Strontium Calcium Silicate Pmma Denture Base Nanocomposite: Mechanical and Viscoelastic Properties

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**ABSTRACT:** Denture bases play an important role in oral function and aesthetics for individuals with missing teeth.The conventionally used PMMA denture bases provide support and stability ,but they have certain limitations such as inadequate strength and susceptibility to wear and fracture. To overcome these drawbacks nano-composite was incorporated into the denture bases to enhance the mechanical and viscoelastic properties. It was also found to have improved wear resistance to abrasive forces ,thus increasing the longevity of the denture.Commercially available PMMA denture base powder and monomer were used .The nanoparticle used for the fabrication was Strontium calcium silicate. 14.25 grams of PMMA denture base powder and 0.75 grams were mixed with 5 ml of monomer. The cast was poured and placed in the hot air oven for 3 hours and then the denture was obtained.Hardness was measured using a microhardness testing machine. Size and shape of PMMA and Strontium calcium silicate was analyzed using a Scanning Electron microscope.The Zebrafish studies was carried out followed by which the hemocompatibility test was done to check if the nanoparticle is suitable for human use. The EDX and FTIR were done to check the purity of the nanoparticle and to confirm whether the synthesized nanoparticle is Calcium Strontium Silicate respectively. The SEM analysis was done to analyze the morphology of the nanoparticle.In the Zebrafish study that was conducted it was found that the nanomaterial was biocompatible. Two groups were taken for the study -control and sample (Ca-Si-P-Sr) were taken and the growth of zebra fish was observed from ovulation state to hatching state ,there was no difference in the growth pattern which confirmed that the nanoparticle was biocompatible. Hemocompatibility test confirmed that the nanomaterial is suitable for human use as the OD value was less than 5%. FTIR studies confirmed that the synthesis nanoparticle was Ca-Si-P-Sr and it was observed at 550-800 nm. The SEM analysis shows that the nanoparticle has needle-like morphology. This study concludes that Ca-Si-P-Si was compatible for human use and had high flexural strength and longevity as compared to conventional PMMA denture base and it could be used for fabrication of denture base.

**Keywords:** Ca-Si-P-Sr, denture base, PMMA, viscoelastic behavior.

# INTRODUCTION

The denture bases have progressed through different stages of development over the century.The first introduced material to fabricate denture bases was vulcanized rubber (vulcanite), but dentists faced challenges in fabrication. Hence this material was replaced by polymethyl methacrylate (PMMA). The PMMA was easy to manipulate and had better physical properties and was aesthetically appealing. The PMMA denture bases were found to exhibit higher levels of impact and flexural fatigue strengths. Several other polymers were also slowly brought into the studies like polystyrene ,polyamide and light activated urethane dimethacrylate resins. But PMMA was the most widely used material for denture fabrications due various attributes like light weight,low cost,aesthetic properties and stability. The PMMA denture bases were highly compatible, reliable ,less toxic and had good teeth adhesion properties [(El Bahra, 2016; Shanmugam et al., 2013)](https://paperpile.com/c/Q1uUFk/6Nxz+9OE5)[(Ajay et al., 2023; Chokkattu et al., 2023; Padarthi et al., 2023)](https://paperpile.com/c/Q1uUFk/AvNZw+5k0df+5UN77)[(Dharman et al., 2023; S. Sindhu et al., 2023; Sreenivasagan et al., 2023)](https://paperpile.com/c/Q1uUFk/BHZde+WoEc9+LBO8S)[(Ramakrishnan et al., 2023; Shenoy & Maiti, 2023; J. S. Sindhu et al., 2023)](https://paperpile.com/c/Q1uUFk/QkIC+vWXG+PUPK)Some other uses of PMMA are : fabrication of bone cement in orthopedic surgery and intraocular lenses. It was also utilized for transparent glass substitutes, interior designs and microcellular foams.Though the PMMA resin material had excellent properties, there were certain drawbacks like poor surface adhesion, weak flexural strength, hardness and less fracture resistance.To overcome these drawbacks the PMMA resin materials were incorporated with some nanomaterials(Almatrafi et al., 2024). The use of nanomaterials in dentistry is recently a developing field of interest. Various nanoparticles like Alumina, Magnesium, Zirconia, Silver, Silicon were used in different studies conducted across the globe(Saadh et al., 2024). The present study involved the use of Calcium Strontium silicate incorporation into the conventional PMMA denture resin material. The amount of nanoparticles added plays a crucial role in determining the characteristics of the denture [(Takhtdar et al., 2023; Viishaal Srikanth Srivatsa & Manogaran, 2024)](https://paperpile.com/c/Q1uUFk/ZBsQ+hiJQ). Optimum amount of Calcium strontium silicate must be added as increased concentration of the material beyond the limit may cause agglomeration thereby reducing the mechanical properties of the denture base leading to reduced fracture toughness and flexural strength.The addition of Calcium strontium silicate increased the thermal conductivity and the surface hardness of the conventional PMMA. Calcium strontium silicate exhibits good thermal stability, it also has good electrical conductivity, it also exhibits optical properties such as fluorescence and it also contributes to the color of ceramic. Earlier the Calcium strontium silicate was used in dentistry in dental ceramics and composites. It was mainly considered due to its biocompatibility, aesthetics, strength and durability. It had appreciable hardness and wear resistance [(Jivangkul et al., 2007; Sathya et al., 2024)](https://paperpile.com/c/Q1uUFk/jn0G+MDsm)[(Kasabwala et al., 2021; Rajeshkumar & Lakshmi, 2021; Varghese et al., 2023)](https://paperpile.com/c/Q1uUFk/fpdjq+Dqnt0+NNVf5)[(Keerthana & Ramesh, 2021; Murugesan, 2021; Tiwari & Jain, 2021)](https://paperpile.com/c/Q1uUFk/AEbG5+OYFsG+Qqjj4)[(Keerthana & Ramesh, 2021; Murugesan, 2021; Subramanian et al., 2021; Tiwari & Jain, 2021)](https://paperpile.com/c/Q1uUFk/AEbG5+OYFsG+Qqjj4+DBnrA)[(*Evaluation Composite Restoration Posterior Teeth Proanthocyanidin Pretreatment Liner Using Fédération Dentaire Internationale Criteria: Split-Mouth Randomized Controlled Trial*, n.d.; Pranati et al., 2021; Sakthi 2021)](https://paperpile.com/c/Q1uUFk/TUA2H+ELauk+3P4h1)[(G. & Ganapathy, 2022; Kumar & Ramesh, 2021)](https://paperpile.com/c/Q1uUFk/D1f70+kK0mT)).The combination of silicate with strontium and calcium improved the bioactivity and the bone bonding ability. Strontium being similar in size and polarity to Calcium, the combination of both the elements were found to generate osteoporotic bone regeneration by synergistic effects. Previous studies have found that the calcium strontium silicate had good osteoconductivity, osteoinductivity. Calcium strontium silicate had better adhesion properties. Strontium is one of the trace elements in the human body and was found to have a special role in bone remodeling [(Scotti, 2010; Thiripelu et al., 2024)](https://paperpile.com/c/Q1uUFk/UcL9+9IQC).The incorporation of Calcium strontium silicate in PMMA denture base improved the elasticity of the conventional denture bases. It improved the ease of processing and adaptation of the material to the mold. The viscoelastic property of the material resulted in improved damping capacity, which enhanced the patient comfort by absorbing and dissipating vibrations during mastication and speech. Calcium strontium silicate was found to inhibit the osteoclastic activity of the bone. The conventionally available PMMA denture bases were found to accumulate fungal and bacterial biofilm on the surface [(Alqutaibi et al., 2023; Paramasivam et al., 2023)](https://paperpile.com/c/Q1uUFk/SWBF+TPWL). The addition of Calcium strontium silicate helped in preventing the growth of accumulation of bacteria and fungi on the PMMA surface. This study aims at evaluating the mechanical and viscoelastic properties of the PMMA denture bases incorporated with Calcium strontium silicate.

# MATERIALS AND METHODS

# MATERIALS

Commercially available PMMA denture base powder ,denture base liquid were selected as the denture base material. Calcium strontium silicate were chosen as the nanofillers for fabricating the nanocomposite denture base specimens.

## SELECTION OF APPROPRIATE PERCENTAGE OF THE MATERIALS

For better results the current percentage of materials should be used. 14.25 grams of commercially available PMMA denture base powder 0.75 grams of the Calcium strontium silicate nanoparticle 5ml of the monomer (denture base liquid) were mixed in correct proportions.

## MIXING OF PMMA WITH CALCIUM STRONTIUM SILICATE

14.25 grams of the commercially available PMMA was mixed with 0.75 grams of Calcium strontium silicate in 5ml of monomer using a stainless steel spatula in a glass beaker until the powder and the resin monomer were uniformly distributed. It was mixed until a dough-like consistency was obtained which was suitable for handling. On reaching the dough stage it was packed into the mould which consisted of three cavities, before pouring the material into the cavity vaseline was applied for easy removal of the specimens. Once the mixture was poured excess of material was removed from the peripherals and the mould was closed. The mould was placed in the curing water bath for 3 hours at 60 ℃ and then was removed and cooled for 30 minutes at room temperature.The mould was then opened and the specimens were removed. Finally the specimens were polished.

## FLEXURAL STRENGTH TEST

The flexural strength was evaluated using a 3 point bend test in a universal testing machine. A 500N load cell was used to record the force and the load was applied using a cross head speed of 5mm/min. The force was recorded in newton and flexural strength in MPa. The flexural modulus is determined as the slope of the linear portion of the stress/strain curve.

## FRACTURE TOUGHNESS TEST

Fracture toughness was conducted using a single edge span notch bend test on the Zwick universal testing machine. The specimens were placed in distilled water and then it was placed in an incubator for 2 hours before testing. After removing the specimens from water it should be placed on the testing ring and the notch specimen was placed directly opposite to the load plunger. A 500N load cell and 1 mm/min cross head speed was used. The force was increased from zero to maximum to test the specimen for fracture toughness.

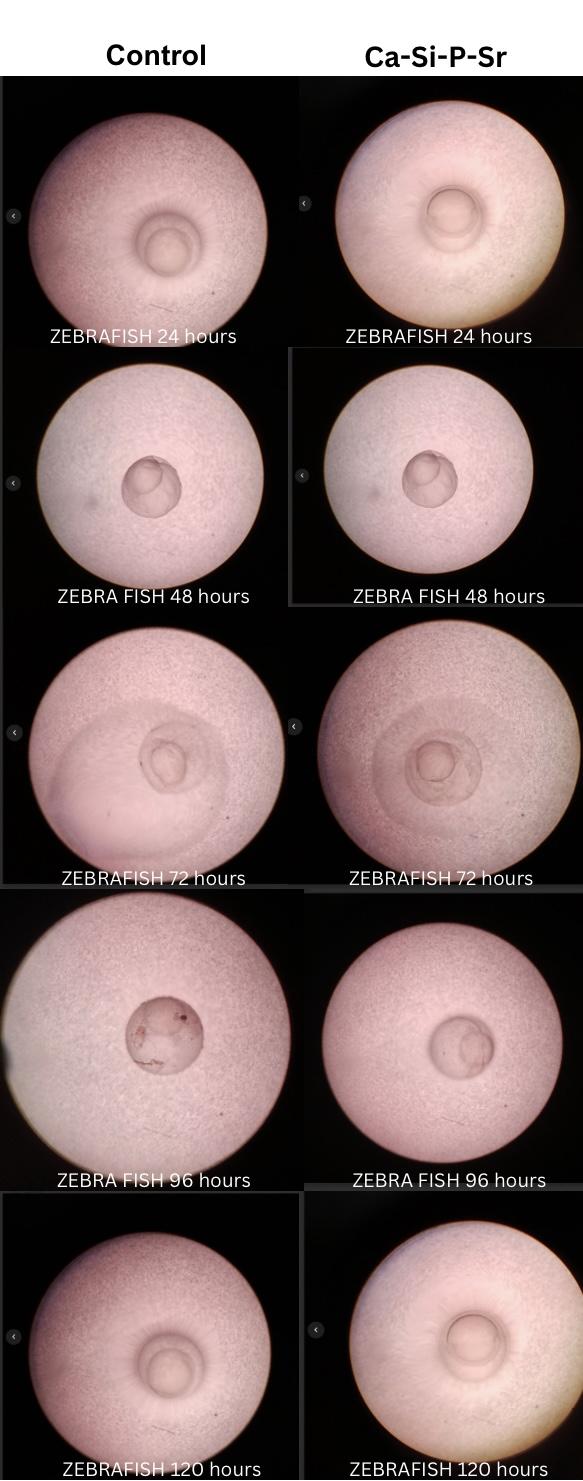
## HARDNESS TEST

The Vickers hardness test was used to measure the hardness of the specimen. A microhardness testing machine was used to perform the Vickers hardness test. The test was done by measuring the diagonals of the pyramid shaped indentation impressed on the specimen.

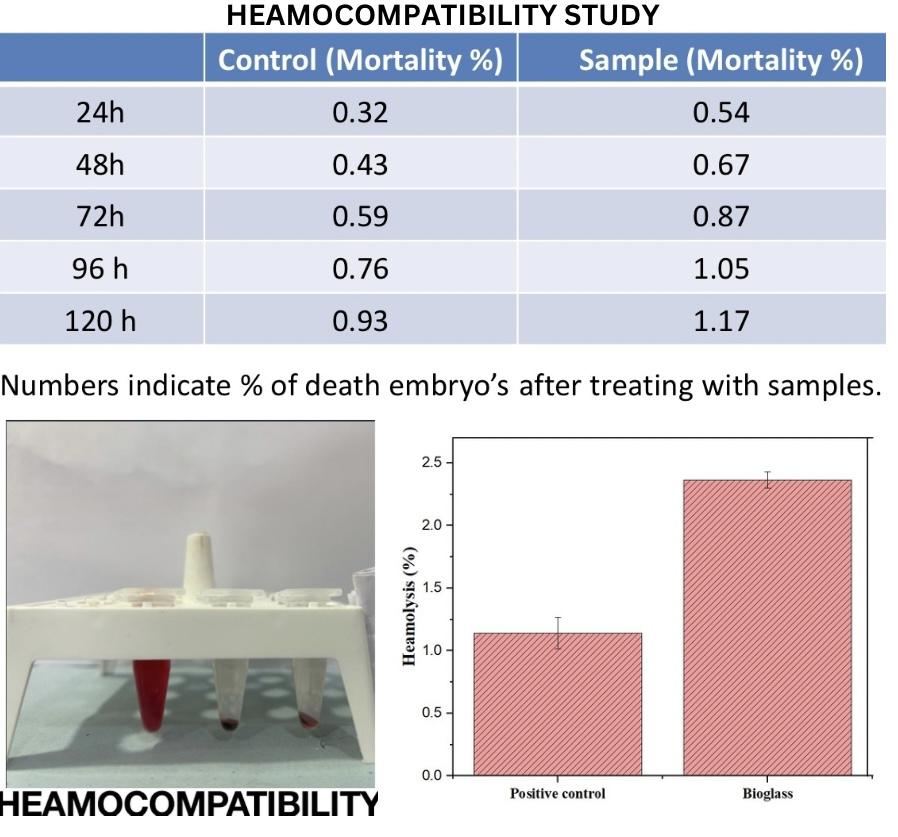
## SEM ANALYSIS

The Sem analysis was done to study the morphology of the nanocomposite incorporated PMMA denture base.

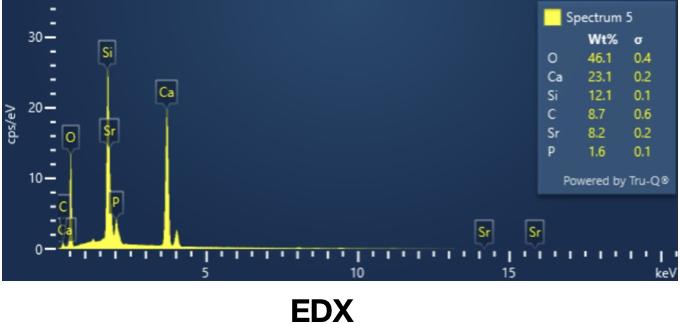
# RESULTS AND DISCUSSION

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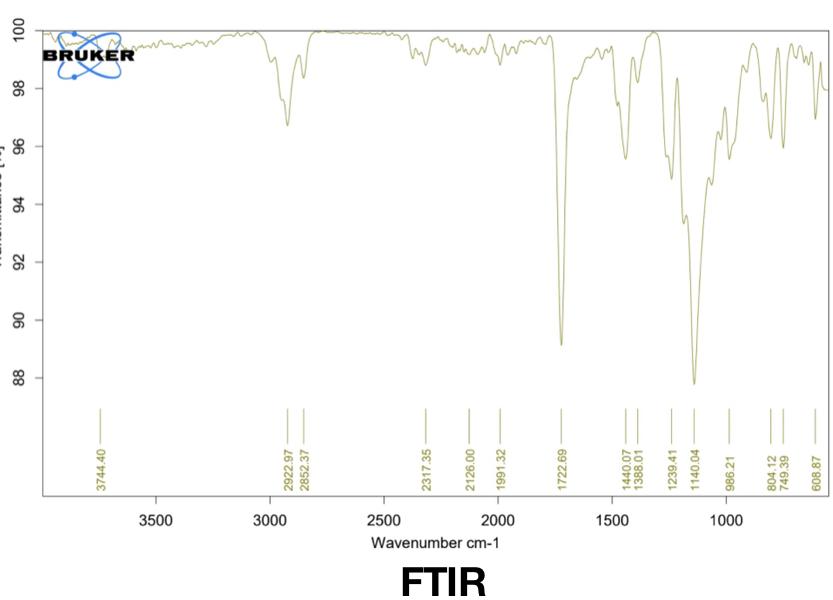
**Figure 1:**Represents the Zebrafish study between two groups control (zebra fish ) and sample (Ca-Si-P-Sr incorporated in zebrafish). The growth pattern of Zebrafish was observed in the groups and it was found that there was no significant difference in the growth pattern between the two groups which inferred that the nanoparticle was biocompatible.

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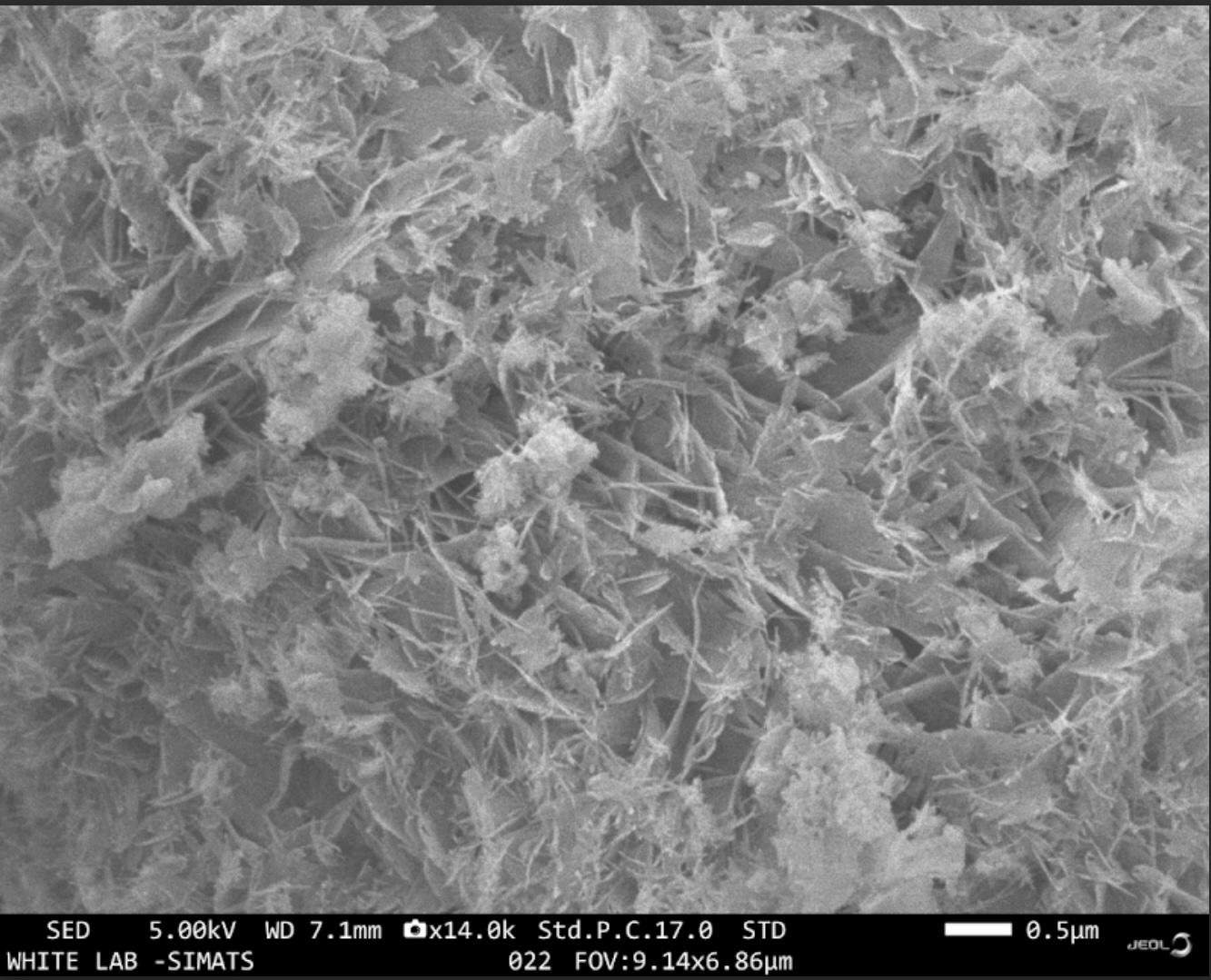
**Figure 2:**Represents the hemocompatibility assay ,the mortality rate was checked and the OD value was observed to be less than 5%,thus confirming that the nanoparticle is suitable for human use.

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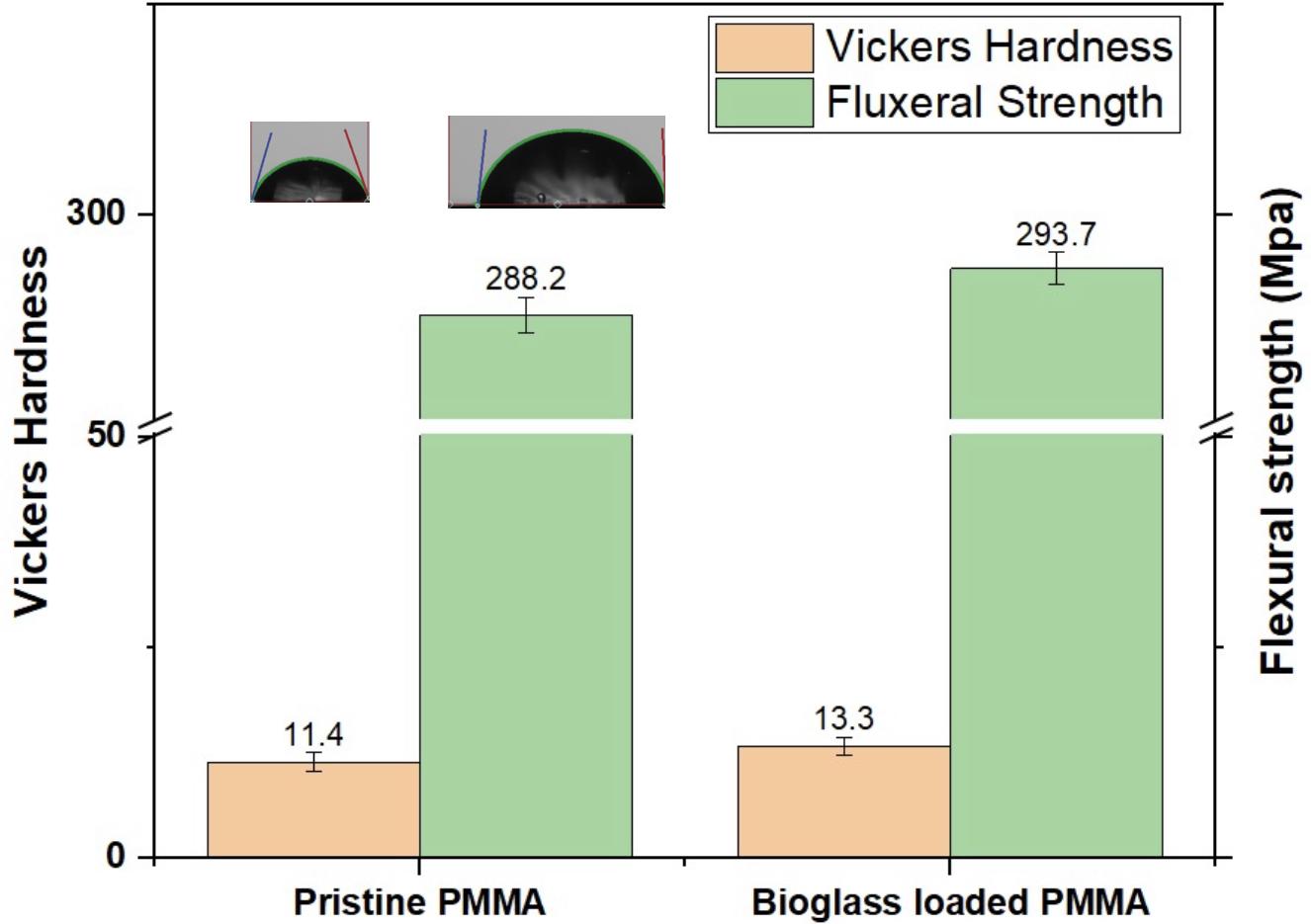
**Figure 3:**EDX-Energy Dispersive X ray .This is done to check the chemical composition and the purity of the nanoparticle .

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**Figure 4:**Fourier Transform Infrared Spectroscopy .This confirms that the synthesized nanoparticle is Ca–Si-P-Sr and the wavelength in which it was observed. Calcium was observed at 1500 nm, Strontium was observed at 550 to 800 nm Phosphorous was observed at 1040nm and Silicon at 1450 nm

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**Figure 5:** SEM Analysis of the nanoparticle confirmed that Calcium strontium Silicate had a needle like morphology and was amorphous in nature.

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**Figure 6:** The above graph represents Vicker’s and Knoops hardness that confirms hardness and flexural strength and the ability to resist deformation. The contact angle of PMMA is 72.36℃ and Ca–Si-P-Sr is 85.51℃ .

The Zebrafish studies was conducted to check the hemocompatibility of calcium strontium silicate. Two groups were taken control(only zebrafish) and sample( Ca-Si-P-Sr incorporated in the zebrafish) and the growth of zebrafish was observed from hatching to ovulation phase at different timeframes (24 hrs,48hrs,72hrs,96 hrs,120 hrs). There was no significant difference in the growth pattern in the two groups thus confirming that the nanoparticle was biocompatible. The hemocompatibility test was done by collecting 5 ml of blood from a healthy individual and centrifuging it by mixing it with Phosphate buffer solution to make it a dilute solution. 10-20 milligrams of the nanoparticle was taken and added in 1 ml of blood sample and was left undisturbed for 1 -2 hours and the Uv reading were checked. If there is an agglomeration it is not biocompatible and if there is no agglomeration it is biocompatible. The nanomaterial was confirmed to be biocompatible as there was no agglomeration and the mortality rate was less than 5%.EDX study confirmed the chemical composition of the nanomaterial and the purity. Traces of silicone phosphorus and oxygen were found in the nanomaterial. The FTIR study confirmed the calcium strontium silicate synthesis and the wavelength at which it was observed. Calcium was observed at 1500 nm, Strontium was observed at 550-800 nm, Phosphorus was observed at 1040 nm and Silicon was observed at 1450 nm.The SEM analysis was done to check the morphology of the nanomaterial. It exhibited a needle-like morphology and amorphous nature. The Vickers hardness test confirmed the hardness and the flexural strength of the nanomaterial being better than the conventional PMMA denture resin that is available.Previous studies have proved that reinforcement of various metal oxides,nanoparticles fibers and ceramics have improved the physical properties of the conventionally available materials. It had improved the impact strength ,flexural strength and toughness of the acrylic resin. The radiopacity and the shrinkage of the acrylic resin improved thereby increasing the longevity of the denture [(Sugimoto et al., 2021)](https://paperpile.com/c/Q1uUFk/d6yV).The addition of nanoparticles was found to improve the bond interaction with the PMMA acrylic resin by modifying the surface of the particles. The three point bend test confirmed the improved wear resistance of the nanoparticle reinforced acrylic resin. However the amount of nanoparticles added should not exceed the optimum level as studies have confirmed that addition of nanoparticles beyond 2.5% caused reduction in the compressive strength. The pH of the nanoparticle also plays an important role which is a prerequisite for the bioactivity of the material [(Ptáček, 2014)](https://paperpile.com/c/Q1uUFk/no4R).Apart from the usage in denture resins the calcium strontium silicate have been used in dentistry for various other uses. It has been used as dental cements, used in pulp capping, root canal sealing, used as bone tissue scaffolds for ingrowth of new bone. Good strength ,faster setting properties ,antimicrobial characteristics, and biocompatibility make it a preferred material for use. The combination of this nanoparticle with silicon nitride proved to be antiviral, thereby reducing a number of bone diseases. In orthopedic surgeries it was used in kyphoplasty to treat painful vertebral compressions. The calcium strontium silicate was found to be acid resistant and is found to be used as a core material in prosthodontics [(Hu et al., 2017; Ptáček, 2014)](https://paperpile.com/c/Q1uUFk/no4R+A80q).The nanoparticle exhibited more resistance to hydrolysis and exhibited improved durability. The mechanical properties of the nanoparticle play a crucial role in the clinical applications. The improved strength and toughness of the nanoparticle is attributed to several factors. It exhibited enhanced damping properties and elastic behavior [(Hu et al., 2017; Ptáček, 2014; Spicer, 2021)](https://paperpile.com/c/Q1uUFk/no4R+A80q+g1yq). However the incorporation of nanoparticles influences the flow characteristics during fabrication therefore the processing techniques must be optimized. Clinical trials should be conducted to assist the patient's comfort, compatibility and are resistant [(Zschech et al., 2021)](https://paperpile.com/c/Q1uUFk/kDnQ).

# CONCLUSION

The denture bases are frequently exposed to the humid oral environment due to the presence of saliva. The characteristics of the conventional PMMA acrylic resin was improved by using the nanoparticles. The denture was more stable and wear resistant. Furthermore future investigations are required to enhance the use of the nanoparticle incorporated PMMA denture base resin.

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