Corresponding Author:Investigating the Bio-Mineralization Properties of Bioactive Glasses Based on Different Silica Compositions

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Abstract: Bioactive glasses stand out in biomaterial research because their ability to unite with biological tissues along with their bone-healing effects drives widespread interest. Bioactive glasses are made up of several oxides where silica (SiO2) functions as the primary substance. The silica content plays an essential part in determining how bioactive glasses interact with biological entities which determines their suitability in clinical applications. Bio-mineralization occurs when mineral phases deposit as hydroxyapatite (HA) on materials during their exposure to physiological fluids. A comprehensive assessment of bioactive glasses with varying amounts of silica allows scientists to study structure-property relationships for enhancing the materials' specific applications.The research investigates the bio-mineralization attributes that bioactive glasses demonstrate when their silicon concentrations differ.For the preparation of 45s5 bioglass we have to mix 45% of SiO2 with 6% of P2O5, 24.5% of CaO,24.5% of Na2O. After mixing all of the contents together, the mixture is dried and then sintered at 1050°C. Bioglasses usually crystallize at 650-700°C.For the preparation of 53sp4 bioglass we have to mix 53% of SiO2 with 4% of P2O5, 20% of CaO and 23% of Na2O.After mixing all of the contents together, the mixture is dried and then sintered at 1050°C, after which the bioglass crystallises.The characterisation of the bioglass was done using XRD spectra and RAMAN spectra . The hemolysis was checked using blood compatibility assay and the bio-mineralisation was observed using a scanning electron microscope.Silica composition significantly affects the bio-mineralization properties of bioactive glasses. By systematically varying the silica content, we observed distinct differences in the mineralization behavior and bioactivity of the glasses. One important finding is that increasing the silica content led to enhanced bioactivity and mineralization potential of the bioactive glasses. This can be attributed to the higher availability of silicate ions, which are essential for the formation of hydroxyapatite, the main component of natural bone. In addition to the bio-mineralization properties, the mechanical properties of the bioactive glasses were also influenced by silica composition. Our results indicate that the silica composition significantly affects the bioactivity, mineralization behavior, and mechanical properties of bioactive glasses.

Keywords: Bioactive glass, bio mineralisation, hydroxyapatite, 45s bioglass, 53sp4 bioglass

# Introduction

Bioactive glasses represent a biomaterial group of glass-ceramics which found their first example in the development of Bioglass. These glass materials demonstrate both bioactivity and biocompatibility thus doctors utilize them for human body procedures which help treat diseased or replaced damaged bones. These silicate-based glasses use bodily fluids to deteriorate while delivering therapeutic contents. Unlike other synthetic bone graft biomaterials, bioactive glass possesses unique anti-infective and angiogenic properties[(Findeisen et al., 2023; Harsha & Subramanian, 2022)](https://paperpile.com/c/JRUoZ2/MUtSg+K5mC)[(Dell’Aquila et al., 2023; Findeisen et al., 2023)](https://paperpile.com/c/JRUoZ2/MUtSg+o0R6m). Presently, bioactive glasses (BGs) are extensively employed to enhance the healing process of osseous defects resulting from traumatic events, tumor removal, congenital pathologies, implant revisions, or infections.[(Solanki et al., 2022)](https://paperpile.com/c/JRUoZ2/Q2nk) Various approaches have been proposed in the past to address extensive bone defects, each with its advantages and drawbacks, highlighting the persistent clinical challenge in the need for synthetic bone substitutes[(Deepika et al., 2022; Ege et al., 2023)](https://paperpile.com/c/JRUoZ2/gkGNY+M7EG). Recent considerations also explore the effectiveness of BGs in soft tissue regeneration. Living organisms perform biomineralization through the natural action of tissue mineral suspension which leads to precise inorganic substance placement including calcium carbonate and calcium phosphate along with silica. [(Chidambaram et al., 2022; Ege et al., 2023; Silva et al., 2023)](https://paperpile.com/c/JRUoZ2/gkGNY+vMDYV+ylvQ)

The biomedical field primarily utilizes 45S5 Bioglass consisting of SiO2, Na2O, CaO, and P2O5 because it drives effective bone repair and tissue engineering applications. Bioactive properties in this glass lead to hydroxyapatite formation when it encounters biological fluids leading to better bone tissue integration. Medical applications of 58S bioglass and its 45S5 Bioglass counterpart include bones transplant materials alongside dental treatments and implant devices that need bone growth stimulation for proper integration. [(Ajay, Rakshagan, et al., 2022; Meng et al., 2023)](https://paperpile.com/c/JRUoZ2/WmZA0+p9iA) The composition of 58S bioglass makes it contain 60% SiO2, 36% CaO and 4% P2O5 by mol while this material faces visibility limitations in medical imaging tools. [(Ajay, Sasikala, et al., 2022; Aytekin et al., 2023)](https://paperpile.com/c/JRUoZ2/1hZMm+yORZ)

Bioactive materials such as Bioglass show potential for medical applications because transition metals found within these materials are significant for bone processes. Current academic research on such modified bioglass suggests it may become a biomedical material. In clinical applications, bioglass is commonly employed in the form of implants for bone repair and regeneration, showcasing its bioactivity and compatibility with surrounding tissues.[(Abreu et al., 2023; Ajay, Suma, et al., 2022)](https://paperpile.com/c/JRUoZ2/t8UDF+2EtH) Beyond bone repair, bioglass has been explored for wound healing applications, contributing to tissue regeneration and wound closure when used in dressings or scaffolds.In the field of regenerative medicine, bioactive materials like bioglass are gaining prominence for their potential to improve tissue-implant interactions and aid in the healing and recovery processes. [(Dharman, 2021; Maiti, 2021; Washio et al., 2023)](https://paperpile.com/c/JRUoZ2/7I6uz+yrt1+W9uP)This review provides fundamental information about silica-based bioactive glasses, encompassing their composition, processing, properties, and therapeutic applications, particularly in bone recovery, bone grafts, and as coatings for dental implants.[(Jabin et al., 2021; Katyal et al., 2021; Platzer et al., 2023)](https://paperpile.com/c/JRUoZ2/X331L+khOO+R4cI)

# Materials and methods

## Synthesis of Bioglass

For the preparation of 45s5 bioglass we have to mix 45% SiO2 with 6% P2O5, 24.5% CaO,24.5% Na2O. After mixing all of the contents together, the mixture is dried and then sintered at 1050°C. Bioglasses usually crystallize at 650-700°C. For the preparation of 53sp4 bioglass we have to mix 53% SiO2 with 4%P2O5, 20% CaO and 23% Na2O.After mixing all of the contents together, the mixture is dried and then sintered at 1050°C, after which the bioglass crystallises [(S et al., 2022; S. & S., 2021)](https://paperpile.com/c/JRUoZ2/Q25P+pvt4).

## Selection of Different Silica Compositions

The research looked at three distinct silica compositions through HSG, ISG, and LSG. The study used well-prepared materials which were transformed into disk-shaped specimens.

## Characterization of Silica Compositions

The accuracy of silica compositions depended on analysis using X-ray diffraction (XRD) and RAMAN spectra as characterization methods. XRD helps evaluate both crystal structure patterns and glass crystallinity but RAMAN spectra identifies the molecular vibrational modes. The microstructure analysis of the bioglass required a scanning electron microscope examination.

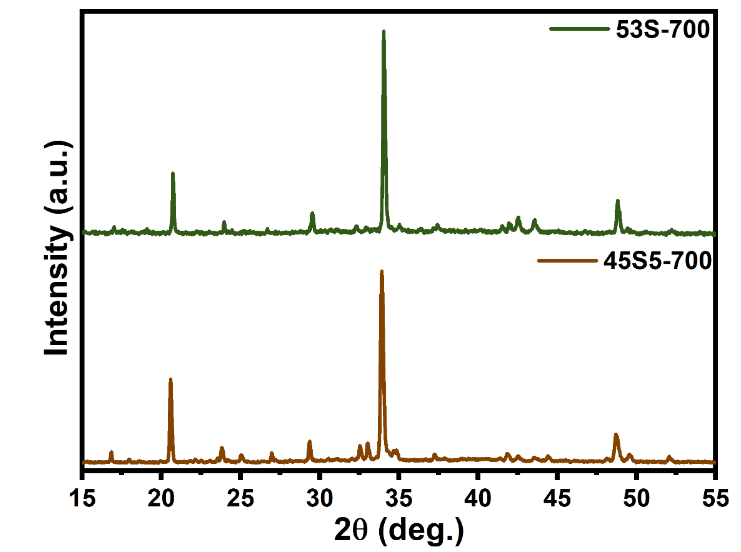
## Evaluation of Bio-mineralization Properties:

The evaluation of bio-mineralization properties for the fabricated silica pellets included seven-day immersion in simulated body fluid (SBF). SBF closely replicates the ionic composition of human blood plasma, facilitating the generation of hydroxyapatite on the glass surface. The examination involved creating a graph correlating the bioglass concentration (mg/mL) with hemolysis (%). The progression of the bio-mineralization process was observed through scanning electron microscopy (SEM)[(Chitra et al., 2020)](https://paperpile.com/c/JRUoZ2/dBlY) .

# Results and Discussion

## X-ray diffraction

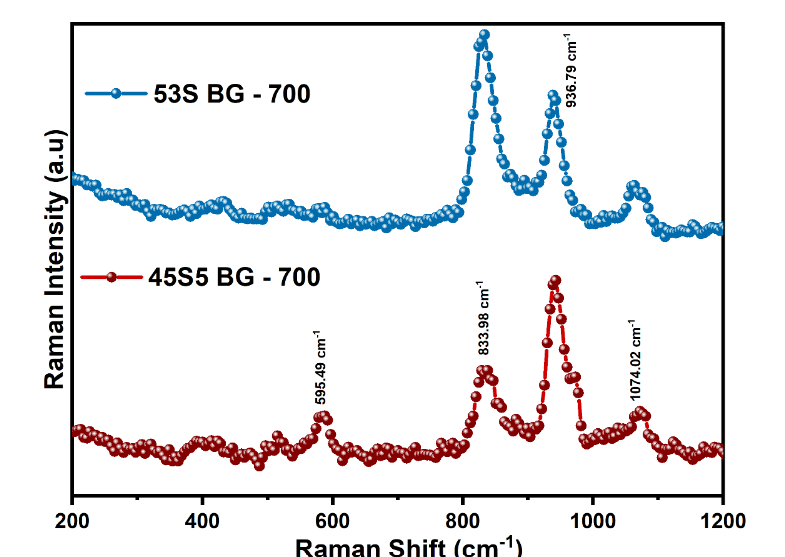
X-ray diffraction serves as a vital tool to analyze crystalline material structure in all sorts of materials including bioactive glass compositions. A single Na2Ca2Si3O9 phase appeared as the dominant substance in the bioactive glass compositions of 45S5 and 53S Bioglass according to figure 1.



**Figure 1:** XRD spectra to analyze the core composition of the bio active glasses.

## Raman Spectra

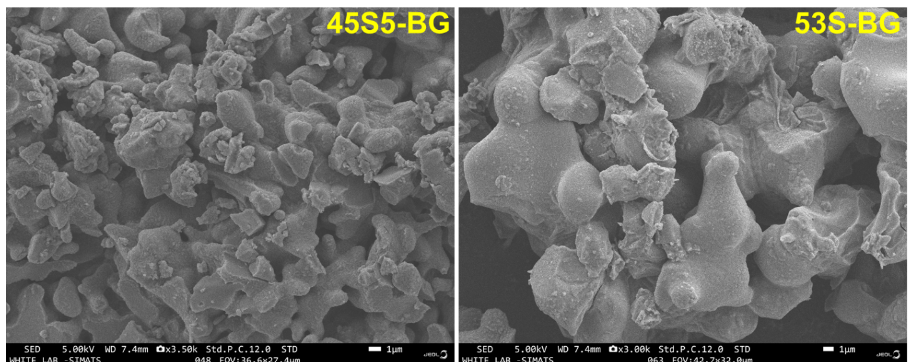
Raman spectroscopy serves as a potent tool for material characterization where it assesses both bioactive glasses and additional materials. Material composition and structure and all chemical properties can be identified through the valuable vibrational bond data obtained from Raman spectra. Though RAMAN spectra show a boost in phosphate vibration at 936.79 Cm−1 for 53sp4 bioglass there is a decrease in silica vibration at 1074.02 Cm−1 observed for 45s5 bioglass (figure 2).



**Figure 2:** Raman spectra was used to find the silica and phosphate concentration in the bioglasses.

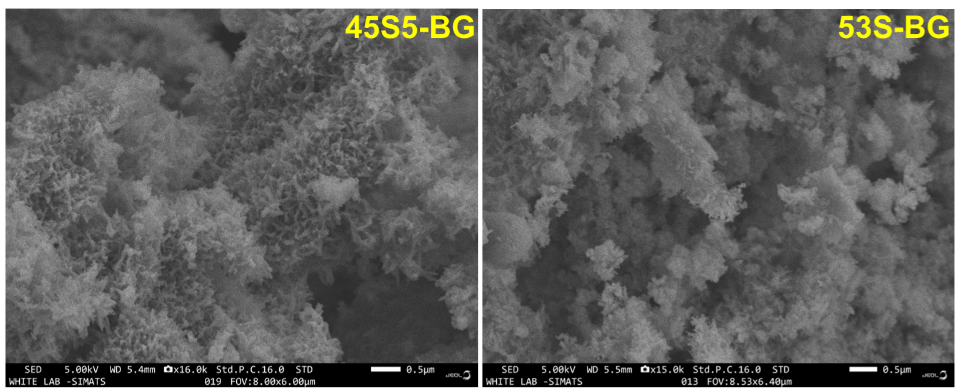
## Scanning Electron Microscopy

SEM functions as a leading imaging technology that serves multiple scientific sectors for detailed surface visualization along with elemental detection. The tiny spherical and flake-like structures shown in figure 3.



**Figure 3:** SEM before bio-mineralisation: to observe the detailed microscopic structures of the bioglass, before bio-mineralisation.

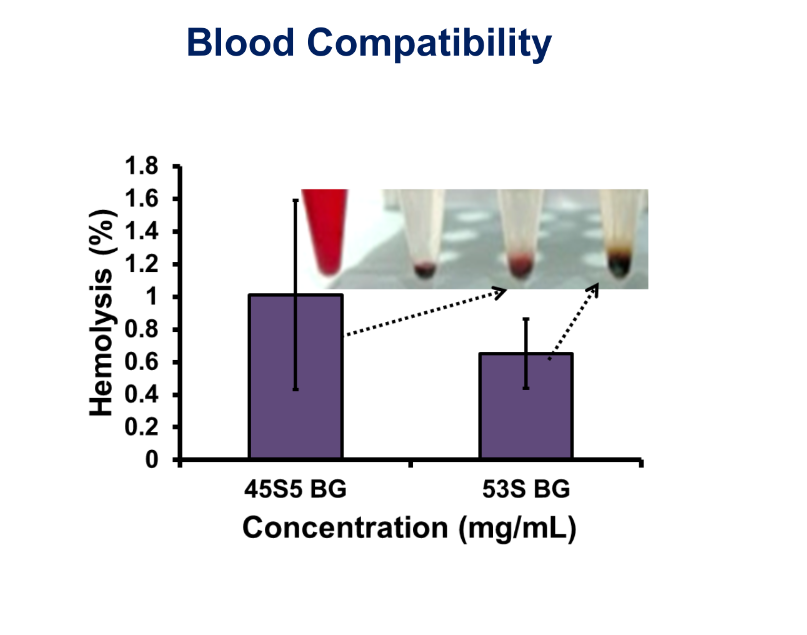
Figure 4 results from silicon abundance in 53sp4 bioglass which causes its particles to become bigger and have more pores than 45s5 bioglass in biomineralized states. Coagulation, platelet activation and complement activation occur. The enhanced sodium and calcium discharge causes maximum cell damage in 45s5 bioglass when compared to 53sp4 bioglass.



**Figure 4:** SEM after bio-mineralisation: to observe the detailed microscopic structures of the bioglass, after bio-mineralisation and to compare before and after structural changes.

## Hemolysis

Blood compatibility assays represent crucial evaluations which measure the blood connection with materials meant for medical devices or implant construction. The tests examine different blood-material interaction characteristics including hemocompatibility.



**Figure 5:** Blood compatibility assay- to compare the percentage of hemolysis in both 45s5 and 53s bioglasses

In XRD spectra, the dominant Na2Ca2Si3O9 phase was observed in both the bioactive glasses 45s5 and 53sp4. In RAMAN spectra, elevated phosphate vibration at 936.79 Cm−1 for 53sp4 bioglass and suppressed silica vibration at 1074.02 Cm−1 was observed for 45s5 bioglass. Small, spherical and flake-like morphology was observed for 45s5 bioglass under scanning electron microscope after being immersed in simulated body fluid for a period of 7 days, normal morphology turned into spiky morphology . And in 53sp4 bioglass, due to the enhanced presence of silica the particles appear bigger and more porous than 45s5 bioglass after biomineralization(Rafi et al., 2024). Through SEM analysis researchers detected linking porosity in glasses which contained greater amounts of SiO2. [(Balaji Ganesh S & Sugumar, 2021; Rajeshkumar, 2021)](https://paperpile.com/c/JRUoZ2/VCAp+YoHB) Nucleation and crystal growth of HA undergoes improvement because the additional space provides favorable conditions. The XRD analysis identified crystalline HA on the glass surface to confirm their bioactivity properties. [(Govindaraj & Dinesh, 2021; Maliael et al., 2021; Sushanthi, 2021)](https://paperpile.com/c/JRUoZ2/gemG+czdr+5LFp) Bio-mineralisation was estimated by immersing the bioglass in Simulated body fluid (SBF), where it was observed that 45s5 bioglass shows enhanced bio-mineralisation than 53sp4 bioglass. In blood compatibility assessment, we have found maximum lysis in 45s5 bioglass than 53sp4 bioglass due the higher concentration of sodium and calcium release (Tuluwengjiang et al., 2024). This compatibility can be acceptable because it attributes to less than 1% lysis.[(Dharman, 2021; Ramamurthy, 2021)](https://paperpile.com/c/JRUoZ2/YZ5Z+EWQ3) So the material can be used for biomedical applications. The obtained results will be presented and analyzed to establish correlations between different silica compositions and bio-mineralization properties. Increased silica content in the samples will lead to better hydroxyapatite layer development and growth due to the superior surface reactivity along with ample silanol groups. Scientific literature helps validate this hypothesis because compositions with high silica levels show better bioactivity outcomes [(Lakshmi, 2021; Obata et al., 2022; Tiwari & Jain, 2023)](https://paperpile.com/c/JRUoZ2/knp14+4kpn+lGmS). Among the both bioactive glasses, 45s5 bioglass is comparatively a little bit more toxic because it shows higher percentage of hemolysis but showed higher bio-mineralisation and 53sp4 bioglass showed lesser percentage of hemolysis but less bio-mineralisation capability. Hence we can say that both 45s5 bioglass and 53sp4 bioglass are good for bio medical use but both have their own advantages and disadvantages hence their use depends on the application.Furthermore, the morphology and crystallinity of the hydroxyapatite layer may also be influenced by the silica content in the glass matrix. [(Graf, S.,Thakkar, D., Hansa, I., Pandian, S.M., Adel, S.M., n.d.; Jones & Clare, 2012)](https://paperpile.com/c/JRUoZ2/gnfTy+cLYH)The different characteristics of the hydroxyapatite layer affect both the structural strength and the rate of degradation and the overall biomedical performance. [(Hench, 2013; Maiti, 2021)](https://paperpile.com/c/JRUoZ2/WV9yD+SRNA)

The research can evaluate both structural aspects and compositional properties of bioactive glasses to quantify their effects on bio-mineralization processes. Researchers must evaluate various silica compounds together with dopants and modifiers to discover the optimal combination that optimizes both bioactivity and biocompatibility of the material. Bioactive glasses demonstrate strong potential to drive bone healing through their mineral-deposit stimulating properties. Scientists in this field should work towards selecting silica-based compositions that speed up tissue repair and healing systems to produce better results in orthopedic and dental procedures. Glasses with different silica concentrations can undergo investigation for their bio-mineralization properties which would advance the development of better drug delivery methods for disease-specific treatment.

# Conclusion

Our investigation highlights the significant effects which silica composition changes have on the bio-mineralization properties of bioactive glasses. Bioactivity increases together with accelerated hydroxyapatite (HA) formation in glasses with higher SiO2 content (45S5) than in glasses with lower SiO2 content (53SP4). Our findings advance understanding of bio-mineralization mechanisms and provide significant insights to improve the properties of bioactive glasses used in regenerative medicine applications.

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