(Study of the effect of adding magnesium oxide nanoparticles on the mechanical properties of 3D printed denture base resin)

Submitted to the Department of Dental Technology /University of the almustaqbal as part of the requirements for obtaining a Bachelor's degree in Dental Technology

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إقرار المشرف

أقرّ بأن إعداد هذا المشروع الموسوم:
دراسة تأثير إضافة جسيمات أوكسيد المغنيسيوم النانوية على الخواص الميكانيكية لراتنج قاعدة طقم الأسنان المطبوع بتقنية ثلاثية الأبعاد

المُعد من قبل الطلبة:

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﴿ نَرْفَعُ دَرَجَاتٍ مَنْ نَشَاءُ ۗ وَفَوْقَ كُلِّ ذِي عِلْمٍ عَلِيمٌ ﴾

صدق الله العلي العظيم
سورة يوسف ـ الآية 76

اهداء

بسم الله الرحمن الرحيم

الحمدُ لله حمداً كثيراً طيباً مباركاً فيه، الحمدُ لله الذي أنار لنا درب العلم، ووهبنا القوة والصبر لإتمام هذا العمل، فما .كان لهذا الجهد أن يكتمل لولا فضله وتوفيقه ورحمته. إليه ننسب كل إنجاز، وبه نستعين في كل بداية ونهايه وإلى أرواحٍ شهدائنا الأبرار، الذين سطروا بدمائهم الطاهرة معاني التضحية والفداء، فكانوا سبباً في بقاء الوطن وعزته، نهدي هذا العمل وفاءً وعرفاناً لما قدموه من تضحيات خالدة إلى العزيز الذي حملت اسمه فخرًا، إلى من كلله الله بالهيبة والوقار، إلى من حصد الأشواك عن دربي وزرع لي الراحة بدلاً منها، إفالحمد لله لكونك أبى

... إلى اليد الخفية التي أزالت عن طريقي العقبات، ومن ظلت دعواتها تحمل اسمي ليلًا ونهارًا .أمي، محبوبتي

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...إلى مصدر قوتي، وأرضي الصلبة، وجدار قلبي المتين اخوتي وأخواتي،

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LIST OF ABBREVIATIONS

Abbreviation	Description
3D	Three-Dimensional
ABS	Acrylonitrile Butadiene Styrene
ADA	American Dental Association
CAD/CAM	Computer-Aided Design/Computer-Aided Manufacturing
DBM	Denture Base Material
DLP	Digital Light Processing
ISO	International Organization for Standardization
MgO	Magnesium Oxide
MPa	Megapascal
NPs	Nanoparticles
PMMA	Polymethyl Methacrylate
PLA	Polylactic Acid
SD	Standard Deviation
SE	Standard Error
SLA	Stereolithography
UV	Ultraviolet
wt%	Weight Percentage

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Abstract

Background: Three-dimensional (3D) printing technology has revolutionized denture base fabrication by enabling precise, customized production without traditional molds. However, 3D-printed denture base resins still exhibit limitations in mechanical strength and fracture resistance. The incorporation of nanoparticles has been proposed as a strategy to enhance these properties.

Aim: This study aimed to evaluate the effect of adding 1% magnesium oxide nanoparticles (MgO NPs) on the mechanical properties of 3D-printed denture base resin, specifically surface hardness, flexural strength, and compressive strength.

Materials and Methods: A total of 60 specimens were fabricated and divided into two groups (n=30 each): a control group (3D-printed resin without additives) and an experimental group (resin reinforced with 1% MgO NPs). Specimens were printed using a Phrozen Sonic Mini KS DLP printer and post-cured under UV light. Hardness, flexural strength, and compressive strength tests were performed according to ISO standards. Independent two-sample t-tests were used for statistical analysis.

Results: The mean hardness values were 77.66 ± 6.16 for the control group and 77.72 ± 1.26 for the 1% MgO group, with no statistically significant difference ($p = 0.976$). However, flexural strength significantly decreased from 82.70 ± 11.70 MPa to 59.37 ± 8.73 MPa ($p < 0.05$), and compressive strength significantly decreased from 91.55 ± 1.94 MPa to 81.50 ± 2.39 MPa ($p < 0.05$).

Conclusion: The addition of 1% MgO nanoparticles did not improve the mechanical properties of 3D-printed denture base resin. While surface hardness remained unaffected, both flexural and compressive strengths were significantly reduced. Further studies are recommended to investigate optimal concentrations and surface treatment of nanoparticles.

Chapter one

Introduction

Introduction :

Despite the growing use of dental implants, traditional partial and complete dentures are frequently the preferred treatment for patients who have lost their teeth for economic and medical reasons. Polymethylmethacrylate (PMMA) is the preferred material for denture bases because of its favorable properties, such as biocompatibility, satisfactory aesthetics, ease of processing, affordability, and stability in the patient's mouth. PMMA is also used in various dental applications, including the fabrication of removable orthodontic devices and retainers, artificial teeth, and fixing broken or damaged dentures. Despite these advantages, inherent limitations often obstruct their clinical performance, such as suboptimal surface hardness, susceptibility to porosity, surface roughness, incomplete polymerization and lower fracture resistance. **(Al-Jubouri et al, 2025, p. 2).**

The inclusion of magnesium oxide in different dental materials was investigated and shown to be an important inorganic material, non-toxic and antibacterial agent

Mechanically, DBMs should have a high elastic modulus, proportional limit, resilience, adequate abrasion resistance, fatigue, and impact strength. **(Alqutaibi et al., 2023)**

Approximately 68% of complete dentures are likely to fracture during the first 3 years of use because of the occlusal load or falling of the denture **(Al-Jubouri et al 2025 p.2)**.

Several studies have been conducted with the goal of enhancing the properties of PMMA by using different curing methods and/or incorporating fillers in its composition. Addition of fillers and fibers to PMMA is a commonly used method to improve both its physical and mechanical properties. **(Gad et al., 2017).**

Previous studies have shown that the properties of PMMA nanocomposites are influenced by the type, shape, size and concentration of the nanofiller **(Sheikh et al, 2022, p.2).**

The incorporation of filler materials into denture base materials has emerged as a promising strategy to address these challenges. Several trials have been conducted Ato overcome the limitations of PMMA and expand its biomechanical properties and clinical application **(Al-Jubouri et al 2025 p.2).**

Compared with larger particles, nanoparticles (NPs) are notable for their tiny size, large surface area, and intense interaction with resin materials, which provide them with unique mechanical, chemical, electrical, optical, and magnetic properties. Metal oxides are among the various kinds of NPs and they are helpful because of their antibacterial qualities and the variety of their physical and chemical characteristics **(Al-Jubouri et al, 2025, p. 2).**

Appropriate amount of MgO could improve the flexural strength and hardness, improving the quality of the denture bases **(Al-Jubouri et al, 2025, p. 11).**

Digital manufacturing technologies have been largely used in dentistry in recent years. The fabrication of removable dentures can be performed at present using the technology of computer-aided design and computer-aided manufacture (CAD-CAM), which includes subtractive methods and additive methods, commonly known as 3D printing and rapid prototyping **(Sheikh et al, 2022, p.2).**

The growing consensus of adapting the 3D manufacturing system over traditional techniques is attributed to several advantages including fabrication of complex geometry with high precision, maximum material savings, flexibility in design, and personal customisation. A wide range of materials that are currently used in 3D printing include metals, polymers, ceramics and concrete. Polylactic acid (PLA) and acrylonitrile butadiene styrene (ABS) are the main polymers used in the 3D printing of composites **(Ngo et al., 2018).**

Due to the revolution of 3D printing in dentistry, the fabrication of a complete denture base without the need of molds or cutting tools can be performed easily due to the ability of 3D-printing technologies in directly receiving CAD data and quickly creating a new digital model. In addition to the reduced time taken by procedures along with the lab work, it also shows advantages in terms of the improvement of tissue adaptation and the ease of duplicating existing dentures. However, the 3D-printing method is more accurate compared to the conventional method, as it eliminates the errors made by lab technicians **(Sheikh et al, 2022, p.2).**

Aim of the study

Evaluate the effect of adding concentration of magnesium oxide nanoparticles (MgO NPs) on the performance of 3D-printed denture base resins. This will be achieved by investigating key mechanical properties including : Flexural strength , hardness and compressive strength

Chapter Two

Literature Review

Review of Literature:

2.1 Historical Development of Denture Base Materials

The concept of using DBMs existed centuries ago. Before the 17th century, denture bases were fabricated using natural materials such as wood, ivory, and the bones of hippopotamuses or whales that were carved to fit the spaces in edentulous regions. In the 18th century, Etienne Bourdet first used gold for making denture bases, but their widespread use in dentistry was prevented due to high cost and poor esthetics due to their color. In 1839, vulcanized rubber was discovered by Charles Goodyear. Vulcanite's introduction as a DBM resulted in a significant decrease in the dentures' cost and successfully replaced previous materials due to its comfort, economy, ease of preparation, and dimensional stability, although it still lacked ideal esthetics and chemical bonding with porcelain teeth. In 1937, Walter Wright first introduced Poly(methyl methacrylate) (PMMA) as a DBM. By 1946, this material became one of the most used materials for denture fabrication due to its ease of processing and pigmenting, adequate mechanical properties, economy, and low toxicity. Despite its widespread use, PMMA does not fulfill the ideal DBM requirements because it is susceptible to fracture under cyclic loading and water absorption, which negatively affects its mechanical properties **(Alqutaibi et al., 2023).**

2.2 Properties and Applications of Polymethyl Methacrylate (PMMA Polymethyl methacrylate (PMMA) is one of the most widely used polymers in dentistry due to its favorable properties and versatility. As stated in the literature, "Amongst these, PMMA is a polymer that is most commonly used in dental laboratories (to make orthodontic retainers and dentures and for repair), dental clinics (for relining dentures and temporary crowns), and industry (such as fabrication of artificial teeth) **(Kostić et al., 2022)**

2.3 Limitations of PMMA Denture Base Materials

been quantified A removable acrylic resin denture is subjected to a multitude of conditions intraorally that could alter its dimensions or structural integrity Characterizing the failure record of removable dentures, Hargreavesfound that 68% of dentures had broken by the end of three years after placement, and Yli Urpo et al. reported that 28% of dentures underwent repair during the first year of use and 39% required repair during the first three years of use. Fracture of acrylic resin removable dentures occurs both outside and inside the mouth. **(Sasaki et al.2016)**

2.4 Heat-Cured and Cold-Cured Acrylic Resins

Heat-polymerized acrylic resin has historically been the primary material for denture bases. As reported, “Heat-polymerized acrylic resin has been the most commonly used denture base material for over 60 years.” This type of resin provides superior mechanical performance during denture repair, where “the group repaired with heat cure acrylic resin and reinforced with glass fiber showed the highest flexural strength.” In conditions without reinforcement, however, performance between the two systems was comparable, as “there was no significant difference between the groups repaired with heat cure and cold cure acrylic resins without reinforcement.”

In contrast, cold-cure (autopolymerized) acrylic resin demonstrates weaker mechanical properties due to limitations in the polymerization process. The study emphasizes that “lower strength of cold cure acrylic resin seems to be due to the insufficient polymerization process.” Furthermore, reinforcement with polyethylene fibers did not improve its mechanical behavior, demonstrated by the finding that “the group repaired with cold cure acrylic resin and reinforced with polyethylene fibers had the lowest flexural strength.” Despite these differences, the research reiterates that “there was no significant difference between the groups repaired with heat cure and cold cure acrylic resins without reinforcement,” supporting the notion that reinforcement is the key factor determining flexural strength **(Heidari et al., 2015).**

2.5 Strategies for Enhancing PMMA Properties

To overcome these limitations, modern research focuses on enhancing PMMA properties by incorporating fibers, nanoparticles, or nanotubes, and by utilizing advanced manufacturing techniques such as CAD/CAM or 3D printing, aiming to improve mechanical performance, wear resistance, and overall durability of dental restorations and denture bases **(Kostić et al., 2022).**

2.6 3D Printing Technology in Denture Base Fabrication

3D printing has been hailed as a disruptive technology which will change manufacturing. Used in aerospace, defence, art and design, 3D printing is becoming a subject of great interest in surgery. The technology has a particular resonance with dentistry, and with advances in 3D imaging and modelling technologies such as cone beam computed tomography and intraoral scanning, and with the relatively long history of the use of CAD CAM technologies in dentistry, it will become of increasing importance. Uses of 3D printing include the production of drill guides for dental implants, the production of physical models for prosthodontics, orthodontics and surgery, the manufacture of dental, craniomaxillofacial and orthopaedic implants, and the fabrication of copings and frameworks for implant and dental restorations.. In denture manufacturing,3D printing replaced traditional methods by enabling the fabrication of customized dentures with greater precision and efficiency. This innovative technique involves layer-by-layer deposition of materials based on digital models, allowing the production of complex and patient-specific denture structures. The integration of 3D printing in dentistry offers the potential for improved fit, comfort, and aesthetics in denture design, marking a significant advancement in the field of prosthodontics. A further advantage of 3D printers is that they eliminate the requirement for several laboratory procedures of molding and lengthy steps of conventional heat-cured acrylic resin prostheses **(Ali et al., 2024).**

2.7 Nanoparticles

are minuscule materials **(**with at least one dimension less than 100 nm) with unique properties, making them more appropriate for novel applications and attractive for medical developments. Nanomaterials are recently reported to have novel preventive and therapeutic usage in dental caries. More studies demonstrated novel applications, including reducing and controlling dental plaque biofilms, improving the antibacterial properties of dental materials, and remineralizing initial dental caries lesions. **(Sharifian et al. 2023)**

2.8 Magnesium oxide nanopartcles

The most frequent nanometals that have been used in dental materials include gold, silver, copper oxide, magnesium oxide, iron oxide, cerium oxide, aluminum oxide, titanium dioxide, and zinc oxide. The antibacterial characteristics of magnesium oxide (MgO) nanoparticles are piqued for usage in medicine. MgO nanoparticles outperform other metal oxide nanoparticles in terms of biocompatibility and degradation by-products, and the U.S. Food and Drug Administration has declared them to be safe. MgO is also known as periclase, and its empirical formula is MgO, and its lattice is made up of Mg2+ and O2 ions linked by ionic bonds . The two most important factors that made MgO nanoparticles superior in use to other nanoparticles are their biocompatibility and their biodegradable by-products (namely magnesium ion). **(Sharifian et al. 2023)**

2.9 Effect of Magnesium Oxide Nanoparticles on Denture Base Materials

Low concentrations of MgO nanoparticles (2% and 4%) were found to improve the mechanical properties of acrylic resin. Adding limited have a positive effect on hardness of surfaces and color changes of acrylic resins. These concentrations produced significant improvements compared with the control group: The results showed there is high significant difference for MgO with the controls . In contrast, a higher concentration of 6% MgO had negative effects. Any increase in concentration of MgO will effect adversely on hardness of surfaces and color stabilities of acrylic resin. Low concentrations enhanced mechanical

performance and maintained acceptable color stability, whereas higher concentrations may lead to particle agglomeration and reduced properties **(Abdulsattar M. H., 2023).**

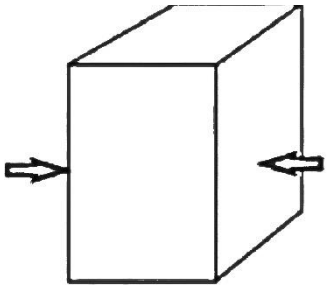
Figure1: 2Mgo oxide

2.10 Mechanical Properties of Denture Base Materials

A.Flexural strength Flexural strength is the maximum stress measured in the test,This test determines not only the strength of the material indicated but also the amount of distortion expected.The flexural strength test is a part of ANSI/ADA specifi-cation No.12 (ISO 1567) for denture base resins. Flexural properties are measured by bending abeam-shaped specimen. In a single cantilever beam configuration, the beam is fixed at one end and a force is applied at a prescribed distance from the fixed end. In a dual cantilever beam configuration, both ends of the beam are fixed and a load is placed on the cen-ter of the beam. In a three-point or four-point flex-ural configuration, the beam is supported on two rollers and a load is applied to the top of the beam. **(Sakaguchi & powers 2012)**

B.Compressive strength

Compressive strength is most useful for comparing materials that are brittle and generally weak in tension. Compressive strength is therefore a useful property for the comparison of dental amalgam, resin composites, and cements and for determining the qualities of other materials such as plaster and investments.Typical values of compressive strength of some restorative dental materials are given when an object is tested in compression, failure might occur as a result of complex stresses in the object.The forces of compression applied to each end of the specimen are resolved into forces of shear along a cone-shaped area at each end and, as a result of the action of the two cones on the cylinder, into tensile forces in the central portion of the mass. Because of this resolution of forces in the body, it has become necessary to adopt standard sizes and dimensions to obtain reproducible test results.if a test specimen is too short, the force distributions become more complicated as a result of the cone formations overlapping in the ends of the cylinder. If the specimen is too long, buckling may occur. Therefore, the cylinder should have a length twice that of the diameter for the most satisfactory results.**(Pfeifer, Ferracane & Sakaguchi, 2025)**



Compressional Stress

C.Hardness

is an important mechanical property that must be ascertained for dental materials to ensure the longevity of restorations placed in the mouth. Technically, it is evaluated by making surface indentations and calculating the resistance offered by the material..**(Nair et al., 2022)**

Chapter Three

Material and

Methods

Table 3.1: The material used in this study

No.	Material	Manufacturer	Country of Origin	Expiration
1	Resin: Denture base V3	Senertek – MonoVat-Chinese	-	12/12/2027
2	Magnesium Oxide nano powders (MgO NPs)	HONGWUNEWMATERIAL Since 2002	-	-
3	Isopropyl alcohol (IPA)	-	-	-
4	UV curing unit	-	-	-
5	Digital analytical balance	-	-	-

Table 3.2: Equipment and instrument that used in the study

No.	Equipment and Instruments	Company	Country of Origin
1	3D Printer (Phrozen Sonic Mini 8KS)	Phrozen Technology	Taiwan
2	Software: EXOCAD	-	-
3	Software: CHITUBOX	-	-
4	Universal Testing Machine	-	-
5	Compressive strength tester	-	-
6	Flexural strength tester	-	-
7	Hardness strength tester	-	-

3.3 Methods

Specimen Design and Dimensions:

All specimens were designed according to the standard dimensions specified by the International Organization for Standardization (ISO) for polymer-based mechanical testing.

Flexural Test (ISO 20795-1:2013):

The preferred test specimen is 80 mm long, 10 mm wide, and 4 mm thick.

Compressive Test (D695):

Cylindrical specimens with a diameter of 12.7 mm (½ inch) and a length of 25.4 mm.

Hardness Test (ISO 20795-1:2013):

The preferred test specimen is 80 mm long, 10 mm wide, and 4 mm thick.

Materials and Methods – Sample Preparation

Resin Material:

The resin used in this study was a photopolymer-based 3D printing material (MonoVat, USA), specifically formulated for vat-photopolymerization systems.

Nanoparticle Addition:

Magnesium nanoparticles were employed as a reinforcing additive in the experimental groups at a concentration of 1 wt%. The required amount of resin was accurately weighed, after which magnesium nanoparticles equivalent to 1% of the resin weight were added. Magnesium oxide (MgO) nanoparticles were incorporated into the photopolymer resin at a concentration of 1 wt%. The required amount of MgO powder was weighed using a digital analytical balance and gradually added to the resin. The mixture was mechanically stirred for 30 minutes to ensure homogeneous dispersion of the nanoparticles.The modified resin was then poured into the resin tank of the 3D printer and printed using the same printing parameters and specimen dimensions as the control group. After printing, the specimens were washed in isopropyl alcohol to remove uncured resin and subsequently post-cured under UV light according to the manufacturer's instructions. These specimens served as the experimental group for mechanical testing.

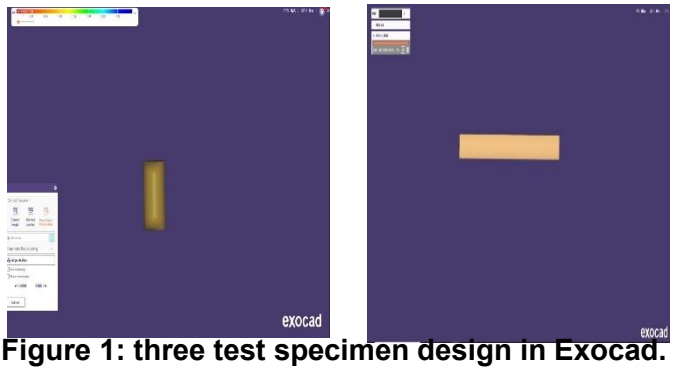


Figure 1: three test specimen design in Exocad.

Table: Samples Grouping

Test Type	Control Group (No MgO)	MgO Added Group	Total per Test
Hardness Test	10 samples	10 samples	20 samples
Compressive Test	10 samples	10 samples	20 samples
Flexural Test	10 samples	10 samples	20 samples
Total Samples	**30**	**30**	**60**

3.4 Specimen Preparation

Prior to the printing process, the resin–nanoparticle mixture was prepared to ensure adequate dispersion and homogeneity. After incorporating 1 wt% magnesium nanoparticles into the weighed resin, the mixture was subjected to ultrasonic agitation for 10 minutes to promote uniform nanoparticle distribution and minimize agglomeration. Subsequently, the resin container was immersed in hot water for 10 minutes and manually shaken to further enhance homogeneity and reduce resin viscosity.

Following the manufacturer's recommendations, this conditioning procedure ensured uniform distribution of photoinitiators and reinforcing additives while improving resin fluidity within the resin tank. The printing process was performed using a vat-photopolymerization system (DLP/SLA). After inserting the USB device, the prepared model—which included all specimens arranged using slicing software—was selected from the printer interface. Default printing parameters provided by the manufacturer, including layer height and exposure time, were applied to ensure dimensional accuracy. Once the resin tank was filled, the printing process was initiated through the device interface.

The printing sequence consisted of three runs: the first run included ten specimens for compression testing and five specimens for flexural testing; the second run

consisted of and five specimens for flexural testing; and the third run included ten specimens for hardness testing, which were conducted on flexural-type specimens. After printing, the specimens were removed from the build platform, cleaned of uncured resin, and post-cured using a UV curing unit. Each side of the specimens was exposed to ultraviolet light for 10 minutes to ensure complete polymer crosslinking and improved mechanical stability prior to testing.

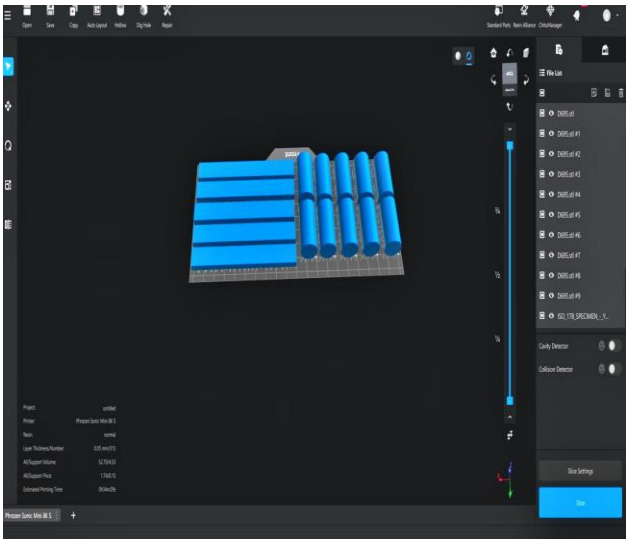


Figure 2: Specimen Layout in the Slicing Software.

Figure 3: Resin Conditioning by Warm-Water Immersion Before Printing

3.5 Preparation of 3D-Printed Resin Specimens (Control Group)

Control specimens were fabricated exclusively from the photopolymer resinwithout the incorporation of magnesium nanoparticles, using the same printing parameters, specimen dimensions, and post-processing procedures described previously. These specimens served as the control group for comparison with

the nanoparticle-reinforced experimental groups during mechanical testing

Preparation of MgO-Reinforced 3D-Printed Resin Specimen

Figure 4 :3D-Printed Resin Test Specimens.

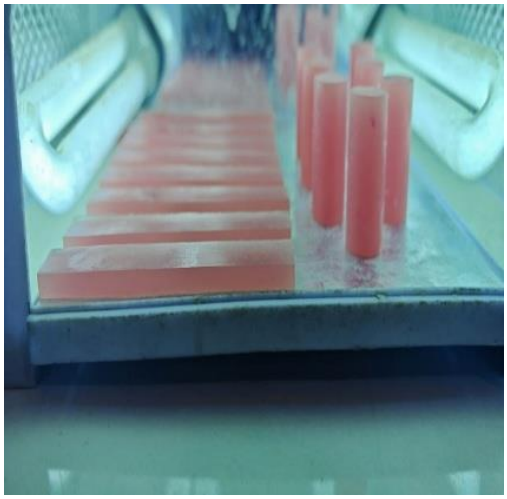


Figure 5:3D-Printed Resin Test Specimens

3.6 Flexural Strength Testing

Flexural strength testing was conducted on rectangular specimens designed according to ISO standard dimensions for polymeric bending tests. The flexural test was performed using a three-point bending configuration. Each specimen was positioned horizontally on the testing fixture, and a vertical load was applied at the midpoint until fracture occurred. The maximum load at failure was recorded, and the flexural strength was calculated accordingly.

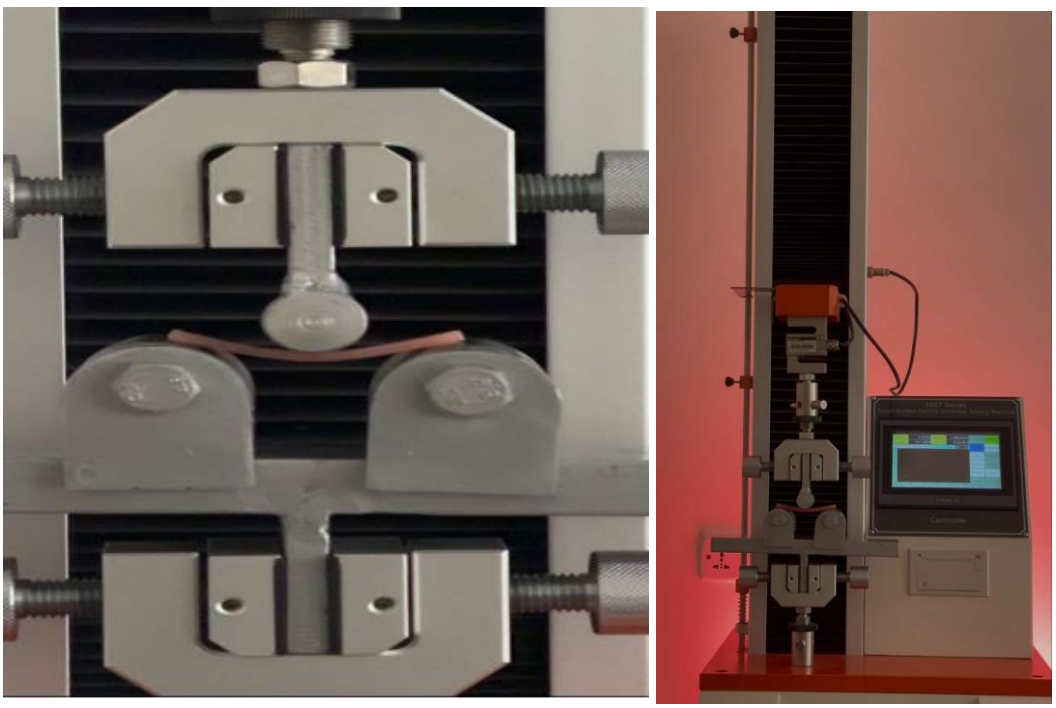


Figure6: Flexural test

3.7 Hardness testing

was conducted on rectangular specimens designed according to ISO standard dimensions for polymeric hardness tests. Each specimen was positioned horizontally on the testing fixture, and a standardized hardness indenter was applied with a controlled force. The measurement was performed at multiple points on each specimen surface to ensure accuracy. The hardness value for each specimen was recorded according to the standard procedure .

Figure7: Hhardnes test

3.8 Compressive testing

was conducted on cylindrical specimens designed according to ISO standard dimensions for polymeric compression tests. Each specimen was positioned vertically on the testing fixture, and a uniaxial compressive load was applied at a constant rate until fracture occurred. The maximum load at failure was recorded, and the compressive strength was calculated according to standard procedures

Chapter Four

Results

Results

This chapter presents the descriptive and inferential statistical analysis of the tested mechanical properties of 3D-printed resin reinforced with 1% MgO nanoparticles compared with the control group. The evaluated properties included hardness, flexural strength, and compressive strength.

4.1. Hardness Test

The descriptive and statistical analysis of hardness values is presented in Table 1. The control group showed hardness values ranging from 67.700 to 85.300, with a mean value of 77.660 ± 6.162. In comparison, the 1% MgO_2 group demonstrated values between 75.300 and 79.700, with a mean of 77.720 ± 1.262.

Although the modified group exhibited a slightly higher mean hardness value than the control group, the difference between groups was minimal. The independent two-sample t-test revealed a t value of −0.030 with a p value of 0.976, indicating that the difference was statistically not significant ($p > 0.05$).

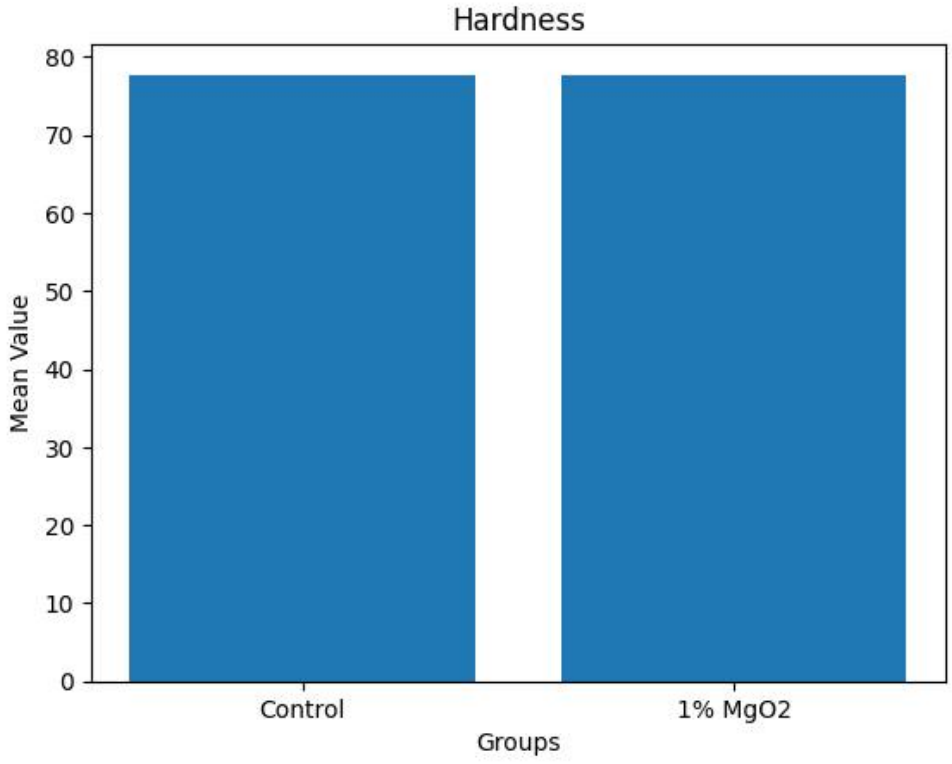
Therefore, the incorporation of 1% MgO nanoparticles did not produce a significant effect on the hardness of the tested material.

TABLE 1: HARDNESS

Descriptive and statistical test of hardness among groups

	Control	1% Mg0
Minimum	67.700	75.300
Maximum	85.300	79.700
Mean	77.660	77.720
SD	6.162	1.262
SE	1.949	0.399
Two sample T test	-0.030	
P value	0.976	Not sig

Sig.=significant at p<0.05



4.2.Flexural Strength Test

The flexural strength results are summarized in Table 2.

The control group recorded flexural strength values ranging from 60.750 to 100.850 MPa, with a mean value of 82.695 ± 11.698 MPa. Conversely, the 1% MgO_2 group showed lower values ranging from

41.380 to 72.960 MPa, with a mean of 59.368 ± 8.729 MPa.

Statistical analysis using the independent two-sample t-test showed a t value of 5.054 and a p value of 0.000, demonstrating a highly statistically significant difference ($p < 0.05$) between groups.

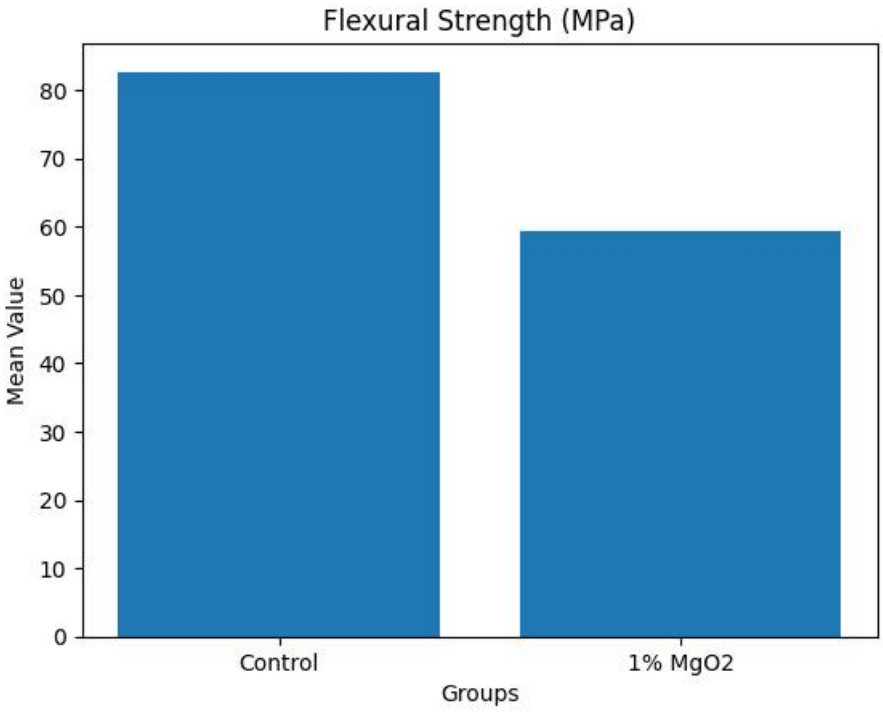
These findings indicate that the addition of 1% MgO nanoparticles resulted in a significant reduction in flexural strength compared with the control group.

TABLE 2: FLEXURAL STRENGTH

Descriptive and statistical test of flexural strength among groups

	Control	1% Mg0
Minimum	60.750	41.380
Maximum	100.850	72.960
Mean	82.695	59.368
SD	11.698	8.729
SE	3.699	2.760
Two sample T test	5.054	
P value	0.000	sig

Sig.=significant at $p<0.05$



4.3. Compressive Strength Test

The compressive strength measurements are illustrated in Table 3.
The control group exhibited compressive strength values ranging from 88.400 to 94.700 MPa, with a mean value of 91.550 ± 1.935 MPa. Meanwhile, the 1% MgO group showed lower values ranging from
77.500 to 85.200 MPa, with a mean of 81.500 ± 2.385 MPa.

The independent two-sample t-test revealed a t value of 10.347 with a p value of 0.000, confirming a statistically significant difference ($p < 0.05$) between the two groups.

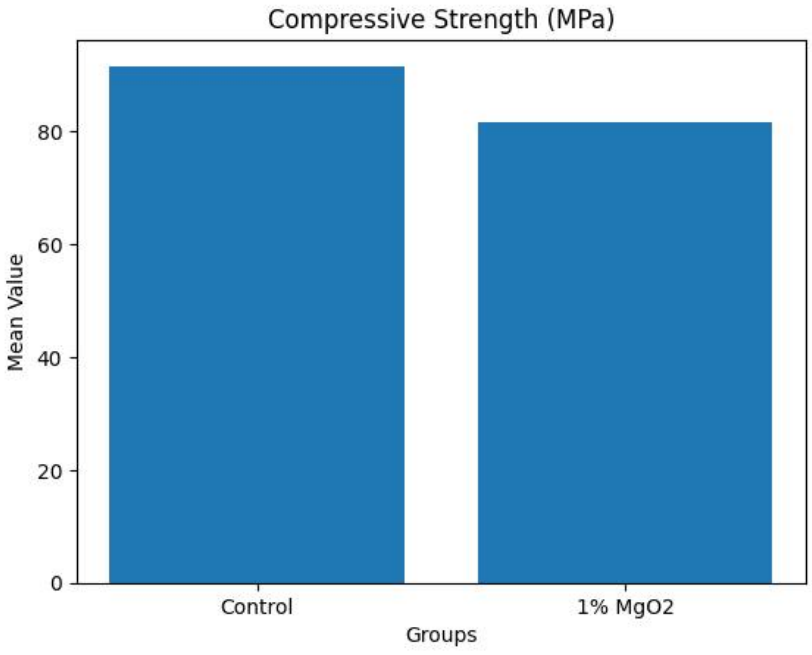
This result indicates that incorporating 1% MgO nanoparticles significantly decreased the compressive strength of the material.

TABLE 3: COMPRESSIVE STRENGTH

Descriptive and statistical test of compressive strength among groups

	Control	1% Mg0
Minimum	88.400	77.500
Maximum	94.700	85.200
Mean	91.550	81.500
SD	1.935	2.385
SE	0.612	0.754
Two sample T test	10.347	
P value	0.000	sig

Sig.=significant at p<0.05



4.4 Summary of Results

Overall, the addition of 1% MgO nanoparticles showed:

- No significant effect on hardness.
- Significant reduction in flexural strength.
- Significant reduction in compressive strength.

These outcomes suggest that while MgO incorporation did not influence surface hardness, it adversely affected the bulk mechanical properties of the tested resin.

Chapter Five

Discussion

&

Conclusion

Discussion Conclusion

5.1 Discussion

The present study aimed to evaluate the effect of incorporating 1% magnesium oxide nanoparticles (MgO NPs) into dental resin composite and to assess their influence on selected mechanical properties, including surface hardness, flexural strength, and compressive strength, compared with the control group.

Hardness Test

The hardness results demonstrated minimal differences between the control group and the 1% MgO NPs group. The mean hardness values of both groups were nearly identical, and statistical analysis revealed no significant difference between them ($p > 0.05$). These findings indicate that the incorporation of MgO NPs at a concentration of 1% did not significantly influence the surface hardness of the material.

Hardness is primarily a surface-dependent property; therefore, minor internal structural modifications may not substantially affect resistance to surface indentation. Several factors may explain the absence of improvement in hardness, including possible non-uniform dispersion of nanoparticles within the resin matrix and particle agglomeration, which reduces the effective reinforcing surface area.

Furthermore, insufficient nanoparticle concentration may have limited the ability of MgO NPs particles to fill microvoids effectively and enhance matrix rigidity. According to Zare et al., the aggregation/agglomeration of nanoparticles reduces the potential enhancement of mechanical properties in nanocomposites due to the restriction of interfacial area.

When nanoparticle clustering occurs, localized defects may form instead of reinforcement zones, thereby minimizing potential mechanical benefits. **(Zare et al., 2018)**

Flexural Strength Test

The flexural strength values of the MgO NPs-modified group were significantly lower than those of the control group ($p < 0.05$). This reduction indicates that the addition of 1% MgO NPs adversely affected the material's resistance to bending stresses. Flexural strength is highly sensitive to internal structural integrity and defect distribution. The observed decrease may be attributed to weak interfacial bonding between nanoparticles and the polymer matrix, which limits effective stress transfer during loading

In addition, nanoparticle agglomeration can create stress concentration areas that promote early crack initiation and propagation. **(Zare et al., 2018)**

Another possible contributing factor is the increase in internal porosity during the mixing process. Entrapped air and particle clustering may act as structural discontinuities, reducing the material's ability to withstand tensile stresses generated during bending. This finding aligns with research by Naguib et al., who demonstrated that nanoparticle effectiveness strongly depends on concentration balance, particle size, surface treatment, and compatibility with the base material**. (Naguib et al., 2024)**

Compressive Strength Test

Similarly, compressive strength values were significantly reduced in the MgO NPs group compared with the control samples ($p < 0.05$). These findings suggest that nanoparticle incorporation did not enhance resistance under compressive loading conditions.

Instead of functioning as reinforcing fillers, MgO NPs nanoparticles may have behaved as microstructural discontinuities within the matrix. Poor particle dispersion and inadequate interfacial adhesion can interrupt load distribution pathways, leading to localized stress accumulation and premature structural failure. **(Zare et al., 2018)**

Additionally, the selected concentration (1%) may not represent the optimal filler ratio required for mechanical reinforcement. Previous studies have demonstrated that nanoparticle effectiveness strongly depends on concentration balance, particle size, surface treatment, and compatibility with the base material. **(Naguib et al., 2024)**

on MgO-substituted PMMA composites showed that higher concentrations (up to 15 wt%) achieved improved compressive strength, suggesting that 1% concentration may be below the threshold for effective reinforcement. **(Alotaibi et al., 2024)**

Overall Interpretation

Although nanoparticles are frequently incorporated to enhance mechanical performance, the present findings demonstrate that MgO NPs addition at a concentration of 1% did not produce the expected reinforcement effect. While surface hardness remained unaffected, both flexural and compressive strengths showed significant reductions compared with the control group.

These results highlight that nanoparticle reinforcement is highly dependent on dispersion quality, interfacial bonding, and concentration optimization**. (Zare et al., 2018)**

According to Zare et al., small nanoparticles and thick interphase present high levels for interfacial parameters, while aggregates/agglomerates of nanoparticles negatively affect the interfacial/interphase properties and tensile strength of polymer nanocomposites. (**Zare et al., 2018)**

Importantly, non-improved or negative outcomes remain scientifically valuable, as they help define the limitations and conditions under which material modification becomes beneficial. As demonstrated by recent studies, lower concentrations (0.3% and 0.5%) of zein-coated MgO NPs have shown significant enhancement in mechanical properties, suggesting that surface treatment and optimal concentration are critical factors for successful nanoparticle integration. **(Naguib et al., 2024)**

5.2 Conclusion

Within the limitations of this study, the following conclusions can be drawn:

1. The incorporation of 1% MgO NPs nanoparticles showed no significant effect on surface hardness compared with the control group.
2. Flexural strength significantly decreased following MgO NPs addition, indicating reduced resistance to bending stresses.
3. Compressive strength values were also significantly lower in the experimental group than in the control group.

4. The tested concentration of MgO NPs did not enhance the overall mechanical performance of the material.
5. Nanoparticle dispersion quality and optimal concentration play critical roles in determining mechanical outcomes

5.3 Recommendations for Future Studies

Based on the current findings and relevant literature, the following recommendations are proposed :

• Investigate different MgO NPs concentrations
(e.g., 0.5%, 2%, or 0.3%) as studies have shown that lower concentrations (0.3% and 0.5%) can significantly improve mechanical properties.

• Apply surface treatment or coupling agents to improve nanoparticle–matrix bonding, following the successful approach of zein-coated MgO NPs.
mechanical properties.

• Evaluate additional properties, including antibacterial activity, surface roughness, and biocompatibility, as these represent important clinical advantages of MgO NPs incorporation.

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