"ANALYSING THE EFFECT OF ADDITION OF SILICA NANOPARTICLES ON MECHANICAL PROPERTIES OF DENTAL STONE AND DIE STONE: AN IN VITRO STUDY"

Dissertation

Submitted to

BABU BANARASI DAS UNIVERSITY,

LUCKNOW, UTTAR PRADESH

In partial fulfilment of the requirements for the degree of

MASTER OF DENTAL SURGERY

IN

PROSTHODONTICS AND CROWN & BRIDGE

BY

DR. RUSA SANNIGRAHI

Under the guidance of

DR. MANOJ UPADHYAY

READER

DEPARTMENT OF PROSTHODONTICS AND CROWN & BRIDGE

BABU BANARASI DAS COLLEGE OF DENTAL SCIENCES, LUCKNOW

(Faculty of Babu Banarasi Das University)

ENROLLMENT NO. 1200329006

YEAR OF SUBMISSION: 2023 **BATCH: 2020-2023**

DECLARATION BY THE CANDIDATE

I, Dr. Rusa Sannigrahi, hereby declare that the Dissertation titled **"ANALYSING THE EFFECT OF ADDITION OF SILICA NANOPARTICLES ON MECHANICAL PROPERTIES OF DENTAL STONE AND DIE STONE: AN IN VITRO STUDY"** is a bonafide research carried out by me under the guidance of Dr. Manoj Upadhyay as Guide, and Dr. Garima Agarwal as Co-Guide.

Date: 14/2/23

Place: Lucknow:

Rusa Sannigrahi

Signature of candidate

CERTIFICATE OF GUIDE

This is to certify that the work incorporated in this dissertation entitled, **"ANALYSING THE EFFECT OF ADDITION OF SILICA NANOPARTICLES ON MECHANICAL PROPERTIES OF DENTAL STONE AND DIE STONE: AN IN VITRO STUDY"** submitted for the degree of MDS (Prosthodontics and Crown & Bridge) has been carried out by **Dr. Rusa Sannigrahi** under my direct supervision and guidance. The work has been done by the candidate herself.

Date: 14/2/23

Dr. Manoj Upadhyay
Reader
Department of Prosthodontics and Crown & Bridge
Babu Banarasi College of Dental Sciences
BBD University
Lucknow – 226028

CERTIFICATE OF CO-GUIDE

This is to certify that the work incorporated in this dissertation entitled, **"ANALYSING THE EFFECT OF ADDITION OF SILICA NANOPARTICLES ON MECHANICAL PROPERTIES OF DENTAL STONE AND DIE STONE: AN IN VITRO STUDY"** submitted for the degree of MDS (Prosthodontics and Crown & Bridge) has been carried out by **Dr. Rusa Sannigrahi** under my direct supervision and guidance. The work has been done by the candidate herself.

Date: 14/2/23

Dr. Garima Agarwal
Reader
Department of Prosthodontics and Crown & Bridge
Babu Banarasi College of Dental Sciences
BBD University
Lucknow – 226028

ENDORSEMENT BY THE HEAD OF THE DEPARTMENT

This is to certify that the work incorporated in this dissertation entitled, **"ANALYSING THE EFFECT OF ADDITION OF SILICA NANOPARTICLES ON MECHANICAL PROPERTIES OF DENTAL STONE AND DIE STONE: AN IN VITRO STUDY"** submitted for the degree of MDS (Prosthodontics and Crown & Bridge) has been carried out by **Dr. Rusa Sannigrahi** in my Department. The work has been done by the candidate herself.

Date: 14/2/23

Swati

Dr. Swati Gupta
Head of the Department
Department of Prosthodontics and Crown & Bridge
Babu Banarasi College of Dental Sciences
BBD University
Lucknow – 226028

ENDORSEMENT BY THE HEAD OF THE INSTITUTION

This is to certify that the work incorporated in this dissertation entitled, **"ANALYSING THE EFFECT OF ADDITION OF SILICA NANOPARTICLES ON MECHANICAL PROPERTIES OF DENTAL STONE AND DIE STONE: AN IN VITRO STUDY"** submitted for the degree of MDS (Prosthodontics and Crown & Bridge) has been carried out by **Dr. Rusa Sannigrahi** under the supervision of Dr. Manoj Upadhyay in the Department of Prosthodontics and Crown & Bridge.

Date: 14/2/23

Dr. Puneet Ahuja
Principal
Babu Banarasi College of Dental Sciences
BBD University
Lucknow – 226028

COPYRIGHT

DECLARATION BY THE CANDIDATE

I hereby declare that Babu Banarasi College of Dental Sciences, BBD University, Lucknow shall have the right to preserve, use and disseminate this dissertation in print or electronic format for academic/research purposes.

Date: 14/2/23

Place: Lucknow:

Rusa Sanwigrahi

Signature of candidate

ACKNOWLEDGEMENT

Composing this treatise was like undertaking an unknown journey, where there was some idea about the destination, but little clue about the means to approach it. It was the presence of my mentors and well-wishers, who ensured that I accomplished this trip comfortably. Now, towards the end of this journey, it is my duty and great pleasure to express thanks to all those who contributed towards the successful completion of this work.

First of all, I wish to express my heartfelt gratitude towards my teacher and guide Dr. Manoj Upadhyay for his invaluable guidance, suggestions, and help. He has personally helped me out at every step. He was available to answer any query and was ready to provide a prompt solution. This study would not have been possible without his unfailing support. I feel honored and privileged to have worked under him.

I am highly obliged to my co-guide Dr. Garima Agarwal for her guidance and support throughout my research work. She has always supported and motivated me with her knowledge throughout.

I wish to express utmost gratitude to our beloved teacher Dr. Swati Gupta, Professor and Head, Department of Prosthodontics and Crown & Bridge, Babu Banarasi College of Dental Sciences, for her noble guidance, suggestions, and caring attitude.

I will always be grateful to Professor Dr. Amrit Tandan for his keen surveillance and unflinching support in my studies. I sincerely thank you sir for always supporting and encouraging me and to stand with me whenever the need arose.

I am deeply indebted to Dr. Shikha Gupta for her constant encouragement and support during this study. She has been a constant source of motivation and inspiration for me to improve in my field.

I would like to thank my batchmates -- Dr. Rakhi Raveendran, Dr. Charu Rukhaya, Dr. Roopali Sharma and Dr. Rajatava Paria for constantly motivating

me during my my dissertation. I am lucky to have them as batchmates. Their compassion and caring nature have given me strength when I needed the most.

I wish to express utmost gratitude to Mr. Ashok Bhagat, Praj Metallurgical Laboratory, Pune for carrying out part of the laboratory testing of the dental specimens. I also sincerely want to thank Dr. Apurva Anand, Dean, School of Engineering, BBD University for allowing me to carry out my research work under his guidance.

I am extremely thankful to Mr. Ashish who helped me out with the ideas regarding the approach to data analysis and took valuable time for doing the statistical analysis of my thesis. I am also thankful to my juniors and seniors for their constant support and motivation.

I thank my parents and in-laws for always being there and supporting me and for being my pillars of strength. They are my biggest inspiration and I can only hope to be a fraction of the people they are. There is no word to describe their immense love and support. I would hereby like to convey my love for my cute nephew Ribhaan who has been like a shining star in my night sky.

Finally, to the person who has made all of this possible, my compassionate and caring husband Dr. Shamick Biswas. It was his support and caring nature that made everything possible. His balanced and positive attitude is what I needed the most. The unconditional love of my husband has helped me sail through moments of uncertainty and self-doubt. Above all, I thank the Almighty for making this study possible

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF APPENDICES

LIST OF ABBREVIATIONS

BC	Before Christ
MPa	Mega Pascal
FT-IR	Fourier transform infrared spectroscopy
SEM	Scanning electron microscope
DTS	Diametral tensile strength
CS	Compressive strength
Ag	Silver
NP	Nanoparticles
NS	Nano-silica
NA	Nano-alumina
ISO	International Organization for Standardization
UTM	Universal Testing machine

ABSTRACT

Aim: This in-vitro study was performed to compare the surface roughness, diametral tensile strength (DTS), and compressive strength of dental stone and die stone before and after the addition of 5wt% silica nanoparticles.

Material and Methods: A total of 120 specimens were prepared, 60 for each dental stone and die stone. No silica particle was added in the control groups. For the test groups, 5wt% silica nanoparticles were added. The specimens were prepared with the aid of a silicone mold and measured 20mm in width and 40 mm in height. The stones were mechanically spatulated and poured into the mold under vibration. The surface roughness of the specimens was measured using TR200 while DTS and compressive strength were measured using the Universal testing machine. The intergroup comparison for the difference in mean scores between two independent groups was done using the independent t-test.

Results: The mean surface roughness of dental stone and die stone in the control group was 3.16µm and 2.96µm respectively and in the test group was 2.88µm and 2.53µm respectively. The mean DTS of dental stone and die stone in the control group was 1.29 MPa and 1.51 MPa respectively, while that in the test group was 1.01 MPa and 1.14 MPa respectively. The mean compressive strength of dental stone and die stone in the control group was 14.02 MPa and 16.25 MPa respectively and in the test group was 10.38 MPa and 11.28 MPa respectively.

Conclusion: Surface roughness was statistically lower for dental stone ($p=0.018$) and die stone ($p=0.0018$) when 5wt% silica nanoparticles were added. There was a statistically significant reduction in the DTS after the addition of silica nanoparticles for both dental stone ($p=0.003$) and die stone ($p=0.0002$). Following silica nanoparticle addition, there was also a statistically significant reduction of compressive strength of both dental stone ($p=0.009$) and die stone ($p=0.0012$).

Keywords: Surface roughness, diametral tensile strength, compressive strength, dental stone, die stone, silica nanoparticles.

INTRODUCTION

The history of using gypsum as a building material can be traced way back to 5000 BC in the ancient land of Egypt. Alabaster, a form of crystallized gypsum, is believed to have been used in the sarcophagus found in Pharaoh Khufu's pyramid in Giza, Egypt. It has also been hypothesized that Cleopatra's wine cup was made from natural gypsum. Since ancient times, gypsum has been considered beautiful and durable and has been used not only as a stone but also as a paving and carving material. The technical details of processing were passed on from the Persian era to the Greco-Roman civilization and were henceforth applied for construction of the European buildings and monuments. [1]

In general, naturally occurring calcium sulfate is referred to as natural gypsum. It can take many different forms, but the two that are most prevalent are anhydrite (CaSO4.2H20) and dihydrate (CaSO4).[2] Gypsum is a mineral commonly associated with sedimentary rocks. Calcination is the process of heating gypsum to dehydrate it and form calcium sulfate hemihydrate.[3] When gypsum is heated in a kettle, a crystalline hemihydrate called dental stone is produced in the form of rods or prisms. Due to the different crystal sizes, surface area, and degree of lattice perfection, the resulting powders are often referred to as α-hemihydrate for dental stone and β-hemihydrate for plaster of Paris. The "sponginess" and uneven form of the β-hemihydrate crystals are their defining features. The α-hemihydrate crystals, on the other hand, are denser and their shape is like prisms. The process is reversed when hemihydrate particles are combined with water. In comparison to the β-hemihydrate, the dihydrate structure produced by the α-hemihydrate is significantly stronger and harder. The main cause of this disparity is that the β-hemihydrate crystals are more porous and irregular in shape, necessitating the use of additional water to moisten the powder particles before stirring and pouring.[3]

Gypsum products are known for their strength, abrasion resistance, compatibility with impression materials, and biological safety. Anatomical models of the oral and maxillofacial structures, dental appliances, and dental restorations including models, dies, and castings, are created using gypsum.[4]

Dental stone is made of α-hemihydrate. It is used to create partial and full denture models and casts. In contrast to dental plaster, which is made of β-hemihydrate, it is tougher, more precise, and has a smoother consistency. Because the dental stone has a smaller particle size and less porosity than plaster, it uses less water.[3] Type IV gypsum (Die stone), made of α-hemihydrate, is the most often utilized substance for making dies and casts. It is resistant to abrasion, shows high accuracy and strength and is capable of reproducing finer details as compared to dental stone. Die stone is used for the production of working casts on which fixed or removable dental prostheses are made.[5]

Gypsum-based products are still used because they may be altered using a variety of physical and chemical techniques.[5] To make the existing dental materials stronger, inorganic filler particles like quartz, strontium, colloidal silica, and zirconia are employed.

The most common laboratory testing methods used to measure the mechanical and physical characteristics of dental stones are compressive and diametral tensile strengths.[6] Surface roughness, which has three components (roughness, waviness, and shape), is a measurement of the minute micro-irregularities on the surface texture.[7] The tensile strength of brittle dental materials having primarily elastic deformation and little to no plastic deformation is assessed using the diametral tensile strength method. This test involves applying a compressive load to a cylindrical specimen in the diametral plane, which is perpendicular to the longitudinal axis.[8] Compressive strength is the internal resistance of a body when it is subjected to a load that tends to compress or shorten it.[3]

Micro-silica particles are added to gypsum to improve its mechanical qualities (surface roughness, diametral tensile strength, and compressive strength). The intrinsic material qualities of such technologically modified and advanced materials have been improved, leading to an improved clinical outcome.

The science of creating and modifying materials in the nanoscale range using a variety of cutting-edge techniques is known as nanotechnology. Nanotechnology developments have resulted in the evolution of dental materials like adhesives and resins with better mechanical characteristics.[9] The modulus of elasticity, yield strength, and internal bond strength of gypsum products are all improved by the inclusion of silica nanoparticles.[10] These nanomaterials, such as adhesives and composite resins, have had their appearances altered as a result of recent technological advancements. These new nanomaterials have enhanced the physical and mechanical properties of materials, leading to better therapeutic results. Silica-based nanoparticles have proved to be indispensable in nanotechnology, owing to their multifaceted properties like size, surface area, biocompatibility, low toxicity, low density, and high adsorption capacity.[11] In this study, there will be an evaluation of surface roughness, diametral tensile strength, and compressive strength of dental stone and die stone on the addition of silica nanoparticles 5wt%.

AIMS AND OBJECTIVES

AIM

Evaluate the mechanical properties of dental stone and die stone after the addition of 5wt% silica nanoparticles.

OBJECTIVES

- Comparative evaluation of the impact of the addition of silica nanoparticles (5wt%) on surface roughness of dental stone and die stone.
- Comparative evaluation of the impact of the addition of silica nanoparticles (5wt%) on diametral tensile strength of dental stone and die stone.
- Comparative evaluation of the impact of the addition of silica nanoparticles (5wt%) on compressive strength of dental stone and die stone.

REVIEW OF LITERATURE

De Cesero L, de Oliveira EM, Junior LH, Papaléo RM, and Mota EG (2017) [5] prepared 180 specimens, 90 each for dental stones (Durone and Fuji Rock). Silica nanoparticles were introduced to one test group at a rate of 1wt% and the other test group at a rate of 5wt%, but none were added to the control group. 24 hours following the initiation of spatulation, the roughness, diametral tensile strength (DTS), and compressive strength were assessed in each of the groups.

The authors concluded that the addition of silica nanoparticles statistically reduced surface roughness for the Durone and Fuji Rock stones ($P < .001$). Durone's DTS and compressive strength were not significantly impacted by the addition of silica nanoparticles when compared to the control group ($P > .05$). However it significantly affected the DTS of Fuji Rock when 5wt% has added and also the compressive strength at both 1wt% and 5wt% ($P < .05$).

Akkus B, Demir N, Karci M and Yazman S. [6] studied the impact of silicon dioxide (SiO_2) and aluminium oxide (Al_2O_3) nanoparticles on the mechanical characteristics of type III and type IV dental stones. 200 disc-shaped specimens with predetermined dimensions were made for compressive strength and diametral tensile strength tests. Subgroups of Control, 1% SiO_2, 5% SiO_2, 1% Al_2O_3, and 5% Al_2O_3 were used. Specimens were stored in dry conditions for seven days before mechanical tests. The Universal testing machine was used for measuring the above-mentioned mechanical properties of the stones. The authors observed that the interaction between the type of dental stone and the nanoparticles was significant ($p < 0.05$).

The Type IV dental stone with 5% SiO_2 nanoparticle addition showed the lowest diametral strength while the Type III dental stone with 5% SiO_2 nanoparticle addition demonstrated the lowest compressive strength. By using SiO_2 and Al_2O_3 nanoparticles, the compressive and diametral strength values for both dental stones were reduced. Dental stones of Type III and Type IV had their compressive and diametral strengths reduced when 1% & 5% SiO_2 and Al_2O_3 nanoparticles were added. The compressive and diametral tensile strength of Type III and Type IV dental stones decreased as the weight percentage of SiO_2 and Al_2O_3 nanoparticles increased.

In their study**, Mitra SB, Wu D, and Holmes BN (2003)** [12] described the creation of nanofillers and a resulting nanocomposite. The in-vitro characteristics of the nanocomposite were compared with those of the already-existing composites. Nanomeric particles and nanoclusters were the two different types of nanofillers employed.

The nanocomposite was discovered to have equal to or greater compressive and diametral strengths as well as fracture resistance than the other commercial composites tested. In comparison to the other investigated composites, the three-body wear findings of the nanocomposite system demonstrated better results. During the prolonged brushing durations, the nanocomposite outperformed the hybrids and micro hybrids in terms of polish retention. The dentin, body, and enamel hues retained polish after prolonged toothbrush abrasion like that of the tested microfill, although transparent shades retained polish better than the microfill.

The authors concluded that the nanocomposite system exhibited great translucency, high polish, and high polish retention. However, it was observed that the physical characteristics and wear resistance of these nanocomposites were comparable to those of other hybrid composites.

Michalakis KX, Asar NV, Kapsampeli V, Magkavali-Trikka P, Pissiotis AL, and Hirayama H (2012) [13] looked at how five different high strength stones changed linearly in dimension after three weeks of storage under two different circumstances. Testing was done on three Type IV dental stones and two Type V dental stones. The dental stone and water were first blended under vacuum, and then under vibration, the mixture was poured into the stainless steel die.

One hour after the pour, the specimens (sample size of 20) were removed from the stainless steel die. Ten different control specimens in total were used. The test and control specimens were each kept in a separate room with a set temperature and humidity level. Over the course of three weeks, the linear dimensional changes were noted at predetermined intervals.

The control group's specimens showed the greatest expansion values between 72 and 96 hours, after which all the specimens in both groups showed a contraction. Between the second and third weeks, there was no discernible difference in the measurements. There were differences between various Type IV and V dental stone products, timing, and storage circumstances which were found to be statistically significant ($P<.001$). The maximum expansion values for the experimental group were obtained at 24 hours, whereas those for the control group were observed between 72 and 96 hours. It was observed that the linear dimensional changes were considerably influenced by the dental stone type, time, and storage state.

Khalil AA, Tawfik A, Hegazy AA, and El-Shahat MF (2013)[10] conducted a study on the Gypsum plaster/silica composites and assessed their normal consistency, porosity setting time, bulk density, and compressive strength after being hydrated for seven and twenty-eight days.

The authors found that adding various silica types decreased the bulk density of the composites while increasing their normal consistency, setting time, apparent porosity, and compressive strength. The above improvement was thought to be caused by silica embedded within the interstitial pores of the cured plaster matrices. Even though the majority of the composites only slightly increased in compressive strength, their composition was advantageous since it either contained an inexpensive, widely accessible constituent (sand) or industrial by-products. The created plaster-silica composites, according to the scientists, had significant economic value and might help maintain a clean and healthy environment by reducing waste.

De Cesero L, Mota EG, Burnett Jr LH and Spohr AM (2014) [14] undertook a study to assess how postpouring time affected the Type IV dental stone's surface roughness, compressive strength, and diametric tensile strength. Three commercially available dental stones were used to create a total of 270 specimens. At 1 hour, 24 hours, and 7 days after pouring, the three parameters i.e, surface roughness, compressive strength, and diametric tensile strength were assessed.

The range of diametric tensile strength varied from 3.94 to 9.20 MPa and the surface roughness for the various dental stone types ranged from 0.3 to 0.64mm. Compressive strength ranged between 26.67 to 65.14 MPa. After pouring, surface roughness, diametric tensile strength, and compressive strength showed a significant increase with time. Roughness (P=.001), diametric tensile strength (P=.004), and compressive strength (P=.001) were all impacted by the commercial brand employed.

Tripathi A, Gupta A, Bagchi S, Mishra L, Gautam A and Madhok R (2016) [15] examined how adding cyanoacrylate, epoxy resins, and gum arabic affected the type IV gypsum die materials' ability to withstand abrasion. Four groups of ten each were created from forty specimens: group A (control), group B (die stone combined with cyanoacrylate), group C (die stone mixed with epoxy resin), and group D (die stone mixed with gum arabic). Abrasion testing, wear volume analysis, Fourier transform infrared spectroscopy (FT-IR), and scanning electron microscope (SEM) examination was performed on each specimen.

Abrasion testing revealed that the gum arabic group had the least wear while the control group had the most wear. Statistics showed that there were intergroup differences ($p < 0.001$). The control and gum Arabic groups had the largest mean difference, whereas the cyanoacrylate and control groups had the smallest. The control group had the largest mean wear volume, whereas the gum arabic group had the lowest.

The authors concluded that type IV gypsum had more resistance to abrasion after adding gum Arabic. Although cyanoacrylates made good adhesives, they had very little resistance to the chemical and physical effects of water and sunshine. Epoxy resins were discovered to be strong adhesives, but only fully cured with heat. Due to inhomogeneity, cyanoacrylate and epoxy resin showed poor physical bonding.

Salah A, Alnori AK, and Elias MZ (2019) [16] conducted a study to examine the impact of various Ag (silver) nanoparticle concentrations on the compressive strength of type IV dental stone. The entire specimen (n=66) was separated into three groups: wet strength,dry strength, and scanning electron microscope (SEM) investigation. They

added several weights of Ag NPs (0.2%, 0.5%, 1.0%, 1.5%, and 2.0% weight) to type IV dental stone and then assessed its compressive strength under wet and dry conditions. The results were contrasted with those of the control group and assessed using SEM.
When compared to the control specimens, the authors found a reduction in compressive strength. Wet strength did not see this considerable decrease in strength, but dry strength did. SEM pictures showed the distribution of NPs inside the specimens as well as the shape of the silver NPs and stone crystals. The authors concluded that adding silver nanoparticles to dental stone decreased its compressive strength and that the NPs were distributed evenly.

Aljubori OM, Aljafery AM and Al-Mussawi RA (2020) [4] carried out a study to assess the surface hardness and linear dimensional stability of dental stone type IV after silica nanoparticles were added to it. A total of 40 type IV stone specimens were created using stainless steel molds for linear dimensional stability and plastic molds for hardness; 20 of the specimens contained silica nanoparticles (test group), while the remaining 20 did not (control group).
A digital caliper was used to assess linear changes in dimension and the Vickers' hardness test was used to evaluate hardness. According to the authors, the addition of silica nanoparticles improved type IV stone's hardness while decreasing its linear dimensional changes.

Tsardaka EC and Stefanidou M (2021) [17] observed how nanoparticles affected the durability of cement and lime pastes after being subjected to salt cycles. In cement and lime pastes, the addition of nano-silica (NS) and nano-alumina (NA) changed the physical as well as mechanical characteristics and behaviour of the pastes through the salt cycles. At days 90 and 180, NA led to an increase in compressive strength, a decrease in open porosity, and a reduction in water absorption in lime pastes.
Additionally, it made it possible to improve compressive strength following sodium sulphate cycles. On the other hand, after the sodium sulphate and saltwater cycles, NS

favored the compressive strength of cement pastes. Additionally, NA helped to improve the pastes' qualities in the latter circumstances.

Sharma A, Shetty M, Hegde C, Shetty NS and Prasad DK [6] examined the dimensional accuracy and tensile strength of a type IV gypsum product after it had been microwaved or dried in the air at various intervals. The tensile strength of 80 specimens made from a cylindrical mold was measured (group A). To assess dimensional accuracy, twenty samples from a master die mold were used (group B). 40 samples from group A were dried outside at room temperature (A1). After 30 minutes, the other 40 were taken out to air dry for 20 minutes. These were dried in a microwave for five minutes (A2). At 1, 2, 4, and 24 hours after drying, ten samples from each group were examined under diametral compression. Ten specimens from group B were air-dried (B1). After 30 minutes, ten specimens were taken out of the mold and allowed to air dry for 20 minutes. These were then dried for five minutes in a microwave (B2).

The researchers discovered no discernible changes between the two groups' dimensional accuracy. In this investigation, microwave oven drying had a favourable impact on a type IV gypsum's DTS, and the microwave oven-dried specimens over the same period were just as accurate as the air-dried specimens.

MATERIAL AND METHODS

Materials and Equipment used in the study with specifications and Company

Materials

- Dental stone (Dentstone)
- Die stone (Kalrock)
- Silica nanoparticles – 5wt% (ISO 9001:2015 certified)

Equipment required:

- Surface roughness test - (TR200)
- Diametral tensile strength - UTM (Universal testing machine)
- Compressive strength – UTM
- Silicone mold
- Rubber bowl and spatula
- Measuring cylinder
- Digital weighing scale

Place of the study

The study was conducted at the following places:

- Diametral tensile strength and Compressive strength using a Universal testing machine were conducted at Praj Metallurgical Laboratory, Pune - 411038.
- Surface roughness test using TR200 device was measured at Babu Banarasi Das Institute of Technology and Management (BBDITM), BBD University, Faizabad Road, Lucknow – 226028

Study subjects/ materials

Dental stone (Dentstone) and Die stone (Kalrock)

Study Sample and size

For each group (n=10 containing 5wt% of silica nanoparticles), surface roughness, diametral tensile strength (DTS), and compressive strength was measured. An equal number of controls matched to the total number of cases was taken.

11.5. Eligibility Criteria

Inclusion Criteria

- Dental stone and Die stone having specific dimensions (as described in Methodology)

Exclusion Criteria

The following dental stone and die stones were excluded:-

- storage in an improper environment (temperature exceeding 22 °C and humidity more than 30%)
- expired products (as specified by the manufacturer)
- not stored in sealed moisture-proof containers
- sample having inaccurate dimensions (chance of fracture during measurement)

The following machines/ equipment were excluded from the study:

- those providing faulty readings
- having inaccurate calibration

Sampling Method

60 specimens each of dental stone and die stone were prepared (including test as well as control specimens). The specimens were divided into Case (n=30 each for dental stone and die stone) and Control group (n=30 each for dental stone and die stone). For the test groups, silica nanoparticles 5wt% were added. No silica particle was added to the control group.

Methodology

A total of 120 specimens were prepared, 60 for each dental stone and die stone. For the control groups, no silica particle was added. For the test groups, 5wt% silica nanoparticles were added.

The following parameters were measured:-

- Surface roughness
- Diametral tensile strength
- Compressive strength

The specimens used for these tests were prepared with the aid of silicone molds. For the surface roughness, diametral tensile strength, and compressive strength tests, the specimens measured 20mm in width and 40 mm in height.

The stone powder and the silica nanoparticles were weighed using a precision digital scale and distilled water was measured using a measuring cylinder. The stones were mechanically spatulated following the time recommended by the manufacturers and subsequently poured into the mold under vibration. Glass slabs were then placed at the top and bottom of the mold to assist in the preparation of the specimens.

The silica nanoparticles used in the study had the following physical properties (Appendix VI):-

Nanoparticles name	Silicon Oxide Nanoparticles
Molecular Formula	SiO2
CAS Number (Chemical Abstracts Service)	7631-86-9
Purity	99.9%
APS (Average particle size)	30-50 nm
Form	Powder
Colour	White
SSA (Specific surface area)	200-600 m2/g
Molecular Weight	60.08 g/mol
Morphology	Spherical
Density	0.02 - 0.1 g/cm3
Melting Point	>1600 °C
Boiling Point	2230 °C

Materials	Recommended water/ powder ratio by the manufacturer	Recommended mixing method by the manufacturer
Dental stone (Control group)	28ml/ 100gm	To 100 grams of dental stone powder, 28ml of distilled water was added and mixing was done in a rubber bowl with a straight spatula for 30-50 seconds. Spatulation was done thoroughly pressing the material against the sides of the bowl until all the powder was absorbed and a thick creamy mix was obtained. Subsequently, the mixture was poured into the silicone mold under vibration to avoid air bubbles in the samples.
Dental stone (Test group - 5wt% silica nanoparticles added)	28ml/ 100gm	To 100 grams of dental stone powder, 5 grams of silica nanoparticles were added and a uniform mix was obtained. To the mixture, 28ml of distilled water was added and mixing was done in a rubber bowl with a straight spatula for 30-50 seconds. Spatulation was done thoroughly pressing the material against the sides of the bowl until all the powder was absorbed and a thick creamy mix was obtained. Subsequently, the mixture was poured into the silicone mold under vibration to avoid air bubbles in the samples.

Materials	Recommended water/ powder ratio by the manufacturer	Recommended mixing method by the manufacturer
Die stone (Control group)	23ml/ 100gm	To 100 grams of die stone powder, 23ml of distilled water was added and mixing was done in a rubber bowl with a straight spatula for 45-60 seconds. Spatulation was done thoroughly pressing the material against the sides of the bowl until all the powder was absorbed and a thick creamy mix was obtained. Subsequently, the mixture was poured into the silicone mold under vibration to avoid air bubbles in the samples.
Die stone (Test group - 5wt% silica nanoparticles added)	23ml/ 100gm	To 100 grams of Dentstone powder, 5 grams of silica nanoparticles were added and a uniform mix was obtained. To the mixture, 23ml of distilled water was added and mixing was done in a rubber bowl with a straight spatula for 45-60 seconds. Spatulation was done thoroughly pressing the material against the sides of the bowl until all the powder was absorbed and a thick creamy mix was obtained. Subsequently, the mixture was poured into the silicone mold under vibration to avoid air bubbles in the samples.

Figure 1: Materials required for preparation of the specimens: A – Dental stone and Die stone; B - Silica nanoparticles; C – Silicone mold; D – Rubber bowl & spatula; E – Measuring cylinder; F – Digital weighing scale; G – Distilled water.

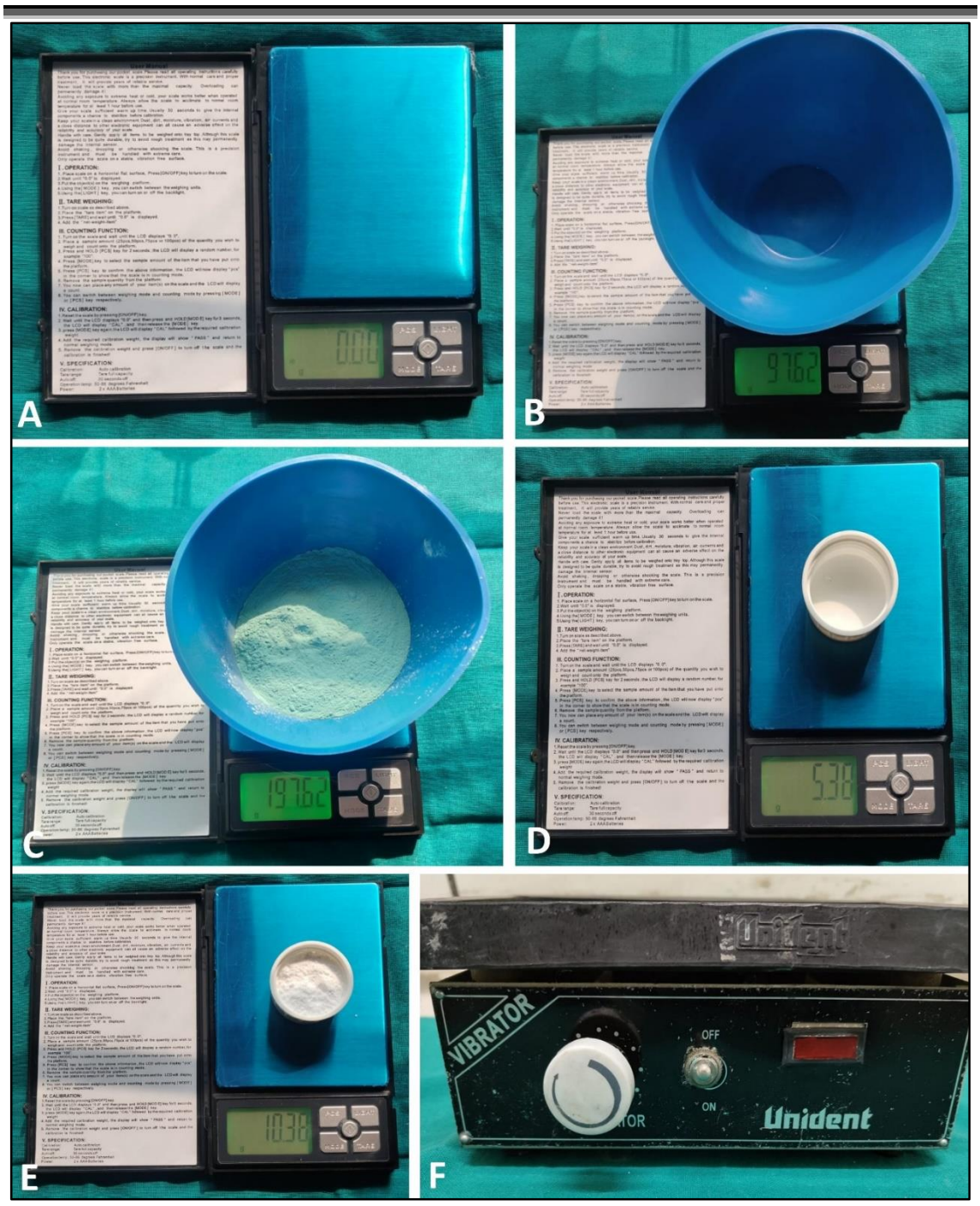


Figure 2: A – Calibrating digital weighing scale to zero; B & C – Measuring 100gm of dental stone powder; D & E - Measuring 5gm of silica nanoparticles; F - Vibrator

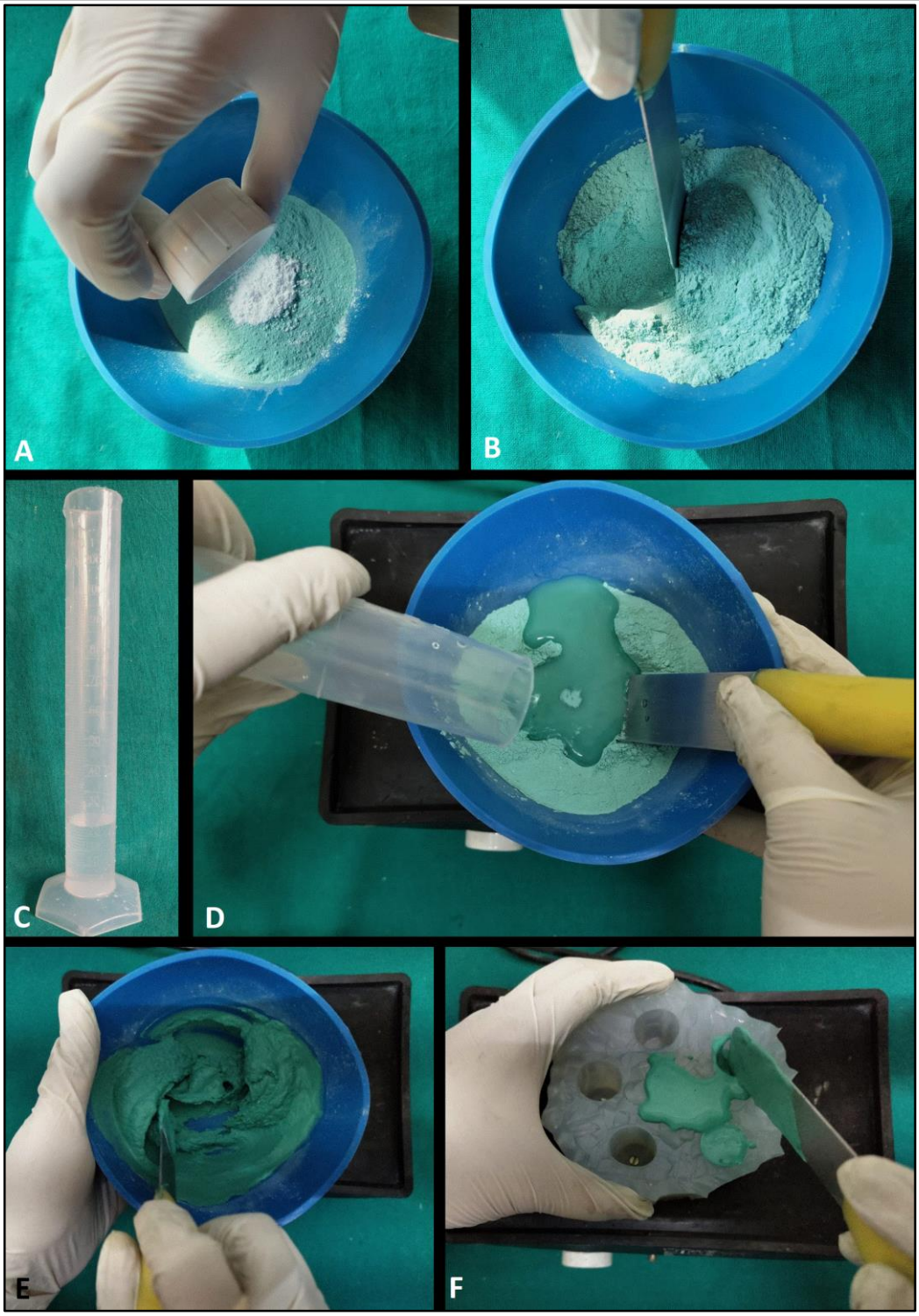


Figure 3: A & B – Mixing silica nanoparticles to dental stone powder to obtain a uniform mix; C – Measuring cylinder to measure 28 ml of distilled water; D - Distilled water being added to the powder; E & F- The stone being mechanically spatulated and poured into the silicone mold under vibration.

Figure 4: A & B – Measuring 100gm of die stone powder; C – Measuring cylinder to measure 23 ml of distilled water; D & E - Mixing silica nanoparticles to die stone powder to obtain a uniform mix; E – Distilled water being added to the powder; G & H- The stone being mechanically spatulated and poured into the silicone mold under vibration.

Figure 5: A – Die stone and dental stone samples (Control and test groups); B – Calibrating TR200 to zero; C – Measuring surface roughness of Dental stone using TR200; D - Measuring surface roughness of Die stone using TR200.

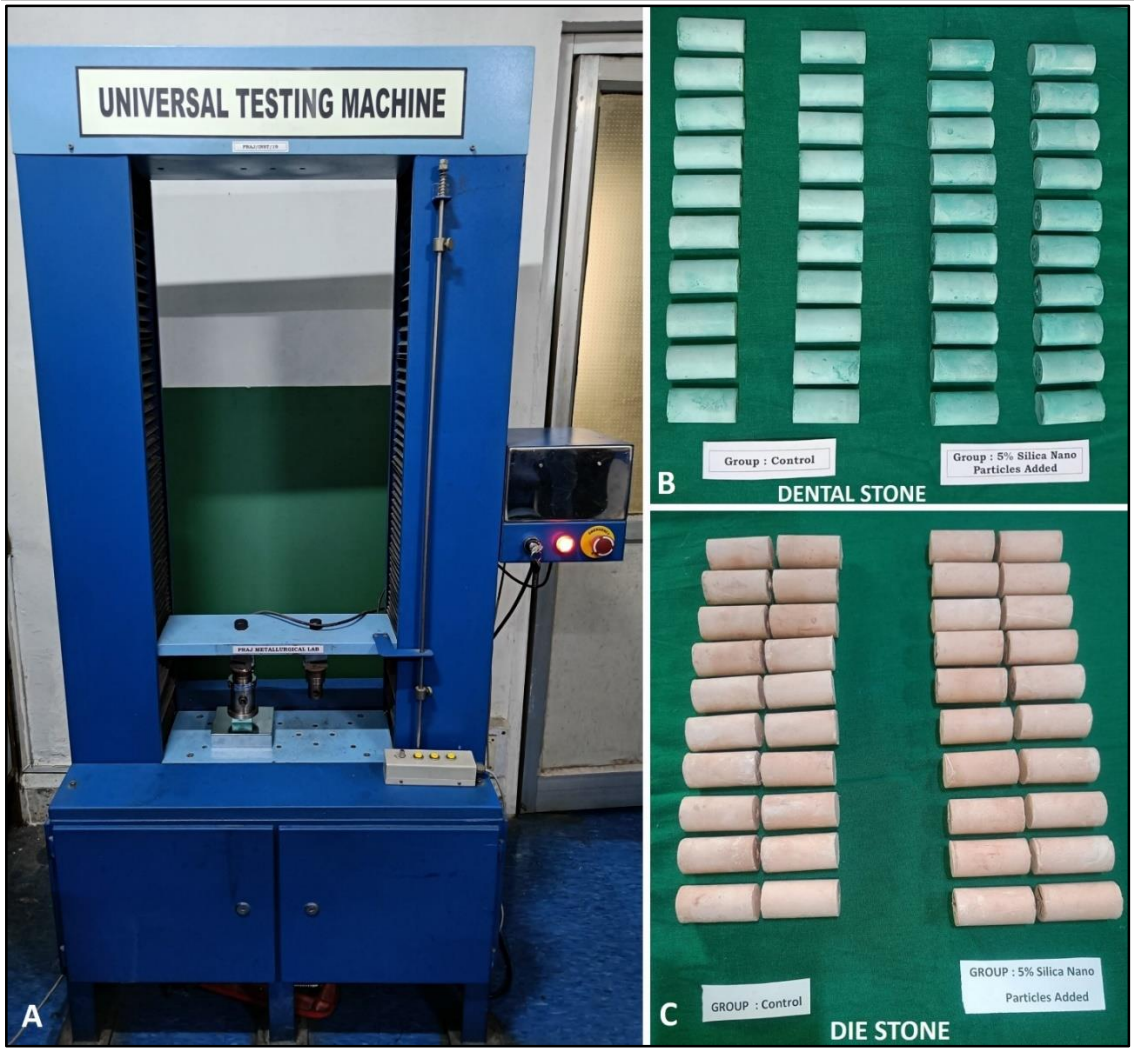


Figure 6: A – Universal testing machine (UTM) for testing Diametral tensile strength and Compressive strength of dental stone and die stone; B – Dental stone (Control and test groups); C – Die stone (Control and test groups)

Figure 7: A & B - Dental stone sample during and after Diametral tensile strength measurement using Universal testing machine; C & D - Die stone sample during and after Diametral tensile strength measurement using Universal testing machine.

Figure 8: A & B - Dental stone sample during and after compressive strength measurement using Universal testing machine; C & D - Die stone sample during and after compressive strength measurement using Universal testing machine

RESULTS AND OBSERVATION

TABLE 1: SURFACE ROUGHNESS OF DENTAL STONE IN THE CONTROL GROUP AND TEST GROUP

	Mean (µm)	**SD**	**Std Error**
Control group	3.16	0.363	0.115
Test group (5wt% silica nanoparticles added)	2.88	0.530	0.167

Table 1 describes the mean surface roughness of dental stone in the control group and test group (5wt% silica nanoparticles added). The mean surface roughness in the control group was 3.16 µm with a standard deviation of 0.363. The mean surface roughness after the addition of 5wt% silica nanoparticles was 2.88 µm with a standard deviation of 0.530.

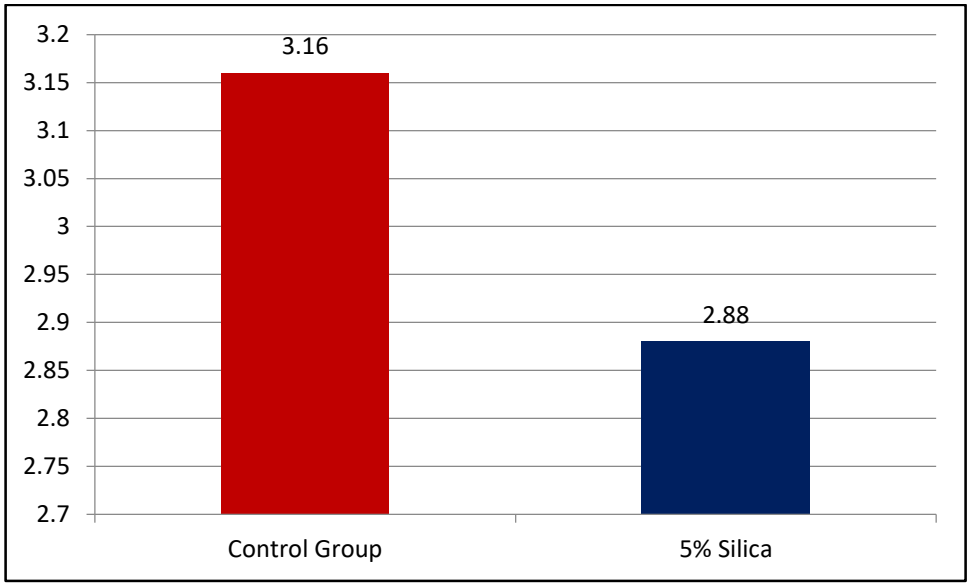


TABLE 2: INTRA-GROUP COMPARISON OF SURFACE ROUGHNESS OF DENTAL STONE IN THE CONTROL GROUP AND TEST GROUP

	Mean (µm)	SD	Std Error	P value
Control group	3.16	0.363	0.115	0.018 (Significant)
Test group (5wt% silica nanoparticles added)	2.88	0.530	0.167	

Independent t-test with p=0.05 significance level

Table 2 describes the intra-group comparison of surface roughness of dental stone between the control group and test group (5wt% silica nanoparticles added). The mean surface roughness in the control group was 3.16 µm with a standard deviation of 0.363. The mean surface roughness after the addition of 5wt% silica nanoparticles was 2.88 µm with a standard deviation of 0.530. There was a reduction in the surface roughness after the addition of 5wt% silica nanoparticles and the reduction was statistically significant with p value of 0.018 (p<0.05-significant).

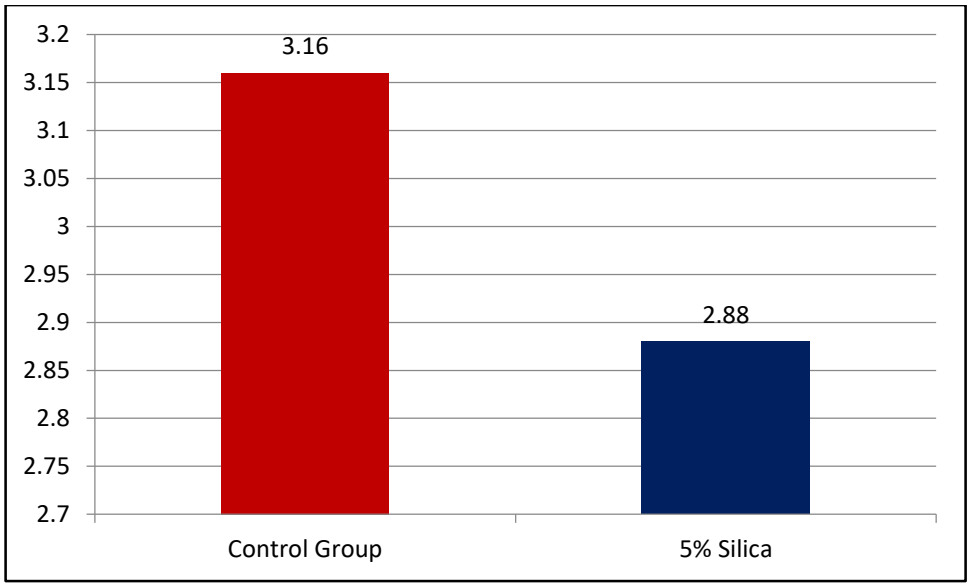


TABLE 3: SURFACE ROUGHNESS OF DIE STONE IN THE CONTROL GROUP AND TEST GROUP

	Mean (µm)	**SD**	**Std Error**
Control group	2.96	0.283	0.089
Test group (5wt% silica nanoparticles added)	2.53	0.229	0.072

Table 3 describes the mean surface roughness of die stone in the control group and test group (5wt% silica nanoparticles added). The mean surface roughness in the control group was 2.96 µm with a standard deviation of 0.283. The mean surface roughness after the addition of 5wt% silica nanoparticles was 2.53 µm with a standard deviation of 0.229.

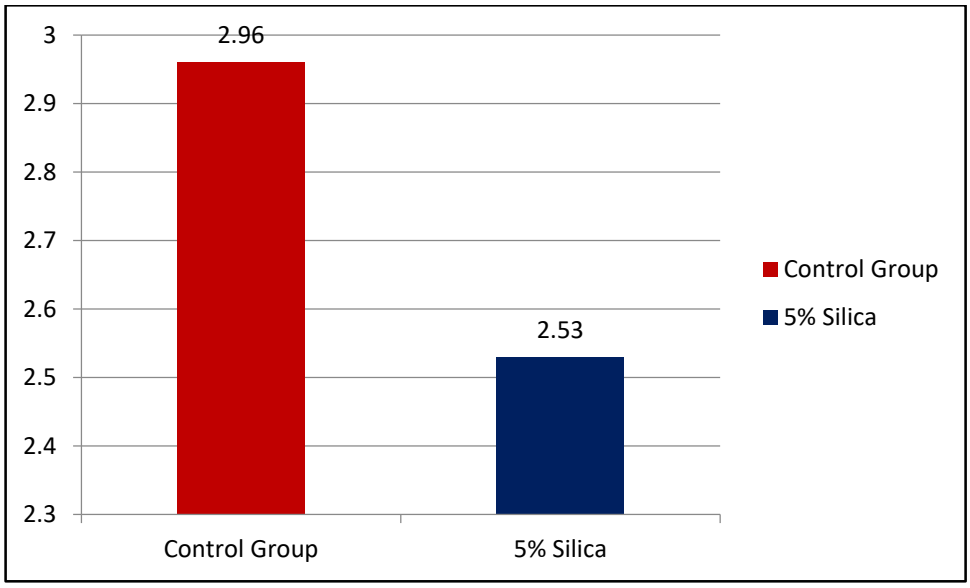


TABLE 4: INTRA-GROUP COMPARISON OF SURFACE ROUGHNESS OF DIE STONE IN THE CONTROL GROUP AND TEST GROUP

	Mean (µm)	SD	Std Error	P value
Control group	2.96	0.283	0.089	0.0018 (Significant)
Test group (5wt% silica nanoparticles added)	2.53	0.229	0.072	

Independent t-test with p=0.05 significance level

Table 4 describes the intra-group comparison of surface roughness of die stone between control group and test group (5wt% silica nanoparticles added). The mean surface roughness in the control group was 2.96 µm with a standard deviation of 0.283. The mean surface roughness after the addition of 5wt% silica nanoparticles was 2.53 µm with a standard deviation of 0.229. There was a reduction in the surface roughness after the addition of 5wt% silica nanoparticles and the reduction was statistically significant with p value of 0.0018 (p<0.05-significant).

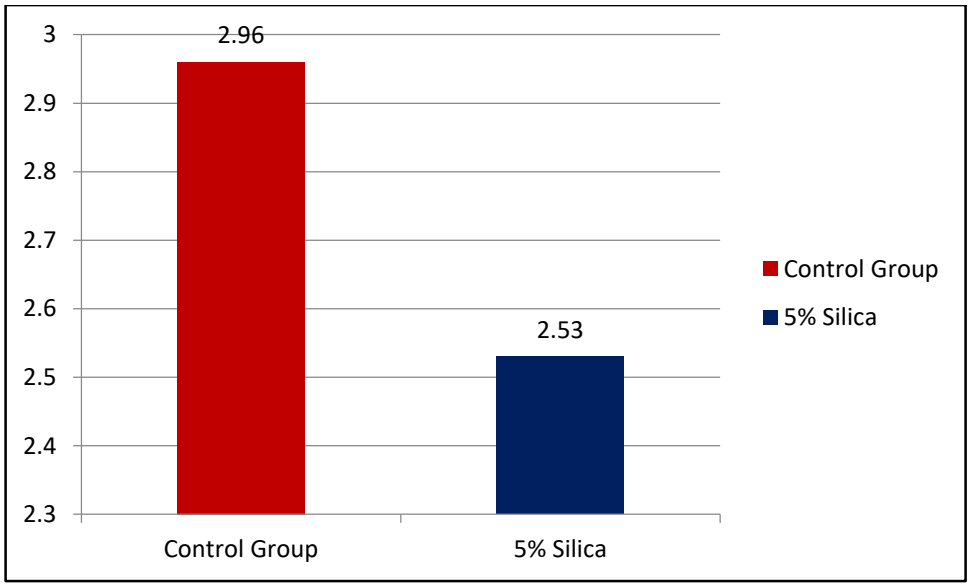


TABLE 5: DIAMETRAL TENSILE STRENGTH OF DENTAL STONE IN THE CONTROL GROUP AND TEST GROUP

	Mean (MPa)	**SD**	**Std Error**
Control group	1.29	0.238	0.075
Test group (5wt% silica nanoparticles added)	1.01	0.101	0.031

Table 5 describes the mean diametral tensile strength of dental stone in the control group and test group (5wt% silica nanoparticles added). The mean diametral tensile strength in the control group was 1.29 MPa with a standard deviation of 0.238. The mean diametral tensile strength after the addition of 5wt% silica nanoparticles was 1.01 MPa with a standard deviation of 0.101.

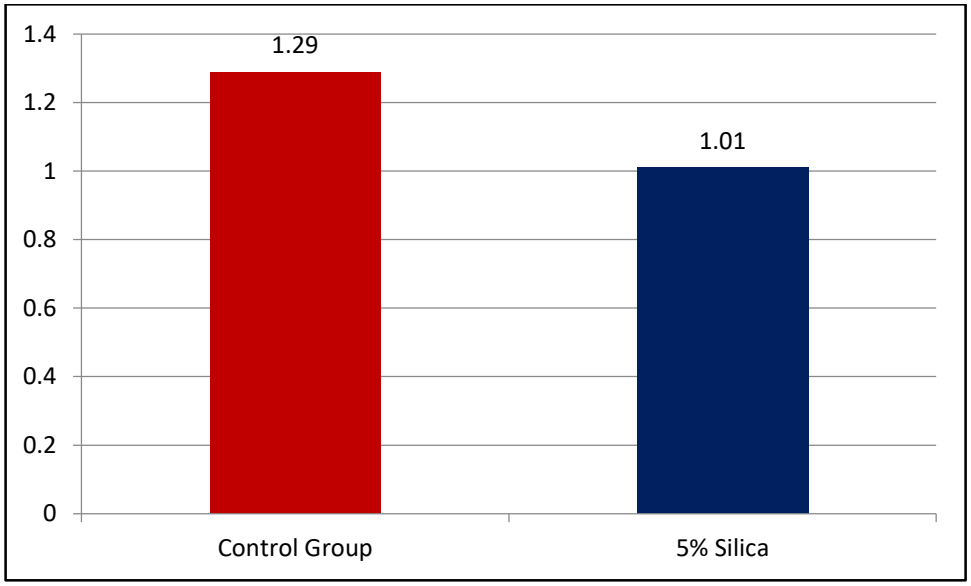


TABLE 6: INTRA-GROUP COMPARISON OF DIAMETRAL TENSILE STRENGTH OF DENTAL STONE IN THE CONTROL GROUP AND TEST GROUP

	Mean (MPa)	SD	Std Error	P value
Control group	1.29	0.238	0.075	0.003 (Significant)
Test group (5wt% silica nanoparticles added)	1.01	0.101	0.031	

Independent t-test with p=0.05 significance level

Table 6 describes the intra-group comparison of diametral tensile strength between control group and test group (5wt% silica nanoparticles added). The mean diametral tensile strength in the control group was 1.29 MPa with a standard deviation of 0.238. The mean diametral tensile strength after the addition of 5wt% silica nanoparticles was 1.01 MPa with a standard deviation of 0.101. There was a reduction in the diametral tensile strength after the addition of 5wt% silica nanoparticles and the reduction was statistically significant with p value of 0.003 ($p<0.05$-significant).

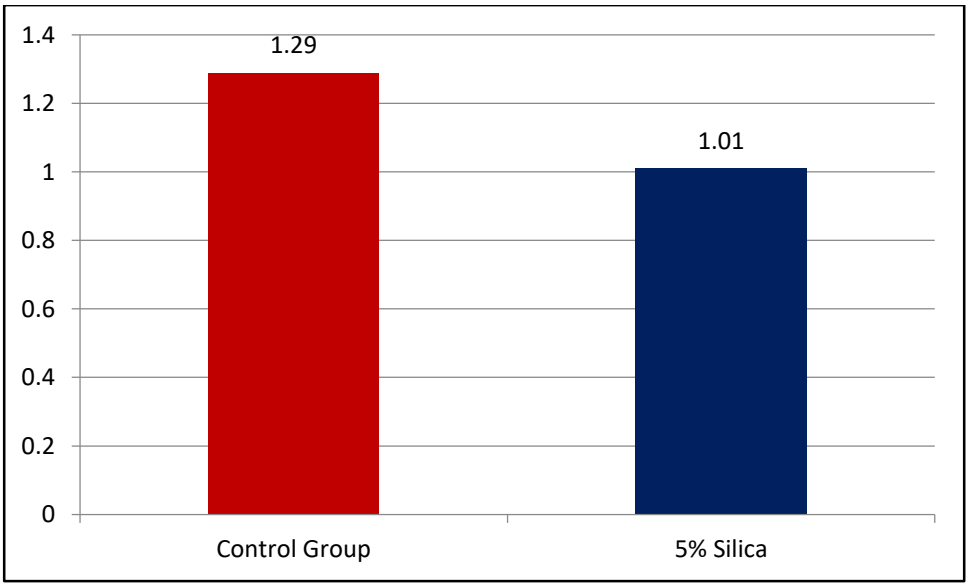


TABLE 7: DIAMETRAL TENSILE STRENGTH OF DIE STONE IN THE CONTROL GROUP AND TEST GROUP

	Mean (MPa)	**SD**	**Std Error**
Control group	1.51	0.159	0.050
Test group (5wt% silica nanoparticles added)	1.14	0.201	0.063

Table 7 describes the mean diametral tensile strength in the die stone in the control group and test group (5wt% silica nanoparticle added). The mean diametral tensile strength in the control group was 1.51 MPa with a standard deviation of 0.159. The mean diametral tensile strength after the addition of 5wt% silica nanoparticles was 1.14 MPa with a standard deviation of 0.201.

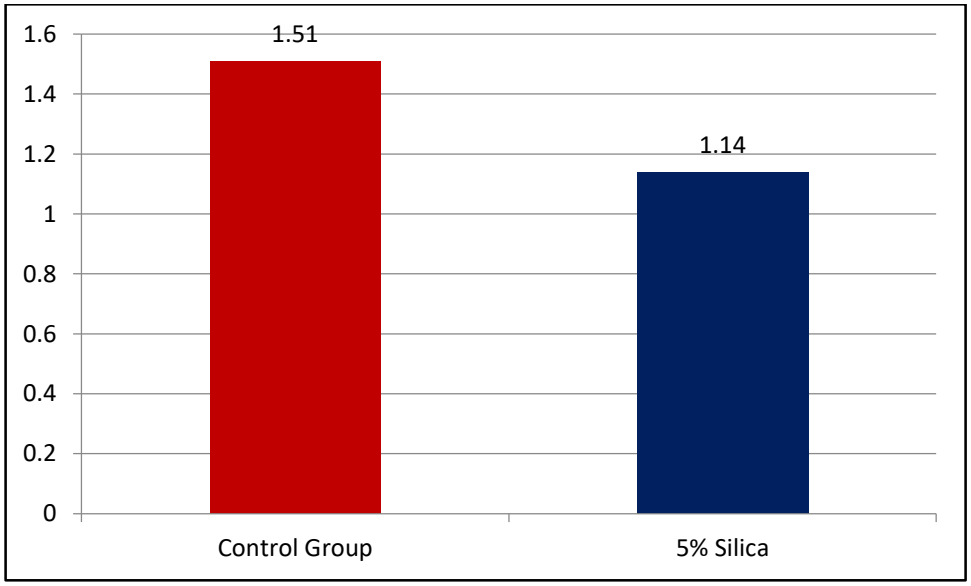


TABLE 8: INTRA-GROUP COMPARISON OF DIAMETRAL TENSILE STRENGTH OF DIE STONE IN THE CONTROL GROUP AND TEST GROUP

	Mean (MPa)	**SD**	**Std Error**	**P value**
Control group	1.51	0.159	0.050	0.0002 (Significant)
Test group (5wt% silica nanoparticles added)	1.14	0.201	0.063	

Independent t-test with p=0.05 significance level

Table 8 describes the intra-group comparison of diametral tensile strength of die stone between control group and test group (5wt% silica nanoparticle added). The mean diametral tensile strength in the control group was 1.51 MPa with a standard deviation of 0.159. The mean diametral tensile strength after the addition of 5wt% silica nanoparticles was 1.14 MPa with a standard deviation of 0.201. There was a reduction in the diametral tensile strength after the addition of 5wt% silica nanoparticles and the reduction was statistically significant with p value of 0.0002 ($p<0.05$-significant).

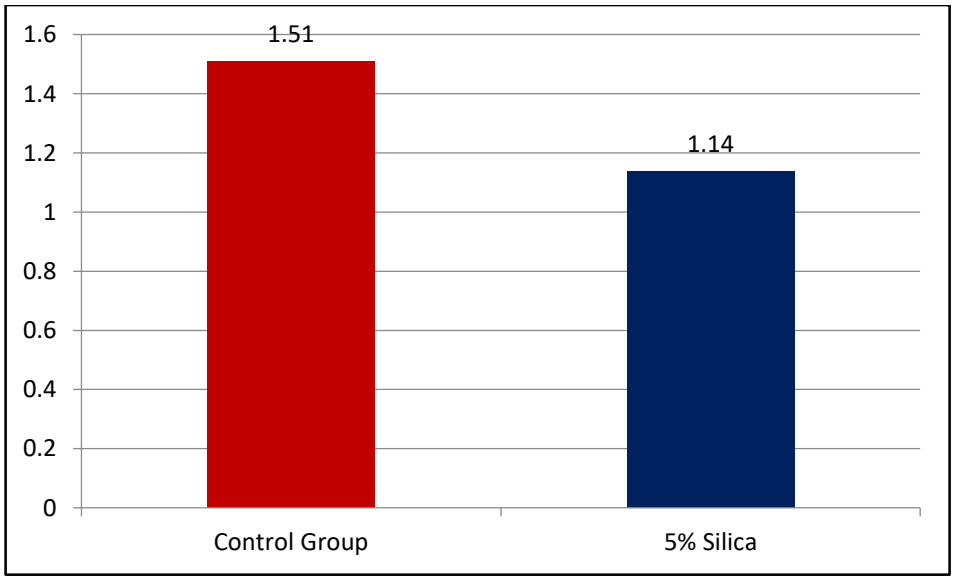


TABLE 9: COMPRESSIVE STRENGTH OF DENTAL STONE IN THE CONTROL GROUP AND TEST GROUP

	Mean (MPa)	**SD**	**Std Error**
Control group	14.02	3.503	1.107
Test group (5wt% silica nanoparticles added)	10.38	1.817	0.574

Table 9 describes the mean compressive strength of dental stone in the control group and test group (5wt% silica nanoparticle added). The mean compressive strength in the control group was 14.02 MPa with a standard deviation of 3.50. The mean compressive strength after the addition of 5wt% silica nanoparticles was 10.38 MPa with a standard deviation of 1.81.

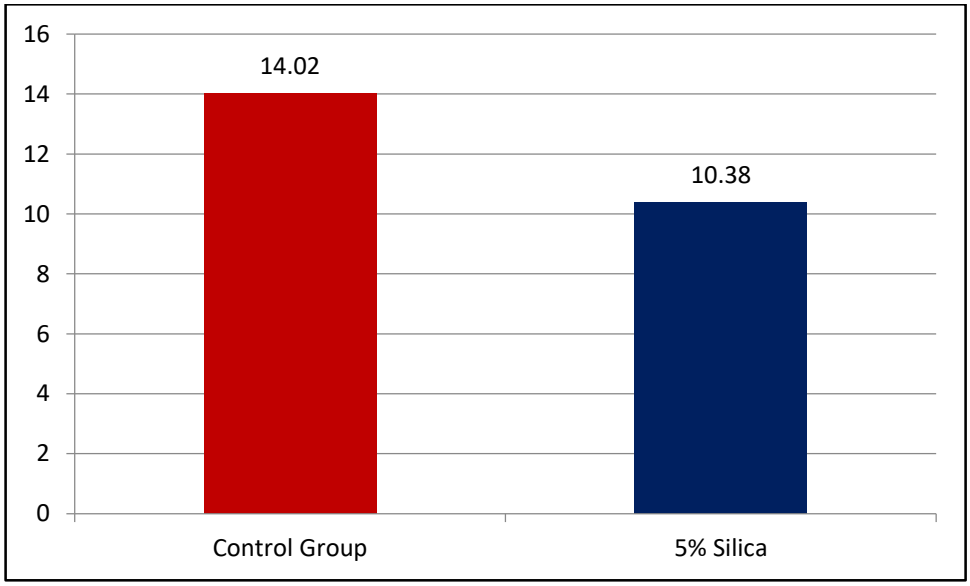


TABLE 10: INTRA-GROUP COMPARISON OF COMPRESSIVE STRENGTH OF DENTAL STONE IN THE CONTROL GROUP AND TEST GROUP

	Mean (MPa)	**SD**	**Std Error**	**P value**
Control group	14.02	3.503	1.107	0.009 (Significant)
Test group (5wt% silica nanoparticles added)	10.38	1.817	0.574	

Independent t-test with p=0.05 significance level

Table 10 describes the intra-group comparison of compressive strength of dental stone between control group and test group (5wt% silica nanoparticles added). The mean compressive strength in the control group was 14.02 with a standard deviation of 3.50. The mean compressive strength after the addition of 5wt% silica nanoparticles was 10.38 with a standard deviation of 1.81. There was a reduction in the compressive strength after the addition of 5wt% silica nanoparticles and the reduction was statistically significant with p value of 0.009 ($p<0.05$-significant).

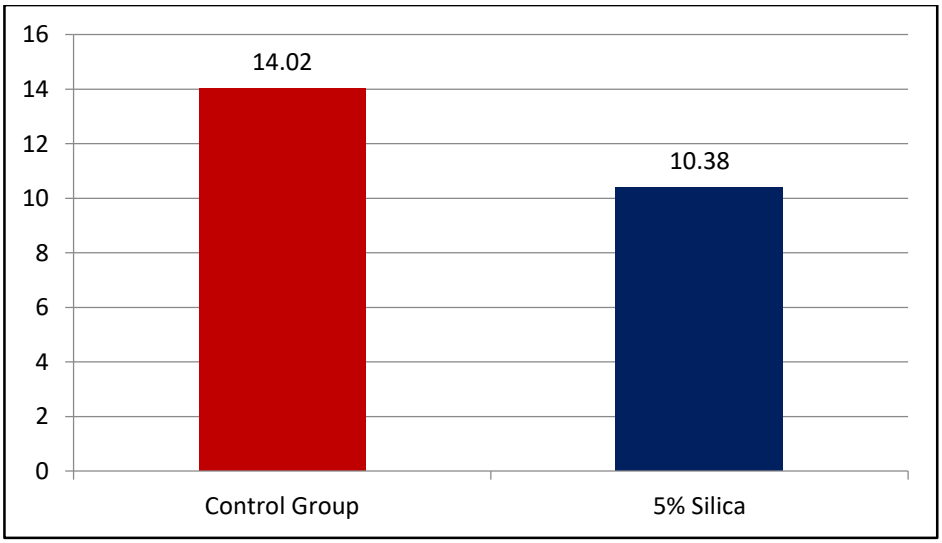


TABLE 11: COMPRESSIVE STRENGTH OF DIE STONE IN THE CONTROL GROUP AND TEST GROUP

	Mean (MPa)	**SD**	**Std Error**
Control group	16.25	3.38	1.062
Test group (5wt% silica nanoparticles added)	11.28	2.34	0.742

Table 11 describes the mean compressive strength of die stone in the control group and test group (5wt% silica nanoparticles added). The mean compressive strength in the control group was 16.25 MPa with a standard deviation of 3.38. The mean compressive strength after the addition of 5wt% silica nanoparticles was 11.28 MPa with a standard deviation of 2.34.

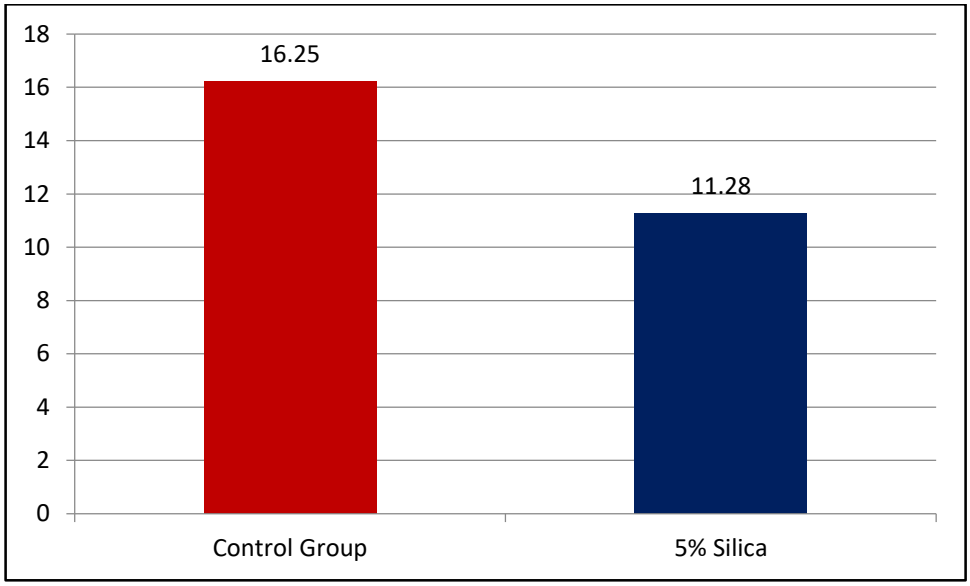


TABLE 12: INTRA-GROUP COMPARISON OF COMPRESSIVE STRENGTH OF DIE STONE IN THE CONTROL GROUP AND TEST GROUP

	Mean (MPa)	**SD**	**Std Error**	**P value**
Control group	16.25	3.38	1.062	0.0012 (Significant)
Test group (5wt% silica nanoparticles added)	11.28	2.34	0.742	

Independent t-test with p=0.05 significance level

Table 12 describes the intra-group comparison of compressive strength between control group and test group (5wt% silica nanoparticles added). The mean compressive strength in the control group was 16.25 MPa with a standard deviation of 3.38. The mean compressive strength after the addition of 5wt% silica nanoparticles was 11.28 MPa with a standard deviation of 2.34. There was a reduction in the compressive strength after the addition of 5wt% silica nanoparticles and the reduction was statistically significant with p value of 0.0012 ($p \leq 0.05$-significant)

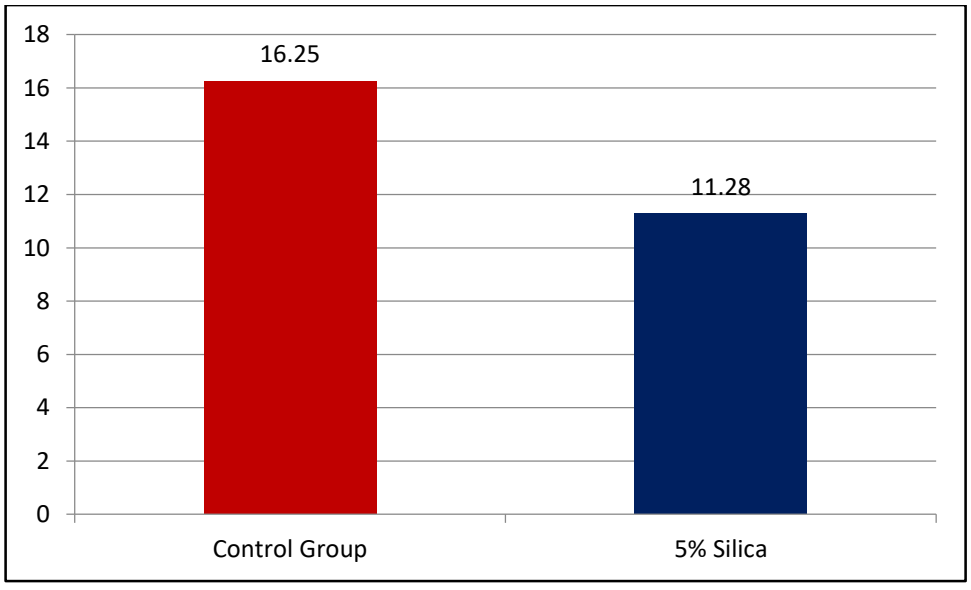


TABLE 13: INTER-GROUP COMPARISON OF CHANGE IN SURFACE ROUGHNESS BETWEEN DIE STONE AND DENTAL STONE AFTER ADDITION OF 5WT% SILICA NANOPARTICLES

	Control (µm)	Test (µm)	Mean Change (µm)	% Change	P value
Die Stone	2.96±0.28	2.53±0.22	0.43±0.41	13.61±12.67	0.417 (Non-Sig)
Dental Stone	3.16±0.36	2.88±0.553	0.27±0.43	8.82±13.05	

Independent t-test with p=0.05 significance level

In die stone, the mean surface roughness in the control group was 2.96±0.28 µm. The mean surface roughness after the addition of 5wt% silica nanoparticles was 2.53±0.22 µm. The mean change after the addition of 5wt% silica nanoparticles was 0.43±0.41 µm and the percentage change was 13.61±12.67. In dental stone, the mean surface roughness in the control group was 3.16±0.36 µm. The mean surface roughness after the addition of 5wt% silica nanoparticles was 2.88±0.553 µm. The mean change after the addition of 5wt% silica nanoparticles was 0.27±0.43 µm and the percentage change was 8.82±13.05. The inter-group comparison of the change in surface roughness after the addition of 5wt% silica nanoparticles between die stone and dental stone was statistically non-significant when analysed using independent t-test.

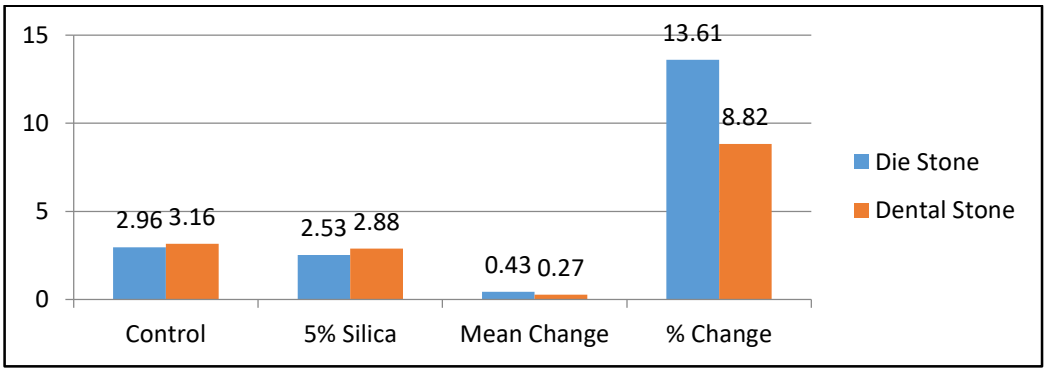


TABLE 14: INTER-GROUP COMPARISON OF CHANGE IN DIAMETRAL TENSILE STRENGTH BETWEEN DIE STONE AND DENTAL STONE AFTER ADDITION OF 5WT% SILICA NANOPARTICLES

	Control (MPa)	Test (MPa)	Mean Change (MPa)	% Change	P value
Die Stone	1.51±0.15	1.14±0.21	0.37±0.25	23.97±14.74	0.410 (Non-Sig)
Dental Stone	1.29±0.23	1.01±0.10	0.27±0.23	19.13±14,56	

Independent t-test with p=0.05 significance level

In die stone, the mean diametral tensile strength in the control group was 1.51±0.15 MPa. The mean diametral tensile strength after the addition of 5wt% silica nanoparticles was 1.14±0.21 MPa.The mean change after the addition of 5wt% silica nanoparticles was 0.37±0.25 MPa and the percentage change was 23.97±14.74. In dental stone, the mean diametral tensile strength in the control group was 1.29±0.23 MPa. The mean diametral tensile strength after the addition of 5wt% silica nanoparticles was 1.01±0.10 MPa. The mean change after the addition of 5wt% silica nanoparticles was 0.27±0.23 MPa and the percentage change was 19.13±14.56. The inter-group comparison of the change in diametral tensile strength after the addition of 5wt% silica nanoparticles between die stone and dental stone was statistically non-significant when analysed using independent t-test.

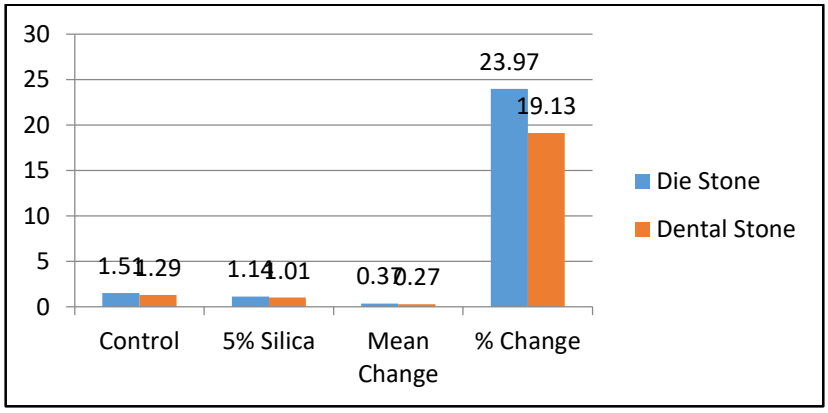
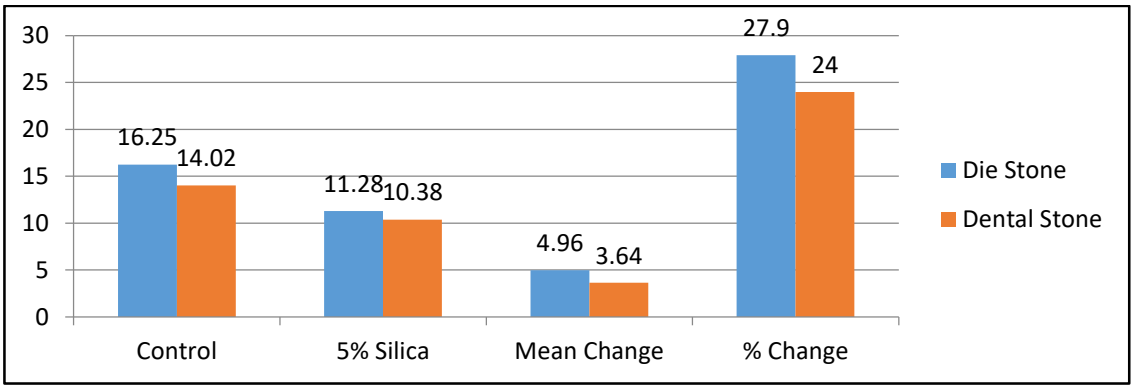


TABLE 15: INTER-GROUP COMPARISON OF CHANGE IN COMPRESSIVE STRENGTH BETWEEN DIE STONE AND DENTAL STONE AFTER ADDITION OF 5WT% SILICA NANOPARTICLES

	Control (MPa)	Test (MPa)	Mean Change (MPa)	% Change	P value
Die Stone	16.25±3.38	11.28±2.34	4.96±3.97	27.90±19.39	0.610 (Non-Sig)
Dental Stone	14.02±3.50	10.38±1.81	3.64±2.45	24.00±13.79	

Independent t-test with p=0.05 significance level

In die stone, the mean compressive strength in the control group was 16.25±3.38 MPa. The mean compressive strength after the addition of 5wt% silica nanoparticles was 11.28±2.34 MPa. The mean change after the addition of 5wt% silica nanoparticles was 4.96±3.97 MPa and the percentage change was 27.90±19.39. In dental stone, the mean compressive strength in the control group was 14.02±3.50 MPa. The mean compressive strength after the addition of 5wt% silica nanoparticles was 10.38±1.81 MPa. The mean change after the addition of 5wt% silica nanoparticles was 3.64±2.45 MPa and the percentage change was 24.00±13.79. The inter-group comparison of the change in compressive strength after the addition of 5wt% silica nanoparticles between die stone and dental stone was statistically non-significant when analysed using independent t-test.



DISCUSSION

The use of calcined gypsum has been known to humanity since time immemorial. Alternative materials like synthetic gypsum, Type V stone, epoxy resin, cyanoacrylate, and gum arabic, have been investigated to produce more precise and durable casts. Gypsum-based materials are used frequently because they are amenable to both physical and chemical modification. Dental materials have been strengthened by the addition of a variety of inorganic filler particles, including quartz, colloidal silica, silica glass containing barium and strontium, and zirconia. Commercial items often contain filler particles that come in a variety of forms and sizes and these can alter the material properties. The application of nanotechnology to the creation of dental products, with the primary objective of increasing their mechanical qualities, has resulted in a major and recent modification in inorganic fillers. [5]

Nanotechnology is the integration of nanoscale structures into sizable material components to achieve better and novel materials. A substance is referred to as a nanomaterial if it has at least one dimension in three dimensions or if its composition has been scaled down to the nanoscale (1–100 nm). [18] Nanostructured materials and nanostructured elements are the two categories into which nanomaterials are often divided. The volume, surface, and quantum effects of nanoparticles provide nanomaterials with exceptional mechanical qualities. When nanoparticles are added to a common substance, the nanoparticles will refine the grain to some extent, creating an intragranular or an intergranular structure, which will improve the grain boundary and improve the mechanical characteristics of the substance. [18] In our study, we evaluated the surface roughness, diametral tensile strength, and compressive strength of dental stone and die stone after the addition of 5wt% silica nanoparticles.

The surface roughness of the dental and die stone samples was measured using the TR200. [19] In our study, the mean surface roughness of dental stone in the control group was 3.16 ± 0.363 µm and in the test group (after the addition of 5wt% silica nanoparticles) was 2.88 ± 0.530µm. There was a reduction in the surface roughness of dental stone after the addition of 5wt% silica nanoparticles and the reduction was statistically significant with p value of 0.018. The mean surface roughness of die stone

in the control group was 2.96 ± 0.283 µm and in the test group (after addition of 5wt% silica nanoparticles) was 2.53 ± 0.229 µm. There was a reduction in the surface roughness of die stone after the addition of 5wt% silica nanoparticles and the reduction was statistically significant with p value of 0.0018.

The Durone stone's mean surface roughness in the study by De Cesero L, de Oliveira EM, Junior LH, Papaléo RM, and Mota EG in 2017 [5] was 0.55 µm. The mean surface roughness decreased after the addition of the silica nanoparticles to 0.36 µm for TGnI (1wt% silica nanoparticles) and 0.29 µm for TGnV (5wt% silica nanoparticles), with a statistically significant difference between CG (control group) and TGnI (P=.001) and between CG and TGnV (P=.001). However, there was no significant difference between the groups TGnI and TGnV (P>.05).

The average surface roughness of the Fuji Rock stone was 0.48 µm. After the silica nanoparticles were added, the mean values for TGnI and TGnV were 0.31 µm and 0.35 µm, respectively. There was a statistically significant difference between CG and TGnI (P=.001) and CG and TGnV (P<.001), but not between the test groups (P >.05).

The deposition of the nanoparticles between the stone particles in the spaces created by the absorption of water can be used to explain the improvement in the surface roughness values of the investigated stones after the addition of silica nanoparticles. The functionalization of the nanoparticles, which enables them to bind to the water molecules present in the powder/liquid mixture, is related to the deposition. Consequently, the stone surfaces grow smoother and have fewer interparticle gaps. [5]

De Cesero L, Mota EG, Burnett Jr LH, and Spohr AM [14] examined the impact of postpouring time on surface roughness, compressive strength, and diametric tensile strength of three varieties of dental stone (Durone, Fuji Rock, and Tuff Rock). At one hour, twenty-four hours, and seven days following the pour, surface roughness, compressive strength, and diametric tensile strength were evaluated. The dental stone brands' mean surface roughness measurements ranged from 0.3 µm (Durone, 1 hour) to

0.64 µm (Tuff Rock, 7 days). The surface roughness and postpouring times varied significantly between the three tested commercial brands (P<.05.)

Durone specimens were observed to have a substantial difference in roughness between them at 1 hour and 24 hours, but not between 24 hours and 7 days. For Tuff Rock, there was no discernible difference between 1 and 24 hours, but a difference between 24 hours and 7 days was observed. Time did not affect the surface roughness of the Fuji Rock dental stone. The methods used to create the small shaped particles and the sources of hemihydrates (obtained chemically or naturally from gypsum) are potential explanations for the variations in behaviour seen.

The difference in mean surface roughness values between our study and that of the published literature could be attributed to the difference in physical properties of the commercially available and routinely used brands of dental stone (Dentstone) and die stone (Kalrock) in our demographical location.

The diametral tensile strength (DTS) of the dental and die stone samples was measured using the Universal testing machine. [5] In our study, the mean diametral tensile strength of dental stone in the control group was 1.29 ± 0.238 MPa and in the test group (after addition of 5wt% silica nanoparticles) was 1.01 ± 0.101 MPa. There was reduction in the diametral tensile strength of dental stone after the addition of 5wt% silica nanoparticles and the reduction was statistically significant with p value of 0.003. The mean diametral tensile strength of die stone in the control group was 1.51 ± 0.159 MPa and in the test group (after addition of 5wt% silica nanoparticles)was 1.14 ± 0.201 MPa There was a reduction in the diametral tensile strength of die stone after addition of 5wt% silica nanoparticles and the reduction was statistically significant with p value of 0.0002.

The mean DTS (Diametral tensile strength) measured for the Durone stone in the study by De Cesero L, de Oliveira EM, Junior LH, Papaléo RM, and Mota EG in 2017 [5] was 6.0 ± 1.4 MPa. . Following silica nanoparticle addition, the mean values were 5.1 ± 0.8

MPa for TGnI and 5.0 ± 0.7 MPa for TGnV. There was no statistically significant difference between the CG and test groups (P>.05). The mean DTS for the Fuji Rock stone was 6.4 ± 0.5 MPa, which is comparable to earlier findings (7.6 ± 2.0 MPa). After the silica nanoparticles were added, the mean values for TGnI and TGnV were 5.2 ± 1.1 MPa and 4.5 ± 1.2 MPa, respectively. There was no statistically significant difference between CG and TGnI or TGnI and TGnV (P>.05). Between CG and TGnV, a statistically significant difference was discovered (P<.05).

In the study by Akkus B, Demir N, Karci M, and Yazman S. [6] in 2018, the control group's mean diametral tensile strength was 8.8 MPa. Type III dental stone with 1% SiO2 and 5% SiO2 nanoparticles had mean diametral tensile strengths of 4.9 MPa and 2.4 MPa, respectively. Dental stones with 1% Al2O3 and 5% Al2O3 nanoparticles had mean diametral tensile strengths of 4.1 MPa and 3.8 MPa, respectively.

The Type IV dental stone's mean diametral tensile strength (control group) was 8.8 MPa. Type III dental stone with 1% SiO2 and 5% SiO2 nanoparticles had mean diametral tensile strengths of 5.4 MPa and 2.1 MPa, respectively. Dental stone with 1% Al2O3 and stone with 5% Al2O3 nanoparticles had mean diametral tensile strengths of 5.9 MPa and 4.9 MPa, respectively.

The mean diametral tensile strength of Type III dental stone and Type IV dental stone control groups was the same. For Type III and Type IV dental stones, the diametral tensile strength values declined as the weight percentage of SiO2 and Al2O3 nanoparticles increased.

According to the study done in 2014 by De Cesero L, Mota EG, Burnett Jr LH, and Spohr AM [14], DTS varied considerably depending on the commercial brand and the time studied (P<.05). The strength increased as storage time after pouring increased. This study's average registered DTS for Fuji Rock at 1 hour (5.13 MPa) was higher than what was seen in the earlier tests (3.16 MPa).

In the study by De Cesero L, Mota EG, Burnett Jr LH, and Spohr AM, [14], the DTS values for Fuji rock were 5.13 ± 0.85 MPa and 7.60 ± 2.07 MPa at 1 hour and 24

hours, respectively. In contrast, DTS in the study by Casemiro LA, Hamida HM, Panzeri H, and Piresde- Souza FC [20] was 3.68 MPa after 1 hour and 3.88 MPa after 24 hours.

For Tuff rock, in the study of De Cesero L, Mota EG, Burnett Jr LH, and Spohr AM, [14] mean DTS were 3.94 ± 0.99 MPa and 7.09 ± 0.97 MPa at 1 and 24 hours, respectively, while Casemiro LA et al.[20] obtained mean DTS of 3.07 MPa and 3.26 MPa after 1 and 24 hours, respectively. These variations could be attributed to testing methodologies like specimen size, various cross-head speeds, and specimen position.

The compressive strength of the dental and die stone samples was measured using the Universal testing machine.[5] In our study, the mean compressive strength of dental stone in the control group was 14.02 ± 3.50 MPa and in the test group (after addition of 5wt% silica nanoparticles) was 10.38 ± 1.81 MPa. There was reduction in the compressive strength of dental stone after the addition of 5wt% silica nanoparticles and the reduction was statistically significant with p value of 0.009. The mean compressive strength of die stone in the control group was 16.25 ± 3.38 MPa. The mean compressive strength of die stone after the addition of 5wt% silica nanoparticles was 11.28 ± 2.34 MPa. There was reduction in the compressive strength of die stone after the addition of 5wt% silica nanoparticles and the reduction was statistically significant with p value of 0.0012.

The control group's mean compressive strength of the Durone stone in the study by De Cesero L, de Oliveira EM, Junior LH, Papaléo RM, and Mota EG was 35.4 ± 5.9 MPa.[5] The mean values for TGnI and TGnV, respectively, were 32.7 ± 10.5 MPa and 32.4 ± 3.8 MPa after the inclusion of silica nanoparticles. For Durone, there was no statistically significant difference between CG, TGnI, and TGnV (P>.05).

The control group's mean compressive strength for Fuji Rock was 42.9 ± 9.0 MPa. The mean values for TGnI and TGnV, respectively, were 31.2 ± 5.8 MPa and 29.8 ± 4.6 MPa after the addition of silica nanoparticles. Between CG and TGnI as well

as CG and TGnV, a statistically significant difference was discovered (P<.05). The test groups did not differ statistically significantly from one another (P>.05).

According to the study by Akkus B, Demir N, Karci M, and Yazman S, [6] Type III dental stone has a mean compressive strength of 50.6 MPa. Dental stone with 1% Al2O3 and 5% Al2O3 had mean compressive strength values of 21 MPa and 17.1 MPa, respectively, while dental stone with 1% SiO2 and 5% SiO2 had mean compressive strength values of 21.8 MPa and 13.9 MPa, respectively.

Type IV dental stone had a mean compressive strength of 36.1 MPa in the control group. Dental stone with 1% Al2O3 and 5% Al2O3 had mean compressive strength values of 25 MPa and 17 MPa, respectively, while dental stone with 1% SiO2 and 5% SiO2 had mean compressive strength values of 24.7 MPa and 14.2 MPa, respectively.[6] The mean compressive strength of the Type III dental stone control group was higher than that of the Type IV dental stone control group. For both Type III and Type IV dental stones, the compressive strength values declined as the weight percentage of SiO2 and Al2O3 nanoparticles increased.

In 2014, De Cesero L, Mota EG, Burnett Jr LH, and Spohr AM [14] found that the compressive strength of the three tested commercial brands varied significantly (P<.05.) The measured compressive strength of dental stones increased with postpouring time. The strength of the dry specimens was roughly twice as strong as what was discovered one hour after mixing. The authors observed that Durone at 1 hour exhibited a strength of 26.6 MPa compared with 56.4 MPa at 7 days). The compressive strength of Fuji Rock and Tuff Rock was examined by Casemiro et al, [20] who found results that were consistent with those of the aforementioned study. Compressive strength for Durone increased from 1 hour to 24 hours and 24 hours to 7 days (P<.05). From 1 hour to 24 hours, a considerable increase was seen for Fuji Rock; however, the difference between 24 hours and 7 days was not significant. The compressive strength of Tuff Rock dental stone did not rise from 1 hour to 24 hours, however, it did significantly increase from 24 hours to 7 days.

Gypsum plaster/silica composites were created in the study by Khalil AA, Tawfik A, Hegazy AA, and El-Shahat MF [10] by mixing plaster with varying percentages of various types of silica. After hydration for 7 and 28 days, their mechanical and physical characteristics, such as normal consistency, setting time, apparent porosity, bulk density, and compressive strength, were assessed. Industrial gypsum plaster, unprocessed sand,

silica fume, and anhydrous silica gel were the materials employed in this study. Gypsum plaster was blended for around 15 minutes with 0.2 to 10% of each type of silica to create plaster/silica composites.

The compressive strength of each 7-day composite was decreased by adding silica fume or silica gel. Due to the additional water required to achieve normal consistency, this effect became more pronounced as the silica content rose. In addition, some of this extra water was kept in the matrix even after 7 days since both types of silica forms were hygroscopic. Depending on the silica type supplied, different effects were seen on the compressive strength of plaster composites. Because the hydration reactions had finished and the remaining water had almost completely evaporated after 28 days, strength improved with curing time for almost all additions. [10]

In a study published in 2019, [16] Salah A, Alnori AK, and Elias MZ sought to determine the impact of various Ag (silver) nanoparticle (NP) concentrations on the compressive strength of type IV dental stones. No statistically significant difference ($P > 0.05$) was found between the wet compressive strength of dental stone for the control and additives containing 0.2%, 0.5%, 1%, 1.5%, and 2% Ag NPs. The dry compressive strength of dental stone did, however, fluctuate significantly ($P \leq 0.05$) depending on the Ag NP concentration. The compressive strength value fell as the concentration of NP additions was raised. Wet compressive strength was not significantly reduced in the majority of NP-incorporated specimens, but dry compressive strength was significantly reduced as NP concentration increased.

During the fabrication of tooth stone specimens with the additives, a decrease in compressive strength was seen when compared to the control specimens. This may be due to the following reasons:- [16]

- reduced cohesion between the gypsum crystals due to a decrease in the number of gypsum crystals as a result of increased concentration of additives in stone materials,
- mild increase in the water ratio during mixing.

Because water causes pores to form inside the material, which weakens it because there are fewer crystals by volume, the increase in the water-powder ratio had a substantial impact on compressive strength. The compressive strength is inversely proportional to the water/powder ratio, i.e greater the water/powder ratio, the lesser the dry strength of the material. The greater the water/powder ratio, more will be the free water content in the set material, leading to fewer nuclei of crystallization per unit volume causing a decrease in the strength of the material.

The stones were filled with silica nanoparticles, an inorganic filler, to enhance their mechanical properties.[5] Because it had been successfully incorporated into several commercial and experimental dental materials, this filler was chosen. Several factors have an impact on the mechanical characteristics of dental stones. The strength of the stones is fundamentally influenced by the water/powder ratio as well as the temperature of the water used in the spatulation. The duration and mode of spatulation (manual or mechanical) are also important factors affecting the mechanical characteristics of dental stones, particularly compressive strength and DTS. The qualities of dental stones are influenced by the size and shape of their particles, as well as by any additions that modify the setting time. The findings of the study might be impacted by the silica nanoparticles' size, functionalization, and various particle concentrations added to the stones.

Limitations of the study

The various limitations of our study include:

- Usage of locally available commercial brands of dental stone (Dentstone) and die stone (Kalrock) which might have different physical and mechanical properties to the other commercial brands of stone used in previously published literature.
- Lack of functionalization of silica nanoparticles (addition of a chemical reagent to enable chemical bonding between the silica nanoparticles and water within the powder/liquid mixture) in the current study which might have improved the results of the mechanical tests.

Since this was an in-vitro study, further studies should be advocated and conducted with varying percentages of silver nanoparticles to determine the optimum required level. Future studies should aim to incorporate the functionalization of silica nanoparticles which might alter the present results.

CONCLUSION

Addition of silica nanoparticles to dental stone and die stone are known to improve their physical and mechanical properties as has been described in the literature. In our study, there was:-

- Reduction in the surface roughness of both dental stone and die stone after the addition of 5wt% silica nanoparticles and the reduction was statistically significant for both.
- Reduction in the diametral tensile strength of both dental stone and die stone after the addition of 5wt% silica nanoparticles which was statistically significant for both.
- Reduction in the compressive strength of both dental stone and die stone after addition of 5wt% silica nanoparticles and the reduction was statistically significant for both the groups.

BIBLIOGRAPHY

1. Felsing WA, Potter AD. Gypsum and gypsum products. Journal of Chemical Education. 1930 Dec;7(12):2788.
2. Karni J, Karni EY. Gypsum in construction: origin and properties. Materials and Structures. 1995 Mar;28(2):92-100.
3. Anusavice KJ, Shen C, Rawls HR, editors. Gypsum products. Phillips' Science of Dental Materials. 12th Edition. Missouri (US) E-Book. Elsevier Saunders publishers; 2013. 17.p.191-192.
4. Hamdy T. Effect of aluminum oxide addition on compressive strength, microhardness and setting expansion of dental plaster. Int J Adv Res. 2019;7(9):652-7.
5. De Cesero L, de Oliveira EM, Junior LH, Papaléo RM, Mota EG. The addition of silica nanoparticles on the mechanical properties of dental stone. The Journal of prosthetic dentistry. 2017 Oct 1;118(4):535-9.
6. Akkus B, Demir N, Karci M, Yazman S. Compressive and diametral tensile strength of dental stones with SiO2 and Al2O3 nanoparticles. Int J Med Sci Innov Res. 2018;3(5):139-47.
7. Wang S, Zhang S, Song H, Chen Y. Surface roughness improvement of the bent thin-walled copper tube by controlling the microstructure and texture components. Procedia Manufacturing. 2020 Jan 1;50:613-7.
8. Della Bona Á, Benetti P, Borba M, Cecchetti D. Flexural and diametral tensile strength of composite resins. Brazilian oral research. 2008;22:84-9.
9. Aljubori OM, Aljafery AM, Al-Mussawi RA. Evaluation the Linear Dimensional Changes and Hardness of Gypsum Product/Stone Type IV after Adding Silica Nanoparticles. Nano Biomedicine & Engineering. 2020 Jul 1;12(3).
10. Khalil AA, Tawfik A, Hegazy AA, El-Shahat MF. Effect of different forms of silica on the physical and mechanical properties of gypsum plaster composites. Materiales de construcción. 2013 Dec 30;63(312):529-37.
11. Aghbolaghi N, Maleki Dizaj S, Negahdari R, Jamei Khosroshahi AR, Rezaei Y, Bohlouli S, Ghavimi MA. Effect of Adding Silica Nanoparticles on the Physicochemical Properties, Antimicrobial Action, and the Hardness of Dental Stone Type 4. International Journal of Dentistry. 2022 Apr 26;2022

12. Mitra SB, Wu D, Holmes BN. An application of nanotechnology in advanced dental materials. The Journal of the American Dental Association. 2003 Oct 1;134(10):1382-90.
13. Michalakis KX, Asar NV, Kapsampeli V, Magkavali-Trikka P, Pissiotis AL, Hirayama H. Delayed linear dimensional changes of five high strength gypsum products used for the fabrication of definitive casts. The Journal of prosthetic dentistry. 2012 Sep 1;108(3):189-95.
14. De Cesero L, Mota EG, Burnett Jr LH, Spohr AM. The influence of postpouring time on the roughness, compressive strength, and diametric tensile strength of dental stone. The Journal of prosthetic dentistry. 2014 Dec 1;112(6):1573-7
15. Tripathi A, Gupta A, Bagchi S, Mishra L, Gautam A, Madhok R. Comparison of the effect of addition of cyanoacrylate, epoxy resin, and gum arabic on surface hardness of die stone. Journal of Prosthodontics. 2016 Apr;25(3):235-40.
16. Salah A, Alnori AK, Elias MZ. Compressive Strength of Type IV Dental Stone With Ag Nanoparticles. Al-Rafidain Dental Journal. 2019 Dec 1;19(1):60-9.
17. Tsardaka EC, Stefanidou M. Testing nano-silica and nano-alumina additions for enhancing the durability of cement and lime pastes. Materials Today: Proceedings. 2021 Jan 1;37:4082-90.
18. Wu Q, Miao WS, Gao HJ, Hui D. Mechanical properties of nanomaterials: A review. Nanotechnology Reviews. 2020 Jan 1;9(1):259-73.
19. Mazumdar P, Chowdhury D. An In Vitro Comparative Evaluation of Surface Roughness Of Different Restorative Materials Using A Dentifrice And A Customised Automated Tooth Brushing Machine. Baba Farid University Dental Journal. 2018;8(1):1-6.
20. Casemiro LA, Hamida HM, Panzeri H, Piresde- Souza FC. Materials for molding: assessing the setting time, tensile and compressive strengths, and particles (SEM). Rev Odon Cien 2006;21:207-11.

APPENDICES

APPENDIX I

Babu Banarasi Das University
Babu Banarasi Das College of Dental Sciences,
BBD City, Faizabad Road, Lucknow – 226028 (INDIA)

Dr. Lakshmi Bala
Professor and Head Biochemistry and
Member-Secretary, Institutional Ethics Committee

Communication of the Decision of the IXth Institutional Ethics Sub-Committee

IEC Code: 22 **BBDCODS/04/2022**

Title of the Project: Analysing the effect of addition of silica nanoparticles on mechanical properties of dental stone and die stone: An in vitro study.

Principal Investigator: Dr Rusa Sannigrahi **Department:** Prosthodontics and Crown & Bridge

Name and Address of the Institution: BBD College of Dental Sciences Lucknow.

Type of Submission: New, MDS Project Protocol

Dear Dr Rusa Sannigrahi,

The Institutional Ethics Sub-Committee meeting comprising following four members was held on 07th April, 2022.

1.	Dr. Lakshmi Bala Member Secretary	Prof. and Head, Department of Biochemistry, BBDCODS, Lucknow
2.	Dr. Amrit Tandan Member	Prof. & Head, Department of Prosthodontics and Crown & Bridge, BBDCODS, Lucknow
3.	Dr. Rana Pratap Maurya Member	Reader, Department of Orthodontics, BBDCODS, Lucknow
4.	Dr. Akanksha Bhatt Member	Reader, Department of Conservative Dentistry & Endodontics, BBDCODS, Lucknow

The committee reviewed and discussed your submitted documents of the current MDS Project Protocol in the meeting.
The comments were communicated to PI thereafter it was revised.

Decisions: The committee approved the above protocol from ethics point of view.

Forwarded by:

Lakshmi Bala

(Dr. Lakshmi Bala)
Member-Secretary
IEC

Member-Secretary
Institutional Ethic Committee
BBD College of Dental Sciences
BBD University
Faizabad Road, Lucknow-226028

(Dr. Puneet Ahuja)
Principal
BBDCODS

PRINCIPAL
Babu Banarasi Das College of Dental Sciences
(Babu Banarasi Das University)
BBD City, Faizabad Road, Lucknow-226028

APPENDIX II

BABU BANARASI DAS COLLEGE OF DENTAL SCIENCES (FACULTY OF BBD UNIVERSITY), LUCKNOW

INSTITUTIONAL RESEARCH COMMITTEE APPROVAL

The project titled **"Analysing the Effect of Addition of Silica Nanoparticles on Mechanical Properties of Dental Stone and Die Stone: An In Vitro Study"** submitted by **Dr Rusa Sannigrahi** Post graduate student from the **Department of Prosthodontics and Crown & Bridge** as part of MDS Curriculum for the academic year 2020-2023 with the accompanying proforma was reviewed by the Institutional Research Committee present on **12th October 2021** at BBDCODS.

The Committee has granted approval on the scientific content of the project. The proposal may now be reviewed by the Institutional Ethics Committee for granting ethical approval.

Prof. Vandana A Pant
Co-Chairperson

Prof. B. Rajkumar
Chairperson

APPENDIX III

BBD UNIVERSITY

BABU BANARASI DAS COLLEGE OF DENTAL SCIENCES
BBD UNIVERSITY, LUCKNOW – 226028

To,
Mr. Apurva Anand,
Professor and Dean,
School of Engineering,
BBD University

Respected Sir,

This is to inform you that our PG student, Dr. Rusa Sannigrahi is pursuing MDS in Prosthodontics, Crown & Bridge and Implantology department from this college. She is doing her thesis on **"ANALYSING THE EFFECT OF ADDITION OF SILICA NANOPARTICLES ON MECHANICAL PROPERTIES OF DENTAL STONE AND DIE STONE: AN IN VITRO STUDY".**

As part of her thesis protocol, she will require measurement of the Surface Roughness of her dental material samples using TR200 Machine which is available in your department. I request you to kindly allow her work in your department under you able guidance.

This research is not funded by any organization.

Thanking you,
Yours sincerely,

Dr. Puneet Ahuja
Principal,
Babu Banarasi College of Dental Sciences
BBD University
Lucknow – 226028

PRINCIPAL
Babu Banarasi Das College of Dental Sciences
(Babu Banarasi Das University)
BBD City, Faizabad Road, Lucknow-226028

APPENDIX IV

BBD UNIVERSITY

TO WHOM IT MAY CONCERN

This is to certify that Dr. Rusa Sannigrahi, a postgraduate student in the Department of Prosthodontics, Crown & Bridge and Implantology, Babu Banarasi Das College of Dental Sciences, Lucknow has successfully completed her thesis-related research work on Surface roughness testing of Dental stone and Die stone in the Department of Mechanical Engineering, Babu Banarasi Das Institute of Technology and Management (BBDITM), BBD University under my supervision.

Title of her thesis - ANALYSING THE EFFECT OF ADDITION OF SILICA NANOPARTICLES ON MECHANICAL PROPERTIES OF DENTAL STONE AND DIE STONE: AN IN VITRO STUDY.

No. of samples tested – 40

Date: 20/12/2022

Signature & Seal…

Dean (School of Engineering)
BBD University
Lucknow

APPENDIX V

PRAJ
Metallurgical Laboratory
B-38, Indira Shankar Nagari,
Paud Road, Near Kothrud PMT Depo,
Kothrud, Pune - 411 038.
Tel.: +91 - 20 - 2528 1584,
Cell : 96650 11314, 9158658634
E-mail : prajdental@gmail.com
Website: www.prajlab.com

DENTAL MATERIAL TEST FACILITY
MDS Thesis in various fields
i.e. Orthodontic, Prosthodontics, Endodontics, Periodontics, Oral Surgery, etc.

Date: 14/12/2022

CERTIFICATE

This is to certify that **Dr. Rusa Sannigrahi** a post graduate student from Babu Banarasi Das University, Lucknow, U.P.has completed research work at Praj Metallurgical Laboratory on the subject "Analysing the effect of addition of Silica Nanoparticles on mechanical properties of Dental Stone and Die Stone : An in vitro study.."

No of samples tested : 80 Nos.

A.M.BHAGAT

PROPRIETOR

PRAJ METALLURGICAL LABORATORY ★ PUNE

APPENDIX VI

NRL® A NANOTECHNOLOGY PRODUCTS

NANO RESEARCH LAB

ISO 9001:2015 CERTIFIED

CERTIFICATE OF ANALYSIS

Silicon Oxide Nanoparticles
(SiO2, Purity : 99.9%, APS : 30-50nm)
CAS # 7631-86-9

Nanoparticles Name	: Silicon Oxide Nanoparticles
Molecular Formula	: SiO2
CAS Number	: 7631-86-9
Purity	: 99.9%
APS	: 30-50 nm
Form	: Powder
Colour	: White
SSA	: 200-600 m2/g
Molecular Weight	: 60.08 g/mol
Morphology	: Spherical
Density	: 0.02 - 0.1 g/cm3
Milting Point	: >1600 °C
Boiling Point	: 2230 °C

Silicon dioxide Nanoparticles Certificate of Analysis -%

SiO2	Al	Fe	Mg	Ca
99.9%	0.02%	0.05%	0.1%	0.08%

H21,Gopalpur,Jadugoda,(E)Singhbhum,Jamshedpur,Jharkhand-832102India,
nanoresearchlab@hotmail.com,www.nanoresearchlab.in, M- 9113197337

WHO GMP CERTIFIED — FDA COMPLIANCE — CE

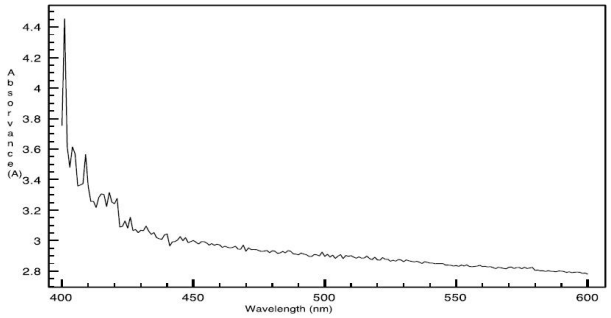


Fig 1 : UV Spectrometer analysis

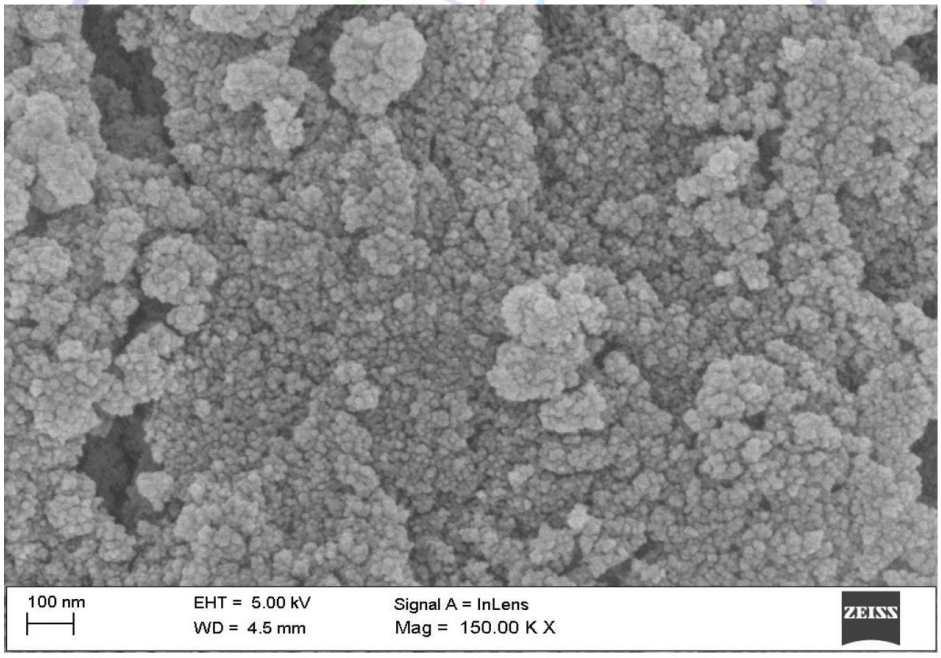


Fig 2 : SEM image of SiO2 Nanoparticles

H21,Gopalpur,Jadugoda,(E)Singhbhum,Jamshedpur,Jharkhand-832102India,
nanoresearchlab@hotmail.com,www.nanoresearchlab.in, M- 9113197337

APPENDIX VII

Surface roughness (Ra) of Dental stone

Sample dimension: 20mm, Thickness: 40mm

Sr. No.	Control group	Test Group: 5wt% silica nanoparticles added
	Surface roughness (µm)	Surface roughness (µm)
1.	3.37	3.30
2.	3.48	2.49
3.	2.70	2.25
4.	3.26	2.79
5.	3.68	3.38
6.	2.77	2.81
7.	3.14	3.66
8.	3.34	3.41
9.	3.22	2.69
10.	2.60	2.09

APPENDIX VIII

Surface roughness (Ra) of Die stone

Sample dimension: 20mm, Thickness: 40mm

Sr. No.	Control group	Test Group: 5wt% silica nanoparticles added
	Surface roughness (µm)	Surface roughness (µm)
1.	2.94	2.73
2.	3.05	2.24
3.	2.83	2.66
4.	2.92	2.37
5.	3.02	2.52
6.	3.40	2.44
7.	2.70	2.95
8.	2.87	2.77
9.	3.44	2.40
10.	2.52	2.31

APPENDIX IX

Diametral tensile strength (MPa) of Dental stone

Sample dimension: 20mm, Thickness: 40mm

Cross head speed: 0.5mm/minute; Area: 2513.28mm^2

Control Group				**Test Group: 5wt% silica nanoparticles added**		
Sr. No.	**Maximum Load (N)**	**Diametral Tensile Strength (MPa)**		**Sr. No.**	**Maximum Load (N)**	**Diametral Tensile Strength (MPa)**
1	3575.5	1.42		1	2680.0	1.06
2	3355.0	1.33		2	2495.5	0.99
3	3272.0	1.30		3	2587.0	1.02
4	4423.0	1.75		4	2595.0	1.03
5	2367.0	0.94		5	2020.0	0.80
6	3803.0	1.51		6	2400.0	0.95
7	2981.0	1.18		7	2450.0	0.97
8	3347.5	1.33		8	2904.5	1.15
9	2741.5	1.09		9	2870.0	1.14
10	2642.5	1.05		10	2666.0	1.06

Formula for Diametral tensile strength: $2P/\pi DT$

Where, P = Load Applied in N, $A = \pi DT$, $\pi = 3.1416$,

D = Diameter of the specimen, T = Thickness of the specimen

APPENDIX X

Diametral tensile strength (MPa) of Die stone

Sample dimension: 20mm, Thickness: 40mm

Cross head speed: 0.5mm/minute; Area: 2513.28mm^2

Control Group				**Test Group: 5wt% silica nanoparticles added**		
Sr. No.	**Maximum Load (N)**	**Diametral Tensile Strength (MPa)**		**Sr. No.**	**Maximum Load (N)**	**Diametral Tensile Strength (MPa)**
1	3850	1.53		1	4200	1.67
2	3910	1.55		2	2850	1.13
3	3850	1.53		3	2900	1.15
4	3380	1.34		4	2810	1.11
5	3900	1.55		5	2680	1.06
6	4100	1.63		6	2950	1.17
7	4200	1.67		7	2470	0.98
8	4450	1.77		8	2640	1.05
9	3350	1.33		9	2950	1.17
10	3200	1.27		10	2380	0.94

Formula for Diametral tensile strength: $2P/\pi DT$

Where, P = Load Applied in N, $A = \pi DT$, $\pi = 3.1416$,

D = Diameter of the specimen, T = Thickness of the specimen.

APPENDIX XI

Compressive strength (MPa) of Dental stone

Sample dimension: 20mm, Thickness: 40mm

Cross head speed: 0.5mm/minute; Area: 314.28mm^2

Control Group				**Test Group: 5wt% silica nanoparticles added**		
Sr. No.	**Maximum Load (N)**	**Compressive Strength (MPa)**		**Sr. No.**	**Maximum Load (N)**	**Compressive Strength (MPa)**
1	3782.0	12.03		1	3205.5	10.20
2	4818.5	15.33		2	3901.0	12.41
3	3489.5	11.10		3	2539.0	8.07
4	6222.0	19.80		4	4018.0	12.79
5	3168.5	10.08		5	3401.5	10.82
6	3441.0	10.95		6	2665.5	8.48
7	6092.5	19.38		7	3906.5	12.43
8	4324.5	13.76		8	2563.0	8.15
9	5037.5	16.03		9	3477.5	11.06
10	3699.0	11.77		10	2950.5	9.39

Formula for Compressive strength: $F/\pi r^2$

Where, F= Load Applied in N, $\pi = 3.1416$, r = Radius of the specimen

APPENDIX XII

Compressive strength (MPa) of Die stone

Sample dimension: 20mm, Thickness: 40mm

Cross head speed: 0.5mm/minute; Area: 314.28mm^2

Control Group				Test Group: 5wt% silica nanoparticles added		
Sr. No.	**Maximum Load (N)**	**Compressive Strength (MPa)**		**Sr. No.**	**Maximum Load (N)**	**Compressive Strength (MPa)**
1	3377	10.74		1	2830	9.00
2	4402	14.00		2	3450	10.97
3	3876	12.33		3	4100	13.04
4	6100	19.40		4	2750	8.75
5	5700	18.13		5	3600	11.45
6	6100	19.40		6	4160	13.23
7	4600	14.63		7	2900	9.22
8	5752	18.30		8	4950	15.75
9	6512	20.72		9	2820	8.97
10	4670	14.85		10	3930	12.50

Formula for Compressive strength: $F/\pi r^2$

Where, F= Load Applied in N, $\pi = 3.1416$, r = Radius of the specimen

APPENDIX XIII

TOOLS FOR STATISTICAL ANALYSIS

The data for the present study was entered in Microsoft Excel 2007 and analysed using the SPSS statistical software 23.0 Version. The descriptive statistics included mean and standard deviation. The level of significance for the present study was fixed at 5%.

The intergroup comparison for the difference in mean scores between two independent groups was done using the unpaired/independent t-test.

The Shapiro–Wilk test was used to investigate the distribution of the data and Levene's test to explore the homogeneity of the variables. The data were found to be homogeneous and normally distributed. Mean and standard deviation (SD) were computed for each variable.

Mean

$$\overline{X} = \frac{\Sigma X}{N}$$

Where:

$\overline{X}$ = the data set mean

$\sum$ = the sum of

X = the scores in the distribution

N = the number of scores in the distribution

Range

$$range = X_{highest} - X_{lowest}$$

Where:

$X_{highest}$ = largest score

X_{lowest} = smallest score

Variance

$$SD^2 = \frac{\Sigma(X - \overline{X})^2}{N}$$

The simplified variance formula

$$SD^2 = \frac{\Sigma X^2 - \frac{(\Sigma X)^2}{N}}{N}$$

Where:

SD^2 = the variance

$\sum$ = the sum of

X = the obtained score

$\overline{X}$ = the mean score of the data

N = the number of scores

Standard Deviation (N)

$$SD = \sqrt{\frac{\Sigma(X - \overline{X})^2}{N}}$$

The simplified standard deviation formula

$$SD = \sqrt{\frac{\Sigma X^2 - \frac{(\Sigma X)^2}{N}}{N}}$$

Where:

SD = the standard deviation

$\sum$ = the sum of

X = the obtained score

$\overline{X}$ = the mean score of the data

N = the number of scores

Independent t-test

An independent t-test can be used to determine if two sets of data are significantly different from each other, and is most commonly applied when the test statistic would follow a normal distribution. The independent samples *t*-test is used when two separate sets of independent and identically distributed samples are obtained, one from each of the two populations being compared

$$t = \frac{\overline{X}_1 - \overline{X}_2}{\sqrt{\left(\frac{(N_1 - 1)s_1^2 + (N_2 - 1)s_2^2}{N_1 + N_2 - 2}\right)\left(\frac{1}{N_1} + \frac{1}{N_2}\right)}}$$

Where X1 =Mean of the first Group, X2 =Mean of the Second Group

APPENDIX XIV

Ouriginal

Document Information

Analyzed document	RUSA - THESIS - FINAL - edited on 9th feb.pdf (D158310320)
Submitted	2/10/2023 9:27:00 AM
Submitted by	Dr. Swati Gupta
Submitter email	drswatigupta30@bbdu.ac.in
Similarity	0%
Analysis address	drswatigupta30.bbduni@analysis.urkund.com

Sources included in the report

Entire Document

"ANALYSING THE EFFECT OF ADDITION OF SILICA NANOPARTICLES ON MECHANICAL PROPERTIES OF DENTAL STONE AND DIE STONE: AN IN VITRO STUDY" Dissertation Submitted to BABU BANARASI DAS UNIVERSITY, LUCKNOW, UTTAR PRADESH In partial fulfilment of the requirements for the degree of MASTER OF DENTAL SURGERY IN PROSTHODONTICS, CROWN & BRIDGE AND IMPLANTOLOGY BY DR. RUSA SANNIGRAHI Under the guidance of DR. MANOJ UPADHYAY READER DEPARTMENT OF PROSTHODONTICS, CROWN & BRIDGE AND IMPLANTOLOGY BABU BANARASI DAS COLLEGE OF DENTAL SCIENCES, LUCKNOW (Faculty of Babu Banarasi Das University) ENROLLMENT NO. 1200329006 YEAR OF SUBMISSION: 2023 BATCH: 2020-2023

ii DECLARATION BY THE CANDIDATE I, Dr. Rusa Sannigrahi, hereby declare that the Dissertation titled "ANALYSING THE EFFECT OF ADDITION OF SILICA NANOPARTICLES ON MECHANICAL PROPERTIES OF DENTAL STONE AND DIE STONE: AN IN VITRO STUDY" is a bonafide research carried out by me under the guidance of Dr. Manoj Upadhyay as Guide, and Dr. Garima Agarwal as Co- Guide. Date: _____ Place: Lucknow: Signature of candidate

iii CERTIFICATE OF GUIDE This is to certify that the work incorporated in this dissertation entitled, "ANALYSING THE EFFECT OF ADDITION OF SILICA NANOPARTICLES ON MECHANICAL PROPERTIES OF DENTAL STONE AND DIE STONE: AN IN VITRO STUDY" submitted for the degree of MDS (Prosthodontics, Crown & Bridge and Implantology) has been carried out by Dr. Rusa Sannigrahi under my direct supervision and guidance. The work has been done by the candidate herself. Date: _____ Dr. Manoj Upadhyay Reader Department of Prosthodontics, Crown & Bridge and Implantology Babu Banarasi College of Dental Sciences BBD University Lucknow – 226028

iv CERTIFICATE OF CO-GUIDE This is to certify that the work incorporated in this dissertation entitled, "ANALYSING THE EFFECT OF ADDITION OF SILICA NANOPARTICLES ON MECHANICAL PROPERTIES OF DENTAL STONE AND DIE STONE: AN IN VITRO STUDY" submitted for the degree of MDS (Prosthodontics, Crown & Bridge and Implantology) has been carried out by Dr. Rusa Sannigrahi under my direct supervision and guidance. The work has been done by the candidate herself. Date: _____ Dr. Garima Agarwal Reader Department of Prosthodontics, Crown & Bridge and Implantology Babu Banarasi College of Dental Sciences BBD University Lucknow – 226028

v ENDORSEMENT BY THE HEAD OF THE DEPARTMENT This is to certify that the work incorporated in this dissertation entitled, "ANALYSING THE EFFECT OF ADDITION OF SILICA NANOPARTICLES ON MECHANICAL PROPERTIES OF DENTAL STONE AND DIE STONE: AN IN VITRO STUDY" submitted for the degree of MDS (Prosthodontics, Crown & Bridge and Implantology) has been carried out by Dr. Rusa Sannigrahi in my Department. The work has been done by the candidate herself. Date: _____ Dr. Swati Gupta Head of the Department Department of Prosthodontics, Crown & Bridge and Implantology Babu Banarasi College of Dental Sciences BBD University Lucknow – 226028

78