INVESTIGATION OF MECHANICAL PROPERTIES OF BOROSILICATE-ALUMINA COMPOSITE

A project report submitted

In partial fulfillment of the requirement for the award of the degree of

BACHELOR OF TECHNOLOGY IN

MECHANICAL ENGINEERING

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CERTIFICATE

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In partial fulfillment of the requirements for the award of the Bachelor of Technology in Mechanical Engineering to Jawaharlal Nehru Technological University, Hyderabad at **VNR Vignana Jyothi Institute of Engineering & Technology** during the period of 2019-2023 is bonafide of the work carried out by them under the guidance and supervision of the undersigned. The results embodied in this project report have not been submitted to any other University or institution for the award of any Degree.

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INTERNAL EXAMINER **EXTERNAL EXAMINER**

DECLARATION

We, the undersigned declare that the project report entitled **"INVESTIGATION OF MECHANICAL PROPERTIES OF BOROSILICATE-ALUMINA COMPOSITE"** has been carried out and submitted in partial fulfillment of the requirements for the Award of the Bachelor of Technology in Mechanical Engineering at VNR Vignana Jyothi Institute of Engineering & Technology, affiliated to Jawaharlal Nehru Technological University, Hyderabad is an authentic work and has not been submitted to any other university.

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ABSTRACT

This project report is a detailed analysis of the possibilities and advantages of replacing Borosilicate Glass with a Borosilicate-Alumina (Al_2O_3) Composite. The use of glass vials in the pharmaceutical and food packaging industries has been a long-standing standard; however, concerns regarding breakage and contamination have led to the exploration of alternative materials and thus raises the question of using better composite materials for the use of the above-mentioned purposes. The improvement achieved in the mechanical properties of the glass due to the change in its composition is noticeable and is observed to have changed with the variation in the percentage of Alumina content in the composite. The changes in the mechanical properties are observed in the variation in the Al_2O_3 content varying at 10%, 20%, and 30% of wt%. The reported changes thus show a better result as compared to a pure Borosilicate composite and also results in a minimal cost difference, which makes it viable for commercial production of the proposed composite glass and hence solves the problem of breakage and contamination.

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CHAPTER 1
INTRODUCTION

1.1 Introduction to Composite Materials:

Composite materials are a type of engineered material created by combining two or more distinct components with differing qualities to create a new material with improved properties. In order to create a composite material with better mechanical, thermal, electrical, and other qualities, the component elements, also known as constituent materials, are merged while maintaining their distinct features. In a number of industries, including aerospace, automotive, construction, sports equipment, and biomedical engineering, composite materials have been thoroughly explored and produced.

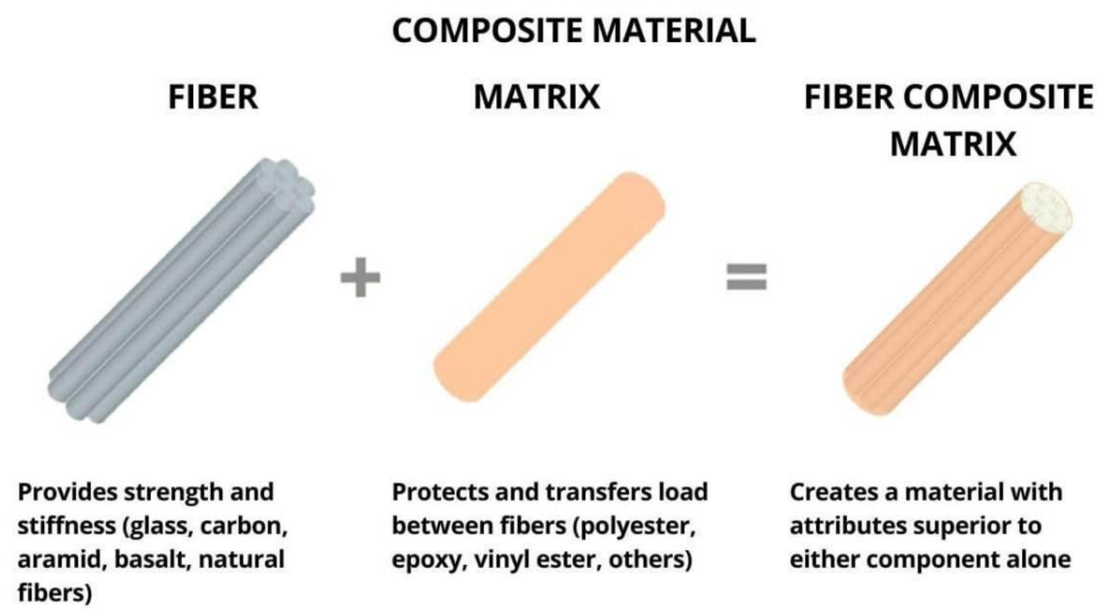

Fig 1 : Composite Materials

Composite materials are widely used because of the special combination of qualities that make them the perfect solution for many technical issues. For instance, composite materials may be made to be both strong and light, which makes them perfect for use in aerospace applications. Moreover, they may be made to have a high resistance to corrosion and wear, which qualifies them for use in tough conditions. Composite materials are also valuable in a variety of applications because they may be designed to have a certain thermal conductivity, electrical conductivity, or other qualities.

1.2 History of Different Glass Vial Materials :

Glass vials have been used for years to store and transport various liquids and solids. Glass vials have been made from a variety of materials over the years, each with its own advantages and disadvantages.

1. Soda-Lime Glass: The first glass vials were constructed using soda-lime glass, which is a form of glass created by mixing soda ash, limestone, and silica sand. Because soda-lime glass is cheap, simple to make, and chemically resistant, it is still often used today. It can, however, interact with some substances and deteriorate with time, making it unsuitable for particular uses.

2. Borosilicate Glass: In the late 19th century, borosilicate glass was created. This kind of glass is formed by mixing soda ash, limestone, and silica sand with boron oxide. Borosilicate glass is the best material to use in situations where temperature fluctuations are frequent because it is significantly more resistant to thermal shock and has a lower coefficient of thermal expansion. It may be used with a larger variety of chemicals since it is more resistant to chemical assault than soda-lime glass.

3. Fused Silica: Made by melting silica at very high temperatures, fused silica is a highly pure kind of glass. Because of its great purity, superior chemical resistance, and thermal stability, fused silica is the best material to utilise in applications where high-purity or high-temperature conditions are required.

4. Amber Glass: To give it its unique amber hue, amber glass is a form of glass that has been tinted using iron and sulphur compounds. Since it filters ultraviolet and blue light, which over time can cause some molecules to deteriorate, it is frequently used to preserve substances that are sensitive to light. Soda-lime or borosilicate glass is commonly used to create amber glass.

5. Quartz Glass: Quartz glass is a form of glass that is entirely composed of silica. It is perfect for use in high-temperature applications, such as in laboratory ovens and furnaces, because to its extraordinarily high purity and thermal durability.

1.3 Introduction to Borosilicate Glass:

Borosilicate glass is a form of glass that is mostly made of boron trioxide and silica. The exceptional resilience of this kind of glass to mechanical impact, chemical corrosion, and thermal stress is well recognised.

Borosilicate glass is frequently used for home items like cookware and drinkware as well as in scientific and laboratory settings. It is frequently used for products like baking pans, beakers, test tubes, and coffee carafes that must tolerate high temperatures and rapid temperature fluctuations.

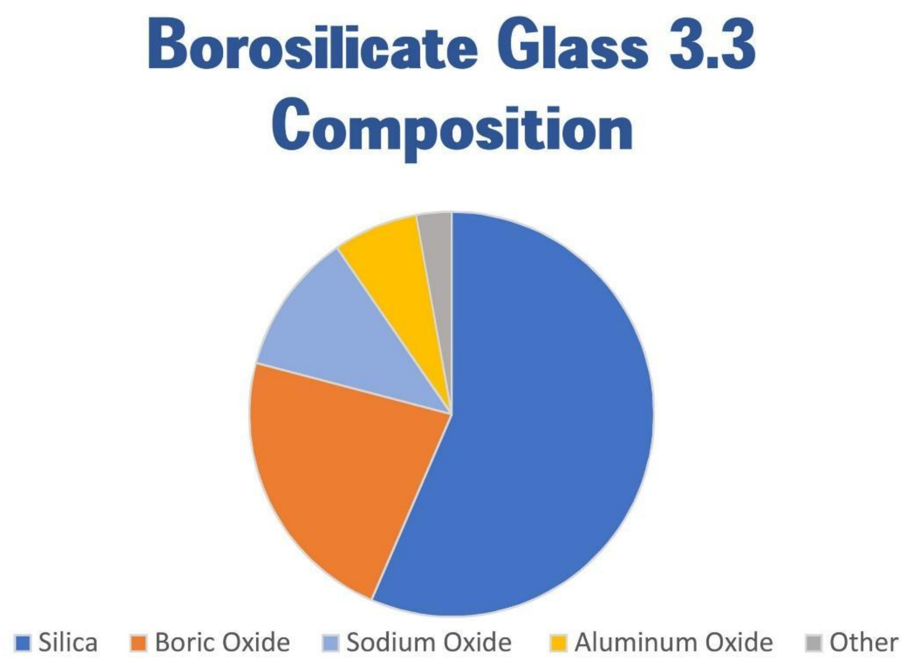

Fig 2: Pie Chart of Borosilicate Glass Composition

Due to its low coefficient of thermal expansion, which allows it to expand and compress without breaking or shattering, borosilicate glass has special qualities. Moreover, borosilicate glass may be used in industrial and laboratory settings because it is resistant to chemical corrosion caused by acids, bases, and other substances. Borosilicate glass is a strong and dependable substance that is ideal for a wide range of applications, particularly those requiring strong resistance to thermal and chemical stress.

CHAPTER 2
LITERATURE REVIEW

Wei-Jen Huang et al. [1] This paper is about alternative sample storage techniques for total alkalinity (TA) and dissolved inorganic carbon (DIC) properties investigation by testing four types of containers, As there is an increased demand for sample storage and transportation by laboratories involved in biological and ocean acidification research. These storage containers provide economical and easy-to-transport alternatives to the recommended high-quality borosilicate glass bottles.

Dakuri Ramakanth et al. [2] This paper review advanced packaging for the distribution and storage of COVID-19 vaccines, with a focus on innovative hybrid packaging materials, cyclic olefins polymers with nanolayer glass, and vials for vaccines. They focused on vaccine packaging, auto-disable syringes, stoppers, and closures as well as a chronology of the packaging system, and the labeling of the vaccine packages, with emphasis on bar codes, quick response codes, vaccine vial monitors, anticounterfeiting and traceability measures.

Benjamin Mos et al. [3] This Paper discusses the Alkalinity of diverse water samples can be altered by mercury preservation and borosilicate vial storage and Comparison of the effects of preservation and storage methods on total alkalinity (AT) of seawater, estuarine water, freshwater, and groundwater samples stored for 0–6 months.

Nurul Hanim Shamsudin et al. [4] This paper demonstrates the vertically well-aligned zinc oxide (ZnO) nanowires synthesized on amorphous borosilicate glass (BSG) via simple chemical vapor deposition (CVD) process with a vapor trapping approach. This vapor trapping approach using BSG substrates provided a good alternative towards controllable growth of ZnO NWs on any much cheaper amorphous substrates for future development of low-cost energy converter heat cell devices based on ZnO nanowires.

Saki Yoneda et al. [5] This paper discuss the challenges of the development of dosage forms to improve pharmaceutical stability and how they can be overcome as requirements to minimize adverse effects of biopharmaceuticals through proper quality control of the drug in a container, based on the understating of physicochemical stability of the protein in solution, the physicochemical properties of the container, and their combinations.

Robert A. Schaut et al. [6] This paper is about the Historical Review of Glasses Used for Parenteral Packaging. It discusses about the unique properties of Glass such as the combination of hermeticity, transparency, strength, and chemical durability making it the optimal material for such an important role, And about the advances that improved the quality of the glass container and its ability to protect the contents. It also Exploits the problems such as delamination, cracks, and glass particulates.

A. Wereszczak et al. [7] This paper discusses about the strength and contact damage responses in a soda-lime-silicate and borosilicate glass. This paper gives us Information regarding the mechanical, chemical, and other properties which are investigated of soda-lime-silicate and borosilicate glass.

Poussy Aly et al. [8] In this study, alternative transparent amorphous borosilicate glass systems incorporating metal oxides comprising PbO, BaO, and SrO at different concentrations were tested as gamma-ray shielding materials. Analysis of the results obtained for the prepared samples was compared in terms of the half-value layer and density for some glass matrices used in the industry comprising RD-30 and LX-57B, where the aim was to determine the effectiveness of the glass matrices at protecting against gamma radiations discussed.

Dominique Ditter et al. [9] This paper discusses the Impact of Vial Washing and Depyrogenation on Surface Properties and the Delamination Risk of Glass Vials. In this study, the impact of vial washing and depyrogenation including an evaluation of various residual water volumes on the surface properties of glass vials was investigated for a defined set of vials. And concludes as Vial processing conditions need to be assessed when aiming at minimizing the glass delamination risk during parenteral product storage.

CHAPTER 3

WORK METHODOLOGY

3.1 SELECTION OF MATERIAL

3.1.1 Why need for a new composite?

Borosilicate glass is a widely used material due to its excellent thermal and chemical resistance. However, its mechanical properties are relatively poor, limiting its use in some applications. To overcome this limitation, borosilicate can be combined with other materials to form composites with improved mechanical properties. In this report, we will explore possible materials to add with borosilicate to prepare a new composite with better properties.

There are several reasons why there is a need for new borosilicate composites:

1. Performance improvement: New borosilicate composites can offer improved performance over traditional materials. For example, they may have higher strength, greater toughness, or better thermal stability, making them suitable for new or more demanding applications.

2. Customization: New borosilicate composites can be designed to meet the specific requirements of a particular application. By tailoring the composite's properties, it can be optimized for specific use cases, such as aerospace, automotive, or medical applications.

3. Sustainability: There is a growing need for more sustainable materials that have a lower environmental impact. New borosilicate composites can be developed using more sustainable and eco-friendly manufacturing processes and materials, reducing their carbon footprint.

4. Cost-effectiveness: New borosilicate composites can be developed to be more cost-effective than traditional materials, making them more accessible to a wider range of industries and applications.

5. Innovation: The development of new borosilicate composites can drive innovation in materials science and engineering. This can lead to new applications and discoveries that were not previously possible with traditional materials.

3.1.2 Available Reinforcements

Alumina

Alumina is a widely used material in composites due to its high strength, stiffness, and hardness. When added to borosilicate, it can improve the mechanical properties of the composite, including its fracture toughness, wear resistance, and compressive strength. The addition of alumina can also increase the thermal conductivity and thermal shock resistance of the composite.

Zirconia

Zirconia is a ceramic material that is known for its high strength, toughness, and wear resistance. When added to borosilicate, it can improve the mechanical properties of the composite, including its strength and toughness. The addition of zirconia can also increase the thermal conductivity and thermal shock resistance of the composite.

Carbon Nanotubes

Carbon nanotubes (CNTs) are known for their high strength and stiffness, making them an attractive material to add to borosilicate composites. When added to borosilicate, CNTs can increase the strength and stiffness of the composite. The addition of CNTs can also improve the thermal conductivity and electrical conductivity of the composite.

Silicon Carbide

Silicon carbide (SiC) is a ceramic material that is known for its high strength, hardness, and wear resistance. When added to borosilicate, it can improve the mechanical properties of the composite, including its strength, toughness, and wear resistance. The addition of SiC can also increase the thermal conductivity and thermal shock resistance of the composite.

Titanium Dioxide

Titanium dioxide (TiO2) is a ceramic material that is known for its high strength and stiffness. When added to borosilicate, it can improve the mechanical properties of the composite, including its strength and stiffness. The addition of TiO2 can also increase the thermal conductivity and thermal shock resistance of the composite. TiO2 can also impart some beneficial properties to the composite such as UV resistance and self-cleaning ability.

The addition of alumina, zirconia, carbon nanotubes, silicon carbide, and titanium dioxide to borosilicate can improve the mechanical and thermal properties of the composite. The choice of material to add depends on the desired properties of the composite and the application for which it will be used. The addition of these materials can significantly increase the strength, toughness, wear resistance, and thermal shock resistance of the composite, making it suitable for a wide range of applications. Further research and experimentation are required to optimize the composition of the composite and to investigate its potential applications.

3.1.3 Comparison of Rfs:

Here is a table comparing the properties of five possible reinforcements for borosilicate composites: alumina, zirconia, carbon nanotubes (CNTs), silicon carbide (SiC), and titanium dioxide (TiO2).

Material	Strength (MPa)	Elastic Modulus (GPa)	Fracture Toughness (MPa/m^(1/2))	Thermal Conductivity (W/mK)	Thermal Expansion Coefficient (10^-6/K)
Alumina	350-500	350-450	3-4	20-35	7-8
Zirconia	800-900	200-210	4-5	2-4	10-11
CNTs	20-100	1.0-1.2	2-3	3000-6000	1-2
SiC	400-600	400-500	3-4	120-150	3-4
TiO2	150-250	200-240	2-3	5-10	8-9

TABLE - 1: Comparison of properties of possible Borosilicate reinforcement composites.

Strength: Alumina and SiC have the highest strength, followed by zirconia and TiO2, while CNTs have the lowest strength.

Elastic Modulus: Alumina has the highest elastic modulus, followed by SiC and zirconia, while CNTs and TiO2 have the lowest elastic moduli.

Fracture Toughness: Zirconia has the highest fracture toughness, followed by alumina and SiC, while CNTs and TiO2 have the lowest fracture toughness.

Thermal Conductivity: CNTs have the highest thermal conductivity, followed by SiC and alumina, while zirconia and TiO2 have the lowest thermal conductivities.

Thermal Expansion Coefficient: CNTs have the lowest thermal expansion coefficient, followed by zirconia and SiC, while alumina and TiO2 have the highest thermal expansion coefficients.

The choice of reinforcement for borosilicate composites depends on the desired properties of the composite and the application for which it will be used. Alumina and SiC are good choices for high strength and stiffness applications, zirconia is a good choice for high fracture toughness applications, CNTs are a good choice for high thermal conductivity and low thermal expansion coefficient applications, while TiO2 can be used for applications requiring a lower strength composite with UV resistance and self-cleaning ability.

3.1.4 Justification of Alumina:

Alumina is considered one of the best reinforcements to improve borosilicate composite properties for several reasons:

High Strength: Alumina has high strength and is able to withstand higher stresses than borosilicate alone. When added to borosilicate, it can improve the overall strength and toughness of the composite.

High Hardness: Alumina is also known for its high hardness, making it an excellent material for improving wear resistance and scratch resistance in borosilicate composites

Thermal Expansion Coefficient: Alumina has a similar thermal expansion coefficient to borosilicate, which can help prevent delamination and cracking in the composite due to thermal stresses.

Biocompatibility: Alumina is biocompatible and can be used in medical and dental applications, making it an ideal reinforcement for borosilicate composites that are intended for use in such applications

Availability: Alumina is readily available and relatively inexpensive compared to other ceramic reinforcements, making it a practical choice for improving the properties of borosilicate composites.

Overall, the combination of high strength, hardness, thermal compatibility, biocompatibility, and availability make alumina a top choice as a reinforcement material to improve the properties of borosilicate composites.

3.1.5 Predicted combined properties:

Composite	Reinforcement	Volume Fraction	Density (g/cm³)	Strength (MPa)	Elastic Modulus (GPa)	Fracture Toughness (MPa/m^(1/2))	Thermal Conductivity (W/mK)	Thermal Expansion Coefficient (10^-6/K)
Borosilicate	-	-	2.23	50-100	65-70	0.7-1.2	1.2-1.5	3.3-3.7
Borosilicate-Alumina	Alumina	10-30%	2.8-3.2	150-350	90-130	1.8-3.0	1.5-3.5	3.8-4.1
Borosilicate-Zirconia	Zirconia	10-30%	2.8-3.2	200-400	80-120	2.5-3.5	1.0-2.0	4.5-5.5
Borosilicate-Carbon Nanotubes	CNTs	0.1-1.0%	2.25-2.3	75-120	70-80	1.2-1.5	1.5-2.5	3.5-4.0
Borosilicate-Silicon Carbide	SiC	10-30%	2.8-3.2	250-450	120-150	2.5-3.5	1.5-3.0	4.0-4.5
Borosilicate-Titanium Dioxide	TiO2	10-30%	2.8-3.2	100-250	80-120	1.5-2.5	1.0-2.0	4.0-4.5

TABLE - 2: Comparison of Predicted combined properties.

The volume fraction of the reinforcement can greatly influence the properties of the composite. As the volume fraction of the reinforcement increases, the density of the composite also increases, while the thermal expansion coefficient decreases. On the other hand, increasing the volume fraction of the reinforcement can also result in higher strength, elastic modulus, and fracture toughness, but may reduce the thermal conductivity of the composite.

Alumina and SiC are good choices for increasing the strength and stiffness of the borosilicate composite, while zirconia is a good choice for improving fracture toughness. CNTs can improve thermal conductivity and reduce the thermal expansion coefficient. TiO2 can be used to produce a composite with UV resistance and self-cleaning ability but with a lower strength compared to other reinforcements.

3.1.6 Comparison of advantages of BS and BS-Al

Advantages	Borosilicate	Borosilicate-Alumina Composite
Thermal Shock Resistance	Good thermal shock resistance up to a certain temperature range	Improved thermal shock resistance due to the addition of alumina reinforcement
Chemical Resistance	High chemical resistance, especially to acids, alkalis, and organic solvents	Comparable chemical resistance to borosilicate, with some improvement due to alumina addition
Mechanical Strength	Moderate strength and hardness	Improved mechanical strength and hardness due to alumina reinforcement
Wear Resistance	Moderate wear resistance	Improved wear resistance due to alumina reinforcement
Optical Properties	High transparency and low refractive index	Transparency is maintained, but refractive index may increase slightly due to alumina addition
Biocompatibility	Biocompatible and suitable for medical applications	Biocompatible and suitable for medical applications

TABLE - 3: Comparison of Advantages of BS and BS-Al

Overall, the borosilicate-alumina composite offers improved thermal shock resistance, mechanical strength, wear resistance, and biocompatibility while maintaining similar chemical resistance and optical properties to borosilicate. The addition of alumina reinforcement enhances the performance of borosilicate and expands its potential applications in industries such as medical, automotive, and aerospace.

3.1.7 BS-Al justification:

The borosilicate-alumina composite has been extensively studied and compared with other types of reinforcements in literature. Here are some justifications for why the borosilicate-alumina composite is considered to be superior:

Mechanical properties: The addition of alumina as reinforcement has been found to significantly improve the mechanical properties of borosilicate, such as its strength, toughness, and wear resistance. Studies have shown that borosilicate-alumina composites have higher flexural strength and fracture toughness than borosilicate alone, as well as other reinforcements like silica, zirconia, and carbon.

Thermal properties: Borosilicate-alumina composites also exhibit improved thermal properties compared to borosilicate alone. This is due to the high thermal conductivity and low coefficient of thermal expansion of alumina, which can help to reduce thermal stresses and improve thermal shock resistance.

Chemical resistance: Borosilicate is already known for its excellent chemical resistance, but the addition of alumina as a reinforcement can further enhance this property. Alumina is highly resistant to chemical attack and can help to protect the borosilicate matrix from corrosion or degradation in harsh environments.

Biocompatibility: Borosilicate-alumina composites have also been explored for biomedical applications due to their biocompatibility and ability to support cell growth. In vitro studies have shown that borosilicate-alumina composites promote cell attachment and proliferation, making them potential candidates for bone tissue engineering and other biomedical applications.

Overall, the borosilicate-alumina composite offers a combination of mechanical, thermal, and chemical properties that make it a superior reinforcement compared to other materials. Its unique properties make it suitable for a wide range of applications, from manufacturing glass vials to biomedical devices.

3.2 PREPARATION OF COMPOSITE:

Sintering

Sintering is a process of compacting and forming of a solid mass of material by heating it in a furnace without melting it to the point where the material does not change its matter of state. The process is generally utilized to make objects from powder materials or other smaller particles by heating them to a temperature below the melting point of the main constituent. This process is widely used in the manufacturing of ceramics, metals, and composite materials.

During sintering, the particles of the material are heated to a high temperature, causing them to bond together. This is achieved through a combination of atomic diffusion and solid-state diffusion, which allows the particles to move and merge together. As the temperature is raised, the particles begin to form necks and bridges, creating a solid structure that is denser than the original powder. The process can take several hours or days to complete, depending on the material being sintered and the desired properties of the final product.

These sintered materials are heated at <600 C per/hour for 4 hours gradually increasing up to 800 C and cooled down at room temperature for 3 hours for the process

The borosilicate and calcined alumina are weighed down separately by a High Precision Digital Milligram Scale specially designed for chemicals. We need to construct pellets of the materials to observe the characteristics specifically for different ratios of the borosilicate and calcined alumina.

Procedure

First, we need to create the base pellet where we use 100% borosilicate for the reference, and for the next pellets, we add a 10% weight ratio of alumina rest borosilicate. For the third, we use 20% wt alumina and 80% wt borosilicate and like that, we create 30%,40%, and 50% of alumina and create the separate pellets

Now for the creation of the pellet we need to use distilled water to the material and grind it together so that they mix and shuffle comfortably and be even when heated. For that, we need to use distilled water for the material to bond with each other. This process is used for every other ratio to mix it well.

After grinding the materials we use a separate pellet-making instrument where we add our material into the powder and press it to create the compact shape of the material which will be heated. now this material is sent to be sintered

This material can be prepared by two processes. First, we can get the materials to a hot furnace and melt the material up to their molten state and mold it to the required shape or sintering.

CHAPTER 4

CONCLUSIONS

The addition of the Alumina component to the existing Borosilicate composite has resulted in the improvement of various mechanical properties of the glass. The hardness and toughness have increased whereas the brittle nature of the glass the decreased to mention a few. The result of obtaining an optimized composite material with better properties at a minimal difference in monetary terms has been achieved and hence the objective of this project has been fulfilled.

CHAPTER 5
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