is now a reality in the glass industry, albeit there are differences in how recovered materials are employed in different glass industries. As a result, sharing best practises and experiences in the field of recycling is critical for the glass industry to continue increasing product recycling rates. Glass researchers have looked into a variety of different types of glass.

For at least 30 years, the output of glass, particularly container and flat glass, has been steadily increasing. New investments in this sector, which have just been completed or are presently under way, have produced hopeful prospects for the industry's future development, with total annual production capacity likely to approach 4 million tonnes in the next years. As a result, demand for fundamental glass-making raw materials has increased, particularly for high-quality silica sand, which can be obtained almost entirely from domestic sources. Glass makers sometimes face difficulties obtaining regular, high-quality raw materials. Global market for industrial silica (quartz) sand is anticipated to be around 300 million tonnes per year, with the glass industry accounting for 34% (102 million tonnes). Demand is expected to rise 5.5 percent per year to 291 million metric tonnes in 2018, with a value of $6.78 billion. According to IMARC

Group's recent analysis, "Silica Sand Market: Global Industry Trends, Share, Size, Growth, Opportunity, and Forecast 2020-2025," the market reached US$ 8 billion in 2020 and is predicted to increase at a modest rate over the next seven years, as shown in Figure 1.1. (IMARC Group, 2020).

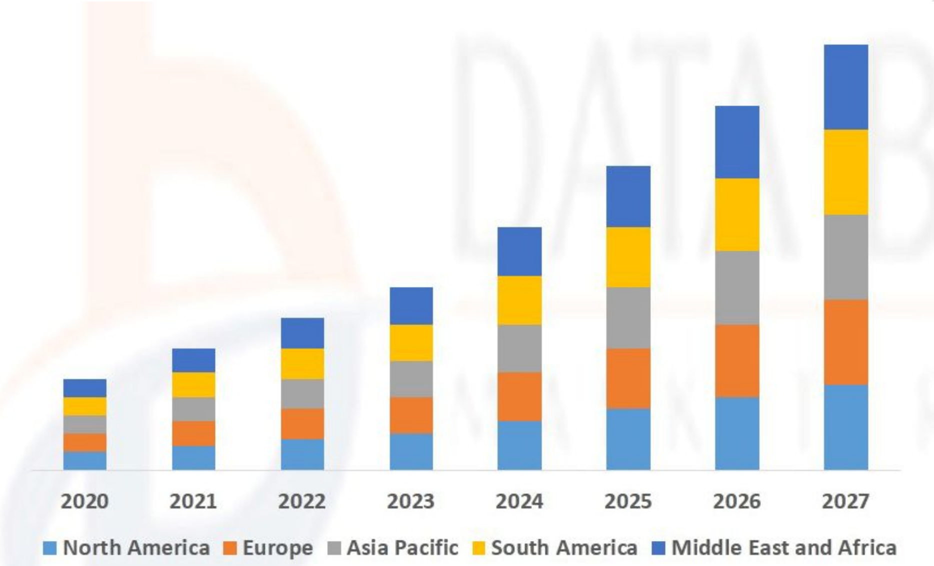

Figure 1.1: Silica sand market growth 2020 – 2027. (IMARC Group, 2020)

While silica sand is abundant, getting access to the correct resources is difficult. The sand had to be of good quality and low in iron, and the deposit had to be large enough. The deposit's closeness to clients is another important aspect. To reduce transportation costs and emissions, silica sand quarries are typically located within 300 kilometres of their major client base. Most crucially, a mining permit will be issued only if the impact on the surrounding environment and community can be reduced to a minimum. Sand was primarily collected from land quarries and riverbeds until recently. However, as a result of extensive exploitation and the fact that this practise has been outlawed in many areas, environmental rules have gotten considerably stricter or have outlawed this activity entirely. The mining of coastal sand has increased dramatically in recent years. As a result of the detrimental environmental impact, global, regional, and national legislation currently regulates marine sand mining activities more strictly. This industry's activities have severe negative environmental consequences, including major changes in local flora and fauna, contamination of groundwater and air, and landscape alteration. All environmental issues of the sand mining process should be given special consideration. The procedure is lengthy and consists of three stages, as shown in Table 1.1. Every stage has an impact on the ecosystem and causes significant harm. The cost of restoring an ecosystem is typically prohibitive, and the ecosystem is frequently unable to be returned to its previous state (Gavriletea, 2017).

Table 1.1: Stages in the life of sand mine.

Precursor to mining	
Prospecting Exploration	Searching for sand resources using multiple exploration techniques. Determining the possible size and value of the sand deposit using different evaluation techniques
Mining proper	
Developing Exploitation	Setting-up and commissioning facilities to extract, treat and transport sand and large scale sand production
Post mining	
Closure and reclamation	Returning the land to its original state

(Source: Gavriletea, 2017)

In recent years, the utilisation of waste or by-products from various sectors and the agricultural sector has gotten a lot of attention in the scientific, technological, ecological, economic, and social spheres. RH is a by-product of rice milling, and RHA is produced in a separate boiler by incineration. Rice-growing countries including China, India, Brazil, the United States, and Southeast Asia have plenty of RH and RHA. As a result, RH has been recycled by being burned to generate energy. This produces RHA, which contains a large amount of amorphous silica (85–95%). RHA has been used widely in the manufacturing of various silicates, zeolites, catalysts, nanocomposite, cement, lightweight construction materials, insulators, and adsorbents throughout the last two decades.

Despite the growing popularity of RHA in various applications, limited research has been devoted to identify the influence of several factors on the properties of silica in RHA. Furthermore, there has been a gap in the method of extraction of silica from RHA. The optimum silica extraction method involved the incineration temperature, incineration period and leaching process has not yet been established. Numerous studies had investigated the incineration period of silica production from RHA and yet the studied only focused on the phase transitions of amorphous to crystalline phase in RHA (Rivas et al., 2018).

In the early discovery of glass, most research focuses on quartz sand silica oxide as forming Network. A spirited debate occurred in the literature concerning the effect of the addition of Zinc Oxide (ZnO) into the borate and tellurite glass system. However, the topic of RHA addition into the SLS glass system was limited with no definitive answers to the fundamental topics. Although many properties of SLS glass such as high insulating properties are good and acceptable, yet, the effects of RHA addition was also limited. The effective use of silica from RHA has the potential to be the replacement of quartz sand in glassmaking, and hence depth understanding is needed to ensure an efficient glass with good physical and elastic properties can be produced. Rather than relying on conventional methods in the glass fabrication process, an eco-friendly and efficient product can be produced to replace the current existing quartz sand based glass. which is harmful to the environment due to its mining process. Ultimately, this research is targeted to enhance and fully utilize the usage of bio-waste in glass applications. In summary, the research questions formulated from the mentioned problem statement are as follows;

i. In terms of elastic and mechanical properties, how synergistic is the use of RHA-based silica addition in SLS glass as a source substitution compared to quartz sand?
ii. What are the factors that will influence the ability of the SLS-RHA glass in both elastic and mechanical tests?
iii. What is the optimal formulation for SLS-RHA glass in order to produce the best elastic and mechanical performance?
iv. Does the silica content from RHA affects the mechanical properties of the glass compared to conventional glass sand quartz?

Furthermore, the utilisation of RHA as a silica source in glass production could reduce environmental pollution and can turn agricultural waste into industrial wealth. Therefore, the investigation on the addition of RHA-based silica for glass production is needed with the attention of assessing physical (hardness) and elastic (longitudinal modulus (L), shear modulus (S), Young's modulus (E), bulk modulus (K), and Poisson's ratio (σ) properties of the glass.

1.3 Research Objectives

The aim of this work is to formulate a novel glass composition comprising recycled SLS glass with the addition of RHA as a new source to substitute the common quartz sand in glass making.

The specific objectives are:

i. To investigate the relationship between the incineration temperatures and the time to produce silica from RHA with optimum silica content.
ii. To assess the microstructure behaviour and material characterization of the newly formulated SLS - RHA glass.
iii. To identify the best optimum mixture and investigate the elastic properties of the newly produced SLS-RHA glass.
iv. To optimize the response of SLS-RHA glass ratio by utilizing response surface methodology (RSM) with relation to hardness properties.

1.4 Scope and Limitation of Work

In achieving the objectives of this study, a series of experimental works were conducted. First, RH morphological analyses were studied. The parameters of the study are the different pre-treatment through chemical pre-treatment and combustion processes on the production of high purity, RHA composition. The collected RH was pre-treated with distilled water and hydrochloric acid separately. Then, RH was incinerated in the furnace with a temperature of 550°c and 800°c for a duration of one hour and two hours. Subsequently, the RHA are characterized into three main analyses:

i. Analysis of high-energy radiation by using X-ray fluorescence (XRF) is involved for element characterization
ii. Microscopy analysis by using a scanning electron microscope (SEM)
iii. Phase identification analysis by using X-ray Powder Diffraction (XRD).

Different samples preparation for SLS-RHA glass were prepared. The glass samples based on the SLS-RHA glass will be prepared using SLS glass and RHA silica powder from x between 0.00 to 0.30 wt. % using conventional melting and quenching technique. The SLS glass samples will also be prepared and can be used as reference material. These glasses were then characterized into two main tests including:

i. The structure of SLS-RHA glass will be measured using the X-ray diffraction technique and SEM to confirm the amorphous structure of the glass sample.
ii. Elastic properties by using Ultrasonic Velocity (UV) test. From these values, physical properties or the strength of the glass can be known and determined.
iii. Mechanical properties test by using hardness test. Data are then analyzed to obtain the best SLS-RHA glass formulation.

The major limitation in this study that could be addressed are this study only focused on using RHA as a silicone dioxide substitution source in glass manufacturing. RHA is known as a very promising alternative source for silica in silica-based glass (Gonçalves et al., 2020). From previous research by da Silva Fernandes et al. (2019), a higher concentration of the recycled filler used in glass fabrication lead to lower the mechanical strength of glass. The highest mechanical strength was shown by the material 10% addition of RHA. Thus, the interest of this research is the ratio of RHA percentage in SLS glass production to achieve optimum mechanical properties of the glass. This research studied the addition of RHA in SLS glass in the range of 0% to 10% as per previous research by da Silva et al. (2019).

1.5 Significance of the Study

Planning waste management and recycling for all of the garbage produced in this country is a massive undertaking that necessitates both logistical planning and scientific knowledge and understanding in order to strike a balance between the process' environmental impact and its cost-effectiveness. Every year, millions of tonnes of waste glass are produced around the world. Because glass does not dissolve in the environment, it is unsustainable once it becomes a waste that is disposed of in landfills.

Glass is made up of roughly 70% sand, as well as a specific mixture of soda ash, limestone, and other natural elements, depending on the qualities required in the batch. Crushed, recycled glass, or cullet, is a vital element in the production of soda-lime glass. In each batch of glass, the amount of cullet utilised varies. Cullet melts at a lower temperature, consuming less energy and using fewer raw resources. The use of milled (ground) waste SLS cullet as a partial replacement for glass in glass manufacturing could be the most crucial step toward developing sustainable (environmentally friendly, energy-efficient, and cost-effective) infrastructure systems.

Numerous researchers had studied and developed the methodologies of treatment and recycling for glass waste materials. One of the development methods was the addition or doping of some oxide elements into the SLS glass structure (Saparuddin et al., 2020). In this research, RHA had been chosen as an oxide to be added into the SLS glass because of its good properties; improving the glass quality by increasing mechanical properties and enhancing chemical durability (Chazot et al., 2021). Furthermore, the utilisation of RHA as a silica source in glass production could reduce environmental pollution and can turn agricultural waste into industrial wealth.

1.6 Thesis Outline

This thesis consists of six chapters. Chapter one discusses the background of the research and problem statement on the current glass fabrication process, the research objectives, scope, limitation of work, significance of the study and outline of the dissertation.

Chapter two presents the extensive review related to the knowledge of this study including the composition of glass, the properties of glass and glass formation, as well as the preparation methods. Literature reviews on the properties of glass related to the current study are presented to gauge the development of newly formulated glass research. A review on related studies that have been carried out and reported previously for the silica extraction method for RHA was also presented in this chapter. Statistical design methods including response surface methodology (RSM) were also reviewed.

Chapter three illustrates the experiment work, materials used, equipment required and sample preparation of the glass fabrication samples are described. The elastic and mechanical properties and morphological studies involved are reported in detail.

Results and discussions are presented in chapter four which includes the RHA material characterization and microstructural analysis, microstructural characterization of SLS-RHA glass fabrication. The results are shown in form of graphs and tables and supported by statistical data using the ANOVA technique. Afterwards, the mathematical model is developed and compared with experimental results. Finally, the mechanical properties comparison for commercially available glass (Plexiglas) and optimum SLS-RHA glass is presented.

Finally, in chapter FIVE, the conclusions on the elastic and mechanical properties of SLS-RHA-glass are drawn. The effects of silica content on the formation of glass are also summarized. Finally, contributions and recommendations for future research are also presented.

REFERENCES

Abbas, A., & Ansumali, S. (2010). Global potential of rice husk as a renewable feedstock for ethanol biofuel production. BioEnergy Research, 3(4), 328-334.

Abdul Wahab, R. A., Mohd Zaid, M. H., Aziz, S. H., Amin Matori, K., Fen, Y. W., & Yaakob, Y. (2020). Effects of Sintering Temperature Variation on Synthesis of Glass-Ceramic Phosphor Using Rice Husk Ash as Silica Source. Materials, 13(23), 5413.

Achenbach, J. D. (2000). Quantitative nondestructive evaluation. International Journal of Solids and Structures, 37(1-2), 13-27.

Achintha, M. (2016). Sustainability of glass in construction. In Sustainability of construction materials (pp. 79-104). Woodhead Publishing.

Adamu, M.; Mohammed, B. S.; Shafiq, N.;, "Flexural performance of nano silica modified roller compacted rubbercrete," International Journal of Advanced and Applied Sciences, vol. 4, no. 9, pp. 6-18, 2017.

Almasri, K. A. M. (2018). Synthesis And Characterization Of Wollastonite Glassceramics Prepared From Cullet Doped With Samarium Oxide.

Aly, K. A., Afify, N., Saddeek, Y. B., & Abousehly, A. M. (2016). Elastic and optical properties of Ge x Se 2 Sb 1- x (0.0= x= 1.0) glasses. Bulletin of Materials Science, 39(2), 491-498.

Anderson, O. L., & Bömmel, H. E. (1955). Ultrasonic absorption in fused silica at low temperatures and high frequencies. Journal of the American Ceramic Society, 38(4), 125-131.

Anderson, O. L., & Dienes, G. J. (1960). Non-crystalline solids. John Wiley & Sons, New York, 1960) p, 453.

Anderson, O. L. (1966). The use of ultrasonic measurements under modest pressure to estimate compression at high pressure. Journal of Physics and Chemistry of Solids, 27(3), 547-565.

Anderson-Cook, C. M., Borror, C. M., & Montgomery, D. C. (2009). Response surface design evaluation and comparison. Journal of Statistical Planning and Inference, 139(2), 629-641.

Andreola, F., Martín, M. I., Ferrari, A. M., Lancellotti, I., Bondioli, F., Rincón, J. M., & Barbieri, L. (2013). Technological properties of glass-ceramic tiles obtained using rice husk ash as silica precursor. Ceramics International, 39(5), 5427-5435.

Ashby, M. F. (2012). Materials and the environment: eco-informed material choice. Elsevier.

Azlina, Y., Azlan, M. N., Hajer, S. S., Halimah, M. K., Suriani, A. B., Umar, S. A., & Imed, B. (2021). Graphene oxide deposition on neodymium doped zinc borotellurite glass surface: Optical and polarizability study for future fiber optics. Optical Materials, 117, 111138.

Basu, S., & Sarkar, D. (2019). Glass processing and properties. In Ceramic Processing (pp. 247-281). CRC Press.

Bakar, R. A., Yahya, R., & Gan, S. N. (2016). Production of High Purity Amorphous Silica from Rice Husk. Procedia Chemistry, 19, 189–195. https://doi.org/10.1016/j.proche.2016.03.092

Benoit, N., Glass, A., & Scott, G. (2018). The Telescope: Evolution of Glassblowing and Grinding Technologies.

Bezerra, M. A., Santelli, R. E., Oliveira, E. P., Villar, L. S., & Escaleira, L. A. (2008). Response surface methodology (RSM) as a tool for optimization in analytical chemistry. Talanta, 76(5), 965-977.

Borek, K., Czapik, P., & Dachowski, R. (2020). Recycled Glass as a Substitute for Quartz Sand in Silicate Products. Materials, 13(5), 1030.

Brauer, D. S. (2015). Bioactive glasses—structure and properties. Angewandte Chemie International Edition, 54(14), 4160-4181.

Chandrasekhar, S., Satyanarayana, K. G., Pramada, P. N., Raghavan, P., & Gupta, T. N. (2003). Review Processing, properties and applications of reactive silica from rice husk—an overview. Journal of Materials Science, 38(15), 3159–3168. http://doi.org/10.1023/A:1025157114800.

Chawre, B. (2018). Correlations between ultrasonic pulse wave velocities and rock properties of quartz-mica schist. Journal of Rock Mechanics and Geotechnical Engineering, 10(3), 594-602.

Chazot, M., Paraillous, M., Jouannigot, S., Teulé-Gay, L., Salvetat, J. P., Adamietz, F., & Dussauze, M. (2021). Enhancement of mechanical properties and chemical durability of Soda-lime silicate glasses treated by DC gas discharges. Journal of the American Ceramic Society, 104(1), 157-166.

Copley, G. J. (2001). The composition and manufacture of glass and its domestic and industrial applications. Caddy, B., Forensic Examination of Glass and Paint. London: Tylor & Francis, 27-46.

Cummings, K. (2002). A history of glassforming. University of Pennsylvania Press.

Da Silva Fernandes, F. A., Arcaro, S., Junior, E. F. T., Serra, J. C. V., & Bergmann, C. P. (2019). Glass foams produced from soda-lime glass waste and rice husk ash applied as partial substitutes for concrete aggregates. Process Safety and Environmental Protection, 128, 77-84.

Dales, J. H. (2002). Pollution, property & prices: an essay in policy-making and economics. Edward Elgar Publishing.

Davison, S., & Newton, R. G. (2008). Conservation and restoration of glass. Routledge.

De Jong, B. H. W. S. (1989). Glass; in "Ullmann's Encyclopedia of Industrial Chemistry; 5th edition, vol. A12, VCH Publishers, Weinheim, Germany, 1989, ISBN 978-3-527-20112-9, pp. 365–432.

De Oliveira Maiaa, B. G., Arcaroa, S., Souzaa, M. T., de Oliveira, A. P. N., de Oliveirab, T. N., & Netoa, J. B. R. (2015). Characterisation of sand casting and oyster shells as potential sources of raw material for the production of soda-lime glasses. CHEMICAL ENGINEERING, 43.

El-Mallawany, R. (1998). Tellurite glasses part 1. Elastic properties. Materials Chemistry and Physics, 53(2), 93-120.

Er-rouissi, Y., Chabbou, Z., Beloued, N., & Aqdim, S. (2017). Chemical Durability and Structural Properties of Al 2 O 3-CaO-Na 2 OP 2 O 5 Glasses Studied by IR Spectroscopy, XRD and SEM. Advances in Materials Physics and Chemistry, 7(10), 353.

Ferreira, S. L. C., Bruns, R. E., da Silva, E. G. P., Dos Santos, W. N. L., Quintella, C. M., David, J. M., ... & Neto, B. B. (2007). Statistical designs and response surface techniques for the optimization of chromatographic systems. Journal of chromatography A, 1158(1-2), 2-14.

Foo, K. Y., & Hameed, B. H. (2009). Utilization of rice husk ash as novel adsorbent: a judicious recycling of the colloidal agricultural waste. Advances in colloid and interface science, 152(1-2), 39-47.

Gavriletea, M. D. (2017). Environmental impacts of sand exploitation. Analysis of sand market. Sustainability, 9(7), 1118. Amon, C. H., Egan, E. R., Smailagic, A., & Siewiorek, D. P. (1997). Thermal management and concurrent system design of a wearable multicomputer. IEEE Transactions on Components, Packaging, and Manufacturing Technology: Part A, 20(2), 128-137.

Gercek, H. (2007). Poisson's ratio values for rocks. International Journal of Rock Mechanics and Mining Sciences, 44(1), 1-13.

Gest, H. (2004). The discovery of microorganisms by Robert Hooke and Antoni Van Leeuwenhoek, fellows of the Royal Society. Notes and records of the Royal Society of London, 58(2), 187-201.

Gonçalves, J., da Silva, G., Lima, L., Morgado, D., Nalin, M., Armas, L. E., & Menezes, J. W. (2020). Production of Transparent Soda-Lime Glass from Rice Husk Containing Iron and Manganese Impurities. Ceramics, 3(4), 494-506.

Gross, D., & Seelig, T. (2017). Fracture mechanics: with an introduction to micromechanics. Springer.

Gross, T. M., Wu, J., Baker, D. E., Price, J. J., & Yongsunthon, R. (2018). Crack-resistant glass with high shear band density. Journal of Non-Crystalline Solids, 494, 13-20.

Haida, Z., Ab Ghani, S., Nakasha, J. J., & Hakiman, M. (2021). Determination of experimental domain factors of polyphenols, phenolic acids and flavonoids of lemon (Citrus limon) peel using two-level factorial design. Saudi Journal of Biological Sciences.

Hashimoto, T., Inukai, H., Matsumura, K., Nasu, H., Ishihara, A., & Nishio, Y. (2018). Effect of glass former (B2O3, SiO2, GeO2 and P2O5) addition to Fe2O3-Bi2O3 glass on pH responsivity. Sensors and Actuators B: Chemical, 257, 807-814.

Hassani, H. (2019). Structure evolution and mechanical properties of ion-exchanged silicate glass.

Hehlen, B., & Rufflé, B. (2021). Atomic Vibrations in Glasses. Encyclopedia of Glass Science, Technology, History, and Culture, 1, 287-300.

Holder, C. F., & Schaak, R. E. (2019). Tutorial on powder X-ray diffraction for characterizing nanoscale materials.

Hussain, F., & Ali, A. (2010). Elastic and plastic properties of soda lime glass by micro-indentation. In Key Engineering Materials (Vol. 442, pp. 294-300). Trans Tech Publications Ltd.

Ibrahim, S., & Meawad, A. (2018). Assessment of waste packaging glass bottles as supplementary cementitious materials. Construction and Building Materials, 182, 451-458.

Jain, S. (2020). Role of Glass as a Smart Material in Future Prospects of Smart City Development: A Review. Tathapi with ISSN 2320-0693 is an UGC CARE Journal, 19(16), 315-325.

Jardine, L. (2000). Ingenious pursuits: Building the scientific revolution. Anchor.

Jin, H.L.;Jeong, H.K.;Jae, W.L.;Hye, S.L.; Jeong, H.C.; Byoung, I.S. (2017). Preparation of high purity silica originated from rice husks by chemically removing metallic impurities, Journal of Industrial and Engineering Chemistry, 79–85.

Jiusti, J., Zanotto, E. D., Feller, S. A., Austin, H. J., Detar, H. M., Bishop, I., ... & Inoue, H. (2020). Effect of network formers and modifiers on the crystallization resistance of oxide glasses. Journal of Non-Crystalline Solids, 550, 120359.

Juoi, J. M., Arudra, D., Rosli, Z. M., Hussain, K., & Jaafar, A. J. (2013). Microstructural properties of glass composite material made from incinerated scheduled waste slag and soda lime silicate (SLS) waste glass. Journal of non-crystalline solids, 367, 8-13.

Karlsson, S., Wondraczek, L., Ali, S., & Jonson, B. (2017). trends in effective diffusion Coefficients for ion-exchange strengthening of soda-Lime-silicate Glasses. Frontiers in Materials, 4, 13.

Khalil, E. M. A., El Batal, F. H., Hamdy, Y. M., Zidan, H. M., Aziz, M. S., & Abdelghany, A. M. (2010). Infrared absorption spectra of transition metals-doped soda lime silica glasses. Physica B: Condensed Matter, 405(5), 1294-1300.

Khassaf, S. I., Jasim, A. T., & Mahdi, F. K. (2014). Investigation the properties of concrete containing rice husk ash to reduction the seepage in canals. International Journal of Scientific Technology Research, 3(4), 348-354.

Kidd, K. E., & Kidd, M. A. (2012). A classification system for glass beads for the use of field archaeologists. Beads: Journal of the Society of Bead Researchers, 24(1), 39-61.

Kilinc, E. (2016). Mechanical and structural properties of soda lime silica glasses as a function of composition (Doctoral dissertation, University of Sheffield).

Kingery, W. D., Bowen, H. K., & Uhlmann, D. R. (1976). Introduction to ceramics (Vol. 17). John wiley & sons.

Klein, J., Stern, M., Franchin, G., Kayser, M., Inamura, C., Dave, S., & Oxman, N. (2015). Additive manufacturing of optically transparent glass. 3D Printing and Additive Manufacturing, 2(3), 92-105.

Kumar, S., & Singh, R. K. (2014). Optimization of process parameters by response surface methodology (RSM) for catalytic pyrolysis of waste high-density polyethylene to liquid fuel. Journal of Environmental Chemical Engineering, 2(1), 115-122.

Le Bourhis, E. (2014). Glass: mechanics and technology. John Wiley & Sons.

Leung, K. M. (2015). Zeolite frameworks with beta-cages (Doctoral dissertation, University of Oxford).

Levelut, C., Le Parc, R., Faivre, A., & Champagnon, B. (2006). Influence of thermal history on the structure and properties of silicate glasses. Journal of non-crystalline solids, 352(42-49), 4495-4499.

Lipson, A., Lipson, S. G., & Lipson, H. (2010). Optical physics. Cambridge University Press.

Lodins, E., Rozenstrauha, I., Krage, L., Lindina, L., Drille, M., Filipenkov, V., & Chatzitheodoridis, E. (2011, December). Characterization of glass-ceramics microstructure, chemical composition and mechanical properties. In 5th Baltic Conference on Silicate Materials (Vol. 5, No. 25, pp. 1-11).

Löffler, J. F. (2003). Bulk metallic glasses. Intermetallics, 11(6), 529-540.

Lotfy, W. A., Ghanem, K. M., & El-Helow, E. R. (2007). Citric acid production by a novel Aspergillus niger isolate: II. Optimization of process parameters through statistical experimental designs. Bioresource technology, 98(18), 3470-3477.

Luo, J. (2017). Understanding shear-induced hydrolysis reactions on soda lime silica glass surface.

Loubser, M., & Verryn, S. (2008). Combining XRF and XRD analyses and sample preparation to solve mineralogical problems. South African Journal of Geology, 111(2-3), 229-238.

Matori, K. A., Haslinawati, M. M., Wahab, Z. A., Sidek, H. A. A., Ban, T. K., & Ghani, W. A. W. A. K. (2009). Producing amorphous white silica from rice husk. MASAUM Journal of Basic and Applied Sciences, 1(3), 512-515.

Mccauley, R. A., De, A. K., & Carr, D. S. (1981). Improved Impact Resistance in Soda-Lime-Silica Glasses Through Zinc Oxide Substitutions. Journal of the American Ceramic Society, 64(11), C-157.

Meejitpaisan, P., Kaewkhao, J., Limsuwan, P., & Kedkaew, C. (2012). Physical and optical properties of the SLS glass doped with low Cr2O3 concentrations. Procedia Engineering, 32, 787-792.

Mehmood, T., Ramzan, M., Howari, F., Kadry, S., & Chu, Y. M. (2021). Application of response surface methodology on the nanofluid flow over a rotating disk with autocatalytic chemical reaction and entropy generation optimization. Scientific Reports, 11(1), 1-18.

Menchaca, C., & Malacara, D. (1988). Design of Galilean-type telescope systems. Applied optics, 27(17), 3715-3718.

Min'ko, N. I., & Nartsev, V. M. (2013). Factors affecting the strength of the glass. Middle East Journal of Scientific Research, 18(11), 1616-1624.

Mohammed, K. S. (2018). A Study of the Optical Properties of Glass (Doctoral dissertation, Sudan University of Science and Technology).

Mohd Zaid, M. H., Matori, K. A., Abdul Aziz, S. H., Zakaria, A., & Mohd Ghazali, M. S. (2012). Effect of ZnO on the physical properties and optical band gap of soda lime silicate glass. International journal of molecular sciences, 13(6), 7550-7558.

Mostafa, A. M. A., Issa, S. A., Zakaly, H. M., Zaid, M. H. M., Tekin, H. O., Matori, K. A., ... & Elsaman, R. (2020). The influence of heavy elements on the ionizing radiation shielding efficiency and elastic properties of some tellurite glasses: Theoretical investigation. Results in Physics, 19, 103496.

Mukherjee, S. (2013). Traditional and Modern Uses of Ceramics, Glass and Refractories. In The Science of Clays (pp. 123-150). Springer, Dordrecht.

Mustaffar, M. I., Mahmud, M. H., & Hassan, M. A. (2017, December). Development of dense glass-ceramic from recycled soda-lime-silicate glass and fly ash for tiling. In AIP Conference Proceedings (Vol. 1901, No. 1, p. 030011). AIP Publishing LLC.

Mysen, B. (2021). Structure of Chemically Complex Silicate Systems. Encyclopedia of Glass Science, Technology, History, and Culture, 1, 197-206.

Mysen, B. O., & Richet, P. (2018). Silicate glasses and melts. Elsevier.

Nascimento, M. L. F. (2014). Brief history of the flat glass patent–Sixty years of the float process. World Patent Information, 38, 50-56.

Ngo, T. D., Kashani, A., Imbalzano, G., Nguyen, K. T., & Hui, D. (2018). Additive manufacturing (3D printing): A review of materials, methods, applications and challenges. Composites Part B: Engineering, 143, 172-196.

Papadogeorgos, I., & K. M. Schure. (2019). Decarbonisation options for the dutch container and tableware glass industry. PBL Netherlands Environmental Assessment Agency.

Partyka, J., & Lesniak, M. (2016). Preparation of glass–ceramic glazes in the SiO2–Al2O3–CaO–MgO–K2O–Na2O–ZnO system by variable content of ZnO. Ceramics International, 42(7), 8513-8524

Pasiut, K., Partyka, J., Lesniak, M., Jelen, P., & Olejniczak, Z. (2021). Raw glass-ceramics glazes from SiO2–Al2O3–CaO–MgO–Na2O–K2O system modified by ZrO2 addition–Changes of structure, microstructure and surface properties. Open Ceramics, 8, 100188.

Pode, R. (2016). Potential applications of rice husk ash waste from rice husk biomass power plant. Renewable and Sustainable Energy Reviews, 53, 1468-1485.

Ponsot, I. (2015). Glasses and Glass-Ceramic Components from Inorganic Waste and Novel Processing.

Ponmalar, D. S. (2020). Tungsten DiSulphide FBG Sensor for Temperature Monitoring in Float Glass Manufacturing. Journal of Information Technology and Digital World, 2(4), 191-200.

Pontikes, Y., Christogerou, A., Angelopoulos, G. N., Rambaldi, E., Esposito, L., & Tucci, A. (2005). Use of scrap soda–lime–silica glass in traditional ceramics. Glass technology, 46(2), 200-206.

Prasara-A, J., & Gheewala, S. H. (2017). Sustainable utilization of rice husk ash from power plants: A review. Journal of Cleaner Production, 167, 1020-1028.

Reddy, B. M., Lakshmanan, P., Loridant, S., Yamada, Y., Kobayashi, T., Lopez-Cartes, C., & Fernandez, A. (2006). Structural characterization and oxidative dehydrogenation activity of V2O5/Ce x Zr1-x O2/SiO2 Catalysts. The Journal of Physical Chemistry B, 110(18), 9140-9147.

Ramesh Kumar, C., & Omkumar, M. (2019). Optimisation of process parameters of chemical mechanical polishing of soda lime glass. Silicon, 11(1), 407-414.

Reeves, E. A. (2009). Galileo's Glassworks: the Telescope and the Mirror. Harvard University Press.

Rivas, A. L., Vera, G., Palacios, V., Cornejo, M., Rigail, A., & Solórzano, G. (2018). Phase transformation of amorphous rice husk silica. In Frontiers in Materials Processing, Applications, Research and Technology (pp. 17-26). Springer, Singapore.

Robertson, G. L. (2016). Food packaging: principles and practice. CRC press.

Saddeek, Y. B. (2004). Ultrasonic study and physical properties of some borate glasses. Materials Chemistry and Physics, 83(2-3), 222-228.

Sani, G., Limbach, R., Dellith, J., Sökmen, I., & Wondraczek, L. (2021). Surface damage resistance and yielding of chemically strengthened silicate glasses: from normal indentation to scratch loading. Journal of the American Ceramic Society, 104(7), 3167-3186.

Saparuddin, D. I., Hisham, N. A. N., Ab Aziz, S., Matori, K. A., Honda, S., Iwamoto, Y., & Zaid, M. H. M. (2020). Effect of sintering temperature on the crystal growth, microstructure and mechanical strength of foam glass-ceramic from waste materials. Journal of Materials Research and Technology, 9(3), 5640-5647.

Saparuddin, D. I., Mohd Zaid, M. H., Aziz, S. H. A., & Matori, K. A. (2020). Reuse of Eggshell Waste and Recycled Glass in the Fabrication Porous Glass–Ceramics. Applied Sciences, 10(16), 5404.

Seghi, R. R., Denry, I. L., & Rosenstiel, S. F. (1995). Relative fracture toughness and hardness of new dental ceramics. The Journal of prosthetic dentistry, 74(2), 145-150.

Shamsudin, Z., Salleh, N., Mohd Juoi, J., Mustafa, Z., & Zulkifli, M. R. (2016). The Effect of Spent Bleach Earth on the Properties of Sintered Green Glass Ceramic Composite. In Key Engineering Materials (Vol. 694, pp. 179-183). Trans Tech Publications Ltd.

Shelby, J. E., & Schubert, U. (1997). Introduction to glass science and technology. Angewandte Chemie-English Edition, 36(20), 2248-2248.

Shelby, J. E. (2020). Introduction to glass science and technology. Royal Society of Chemistry.

Shen, Y. (2017). Rice husk silica derived nanomaterials for sustainable applications. Renewable and Sustainable Energy Reviews, 80, 453-466.

Shinohara, Y., & Kohyama, N. (2004). Quantitative analysis of tridymite and cristobalite crystallized in rice husk ash by heating. Industrial health, 42(2), 277-285.

Sidebottom, D. L. (2019). Connecting glass-forming fragility to network topology. Frontiers in Materials, 6, 144.

Silva, R. V., De Brito, J., Lye, C. Q., & Dhir, R. K. (2017). The role of glass waste in the production of ceramic-based products and other applications: A review. Journal of Cleaner Production, 167, 346-364.

Skrabec Jr, Q. R. (2007). Michael Owens and the glass industry. Pelican Publishing.

Smekal, A. G. (1951). On the structure of glass. Journal of the Society of Glass Technology, 35, 392-395.

Soltani, N., Bahrami, A., Pech-Canul, M. I., & González, L. A. (2015). Review on the physicochemical treatments of rice husk for production of advanced materials. Chemical engineering journal, 264, 899-935.

Sundaram, B. M., & Tippur, H. V. (2018). Full-field measurement of contact-point and crack-tip deformations in soda-lime glass. Part-I: Quasi-static Loading. International Journal of Applied Glass Science, 9(1), 114-122.

Tarley, C. R. T., Silveira, G., dos Santos, W. N. L., Matos, G. D., da Silva, E. G. P., Bezerra, M. A., ... & Ferreira, S. L. C. (2009). Chemometric tools in electroanalytical chemistry: methods for optimization based on factorial design and response surface methodology. Microchemical journal, 92(1), 58-67.

Teresa, P. E., Naseer, K. A., Piotrowski, T., Marimuthu, K., Aloraini, D. A., Almuqrin, A. H., & Sayyed, M. I. (2021). Optical properties and radiation shielding studies of europium doped modifier reliant multi former glasses. Optik, 247, 168005.

Tomozawa, M., Hong, J. W., & Ryu, S. R. (2005). Infrared (IR) investigation of the structural changes of silica glasses with fictive temperature. Journal of non-crystalline solids, 351(12-13), 1054-1060.

Umeda, J., Kondoh, K., & Michiura, Y. (2007). Process parameters optimization in preparing high-purity amorphous silica originated from rice husks. Materials Transactions, 48(12), 3095-3100.

Varshneya, A. K. (2006). Fundamentals of inorganic glasses (Sheffield: Society of Glass Technology).

Vasantharani, P., & Rajeswari, S. (2017). “Characterization of Manganese Doped Sodium Borate Glasses Used to Spectroscopic Methods”, International Journal of Applied and Advanced Scientific Research, 2(2), 222–224.

Vogel, W. (2012). Glass chemistry. Springer Science & Business Media.

Wahab, E. A., & Shaaban, K. S. (2020). Enhancement of optical and mechanical properties of sodium silicate glasses using zirconia. Optical and Quantum Electronics, 52(10), 1-19.

Wasanapiarnpong, T., Vorajesdarom, B., Rujirakamort, E., Nilpairach, S., & Mongkolkachit, C. (2011). Fabrication of Silica Glass from Rice Husk Ash with Spodumene Additions. In IOP Conference Series: Materials Science and Engineering (Vol. 18, No. 22, p. 222028). IOP Publishing.

Yu, Q., You, L., Wood-Sichra, U., Ru, Y., Joglekar, A. K., Fritz, S., & Yang, P. (2020). A cultivated planet in 2010: 2. The global gridded agricultural production maps. Earth System Science Data.

Yu, Y., Wang, M., Krishnan, N. A., Smedskjaer, M. M., Vargheese, K. D., Mauro, J. C., & Bauchy, M. (2018). Hardness of silicate glasses: Atomic-scale origin of the mixed modifier effect. Journal of Non-Crystalline Solids, 489, 16-21.

Zanotto, E. D., & Mauro, J. C. (2017). The glassy state of matter: Its definition and ultimate fate. Journal of Non-Crystalline Solids, 471, 490-495.

Zarib, Noratiqah. (2019). Extraction Of Silica From Rice Husk Via Acid Leaching Treatment. 175-183. 10.15405/epsbs.2019.05.02.16.

Zolgharnein, J., Shahmoradi, A., & Ghasemi, J. B. (2013). Comparative study of Box–Behnken, central composite, and Doehlert matrix for multivariate optimization of Pb (II) adsorption onto Robinia tree leaves. Journal of Chemometrics, 27(1-2), 12-20.

Zou, Y., & Yang, T. (2019). Rice husk, rice husk ash and their applications. In Rice Bran and Rice Bran Oil (pp. 207-246). AOCS Press.