



Water Absorption of (Poly MethylMethacrylate) / Hydroxyapatite Denture Base Composite Material (Effect of Filler Loading)

Jamal Moammar Aldabib^{1*}

Department of Dental Technology, Faculty of Medical Technology, Bani Waleed University, Bani Walid, Libya

*Corresponding author: jamalald71@gmail.com

Received: January 30, 2026

Accepted: March 30, 2026

Published: April 2, 2026

Abstract:

Water absorption is the primary factor driving the degradation of dental polymers and resin-based composites in the oral environment. Water acts as a plasticizer and a solvent, causing hydrolytic degradation that leads to the weakening, softening, and long-term failure of restorations. Therefore, the current study aimed to evaluate the water absorption of PMMA/HA composite as a function of different HA loadings. The water absorption test was carried out according to ISO 1567-2001 specifications. Water absorption of PMMA/HA composites was influenced by the filler content and the interfacial coupling between the HA and the PMMA matrix. Water absorption for all formulations generally increases with higher exposure time, reaching higher values in the first 7–14 days (faster absorption) and continuing to increase, albeit at a reduced, slower rate, between 14–28 days as the material approaches saturation. Within the limitations of the current study, it can be said that lower HA loadings provide better resistance to water-induced degradation than higher loadings, which may cause filler agglomeration and increased porosity.

Keywords: Acrylic Denture Base, Hydroxyapatite, PMMA/HA, Water Absorption, Degradation

Introduction

Water remains the leading factor in the long-term degradation of dental materials, necessitating, on average, replacement of restorations within 5 years due to, among other factors, material breakdown (Drummond, 2008). It has been generally established that water has the main effect on degradation of dental polymers and dental composites (Amin et al., 2022; Gauthier et al., 2023; Guo, Yu, Gao, Zhang, & Zhao, 2022; Saini, Vaddamanu, Dermawan, Mosaddad, & Heboyan, 2024). Chemical composition and viscosity of water and saliva showed no difference between mechanical properties of polymeric denture base. Water is the most abundant component of saliva (Lacoste-Ferré et al., 2011). It is one of the main factors to cause biodegradation (Guo et al., 2022; Hanno & Metwally, 2024; Hany & Habib, 2022). The oral environment necessarily facilitates water sorption from the saliva to the resin, which is a polar material. Water molecules can easily penetrate the polymer network allowing the diffusion of unbound/uncured monomers and/or additives from the material network (Bettencourt et al., 2010; Bettencourta et al., 2010; Cervino, Cicciù, Herford, Germanà, & Fiorillo, 2020). It is well known that because of the weak secondary bonds in polymer materials, water molecules are able to penetrate between the polymer chains in a process called water absorption (Sahu & Gupta, 2022). Absorbed water is accountable for the hydrolytic degradation of polymers. Additionally, the ions carried by the water may cause the polymer to break down more quickly or to become stained or malodorous (Billingham, Knight, Garside, & Mills, 2023; Demir, Murat Dogan, & Dogan, 2010; Yao, Yang, Lu, Qiu, & Zeng, 2024). Water sorption of a material represents the amount of water absorbed on the surface and absorbed into the body of the material during fabrication and during the service as well (Al-Maharma & Al-Huniti, 2019). Usually a serious warpage and dimensional change in the material are associated with a high percentage of water sorption (Coca-Gonzalez & Jimenez-Martinez, 2025; Shirangi & Michel, 2010). During the service, the denture base is surrounded with the saliva, as a result of that; the denture base absorbs the saliva in the oral cavity (Alqutaibi et al., 2023; Lakhyani & Wagdargi, 2012). Water is the most abundant component of saliva as such is one of the main factors to cause biodegradation (Chojnowska et al., 2018; Guo et al., 2022). The oral environment necessarily facilitates water

sorption from the saliva to the resin, which is a polar material. Water molecules can easily penetrate the polymer network allowing the diffusion of unbound/uncured monomers and/or additives from the material network (Bettencourt et al., 2010; Čekalović Agović et al., 2025). Intraorally, denture base acrylic resins are subjected to many different types of stresses such as the repeated masticatory forces which lead to the fatigue phenomenon (J. M. Aldabib, 2025; Aldabib). As a consequence, fracture of the denture base results. In the long term, the aqueous environment could affect the fracture toughness of acrylic denture base (J. M. Aldabib & Ishak, 2021; Babeer, 2025; Sasaki, Hamanaka, Takahashi, & Kawaguchi, 2016). Biodegradation may induce significant changes in the physical and mechanical properties of the materials that may ultimately lead to the catastrophic failure of the material. Fracture mechanics evaluates the effect of cracks/flaws on the fracture resistance of a material (S. Chen et al., 2023; MAROM, 1989). Crack could occur naturally in a material or develop during service (J. M. Aldabib & Ishak, 2020). Crack propagation of flaws in the resin composite structure can lead to marginal fracture or surface degradation (Ritchie, Gilbert, & McNaney, 2000). K_{IC} is related to the stress field around a sharp crack. (Kim, Kwon, & Lee, 1994; Qiao, Zhang, & Zhang, 2023). Thus, a material with high fracture toughness will tend to resist the formation and propagation of microflaws, which may be caused by repetitive masticatory forces applied during the function (J. Aldabib, 2020; K.-J. Söderholm, 2012). Poly methyl methacrylate (PMMA) is a widely used thermoplastic in dental and medical applications (dentures, bone cements, lenses) known for its biocompatibility, transparency, and ease of processing (J. M. Aldabib, 2025). However, it is not an ideal material, and its disadvantages in these areas are well-documented. Despite its relatively hydrophobic nature, PMMA can absorb water, particularly in oral environments or bodily fluids. Absorbed water acts as a plasticizer, disrupting the intermolecular forces between polymer chains. This results in reduced stiffness, lower strength, and decreased fatigue resistance (Moghbelli, Banyay, & Sue, 2014; N'diaye, Pascaretti-Grizon, Massin, Baslé, & Chappard, 2012). The addition of fillers like zirconium oxide or titanium dioxide are used. These fillers do not completely eliminate the material's susceptibility to water absorption and degradation (Ali Sabri, Satgunam, Abreeza, & N. Abed, 2021; Singh, 2019). Hydroxyapatite is a suitable filler for improving the physical properties of PMMA, with low, controlled concentrations offering the best reduction in water-related degradation (Halib et al., 2017; Toriello, Afsari, Shon, & Tijing, 2020). Therefore, the current study was designed to investigate the effect of different hydroxyapatite ceramic powder concentrations into PMMA denture base material on water absorption.

Material and Methods

Materials

The powder components consisted of poly (methyl methacrylate) PMMA with high molecular weight (i.e. 996,000 GPC – Aldrich, USA), benzoyl peroxide of particle size $\leq 106 \mu\text{m}$ (Merck Chemical Company, Germany) and Hydroxyapatite (HA) ceramic powder of particle size $5 \pm 1 (\mu\text{m})$ (Fluidinova, Portugal). Whereas, the liquid components consisted of methyl methacrylate (MMA) (Aldrich USA) stabilized with 0.0025% hydroquinone plus 10% ethylene glycol dimethacrylate (EGDMA) as cross linking agent (Aldrich USA).

Samples Preparation

Three different ratios (i.e. 5, 10, and 15% by weight) of HA filler were added into the matrix (PMMA and 0.5% BPO) to be compared with pure PMMA and the conventional material. The powder components were mixed using the planetary ball milling technique (PBM) for 30 min using Zirconium oxide jar and balls. The running speed was set at (150 rpm) and the powder to ball weight ratio (PBR) was 1:10. The milling was stopped at every 3 min and continued after 6 min during the run time to prevent the problem of overheating and premature polymerization. The mixing of powder to liquid (P/L) was done according to standard dental laboratory usage. After reaching the dough stage, the mix was packed into a mould and was compression molded under pressure of 14 MPa, at room temperature for 30 min. The final polymerization (curing process) was carried out using a water bath at 78°C for 1 1/2 h. The mould was then left to cool slowly at room temperature. The samples were next removed.

Water Absorption Test

The water absorption test was carried out according to ISO 1567-2001 specifications. The specimens were dried in a vacuum oven at $37 \pm 1^\circ\text{C}$ for 24 h and kept in a desiccator containing silica gel for 24 h before immersion in distilled water. The specimens were weighed using an analytical balance with an error reading of 0.0001 g.

Next, the specimens were immersed in distilled water at room temperature for 28 days. The water absorption was evaluated at intervals time.

The percentage change in weight was calculated via:

$$\text{Change in weight} = \frac{W_1 - W_0}{W_0} \times 100$$

W_0 and W_1 are the weight of the specimens before and after the immersion respectively.

According to ISO 1567-2001 specifications, the calculated value of the water sorption, W_{sp} for each specimen, expressed in micrograms per cubic millimeter ($\mu\text{g}/\text{mm}^3$) is given by:

$$W_{SP} = \frac{m_2 - m_1}{V}$$

where, m_2 is the mass of the specimen, in micrograms (μg), after immersion in water

m_1 is the reconditioned mass of the specimen, in micrograms (μg)

V is the volume of the specimen, in cubic millimeters (mm^3)

Results and discussion

Figure 1 illustrates the amount of water absorption of PMMA/HA composites as a function of different filler loading as well as that of the conventional material and neat PMMA after being exposed to distilled water at room temperature for 28 days. In general, the water absorption for all formulations was increased with increasing the exposure time. The water absorption rate was relatively higher between the time periods of 0–7 and 7–14 days of water immersion for all formulations, after which a decrease in the rate of water absorption between the time periods of 14–28 days was observed. A similar observation was reported by (Durkan, Oezdemir, Pamir, & Usanmaz, 2010).

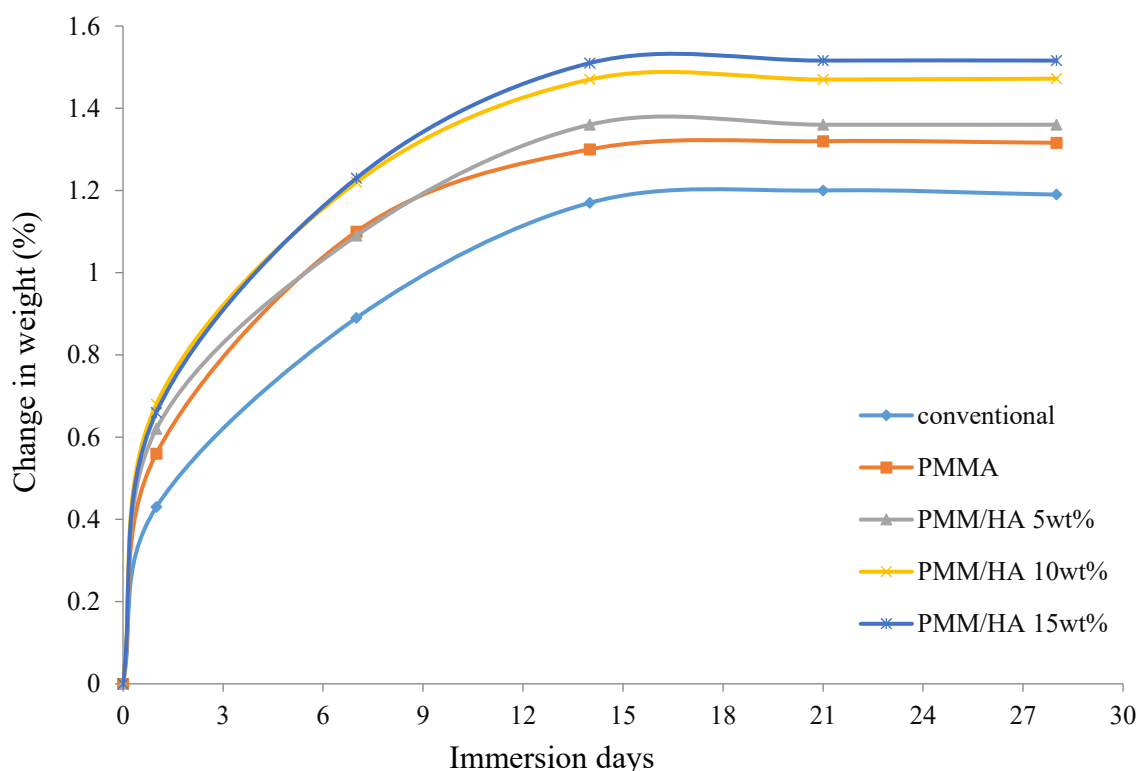


Fig. 1: Effect of filler loading on the water absorption of PMMA/HA composites compared to that of the conventional material and neat PMMA after immersion in distilled water for 28 days.

Table 1 summarizes the maximum values of absorbed water by PMMA/HA composites after being exposed to distilled water for 28 days at room temperature. The conventional material and neat PMMA are also included for comparison. It can be clearly seen that the water absorption values of PMMA/HA composites as well as the conventional material and neat PMMA are well below the value specified by the ISO standard for denture base materials (1567-2001).

Table 1: Maximum water absorption of PMMA/HA composites compared to that of the conventional material and neat PMMA after immersion in distilled water for 28 days.

| Formulation | Weight increase by (%) | Corresponding of water absorption ($\mu\text{g}/\text{mm}^3$) |
|----------------|------------------------|---|
| Conventional | 1.19 | 13.19 |
| PMMA | 1.31 | 15.17 |
| PMMA/HA 5 wt% | 1.36 | 15.56 |
| PMMA/HA 10 wt% | 1.47 | 17.09 |
| PMMA/HA 15 wt% | 1.51 | 18.28 |

**ISO standard (1567-2001) value: max weight increase percentage: 1.99% corresponding of water absorption increase to $32 \mu\text{g}/\text{mm}^3$*

The amount of absorbed water for the filled samples is higher than that of the conventional material and neat PMMA. This is due to an increase in the hydrolytic degradation of the silane coupling agent, causing a filler-matrix debonding (Sideridou & Karabela, 2009; K.-J. M. Söderholm, 1984). Hydrolytic degradation reduces the interfacial siloxane bridge bonds present at the filler/matrix interface to the original silanol groups, thus producing hydroxyl ions. The production of hydroxyl ions during hydrolytic degradation of the siloxane bridge bonds cause the concentration of OH⁻ ions at the interface to increase which further promotes the degradation of the interface and the reaction to become autocatalytic. Subsequently, degradation of the silane interface initiates particle debonding (Antonucci, Dickens, Fowler, Xu, & McDonough, 2005; H. Chen et al., 2018; K.-J. M. Söderholm, 1984). It can also be seen that the maximum amount of water absorption increased with increasing the filler loading and reached a maximum value of 1.51 wt% at a filler loading of 15 wt%. The increase of the water absorption at higher filler loading can be attributed to the presence of agglomerates. The water can be accommodated at the interface between these agglomerates and the matrix. Thus, the water absorption corresponds to the different dispersion state at different filler loading (Lau, Vaughan, Chen, Hosier, & Holt, 2013; Šupová, Martynková, & Barabaszová, 2011). According to (Al-Mufti, Almontasser, & Rizvi, 2023), there is a significant relationship between the maximum water uptake and the filler concentration in the composite; the maximum water uptake increased as the filler loading increased. Excessive water uptake can promote breakdown causing a filler-matrix debonding in the presence of porosity and inclusions of filler particle aggregates. This phenomenon would be involved in the water absorption as they appear loosely embedded in the matrix (Tham, Chow, & Ishak, 2010).

Conclusion

The incorporation of HA increases the water absorption of PMMA compared to the neat material, with the highest rate of increase occurring in the first two weeks of immersion. The current study indicates that the maximum water uptake in HA/PMMA composites has a significant relationship with the concentration of hydroxyapatite filler, often increasing as the filler loading increases. The absorption process typically follows Fickian behavior, characterized by an initial rapid water uptake (0–14 days) due to capillary action and the presence of micro-pores, followed by a slower, leveling-off rate (14–28 days). Lower percentage of HA loading provides better resistance to water-induced degradation compared to higher loadings that may cause filler agglomeration and increased porosity.

Ethical Approval: This article does not contain any studies with human participants or animals performed by the author.

References

- Al-Maharma, A. Y., & Al-Huniti, N. (2019). Critical review of the parameters affecting the effectiveness of moisture absorption treatments used for natural composites. *Journal of Composites Science*, 3(1), 27.
- Al-Mufti, S. M., Almontasser, A., & Rizvi, S. J. (2023). Unsaturated polyester resin filled with cementitious materials: a comprehensive study of filler loading impact on mechanical properties, microstructure, and water absorption. *ACS omega*, 8(23), 20389-20403.
- Aldabib, J. (2020). Reinforcement of poly (methyl methacrylate) denture base material. *Dental and Medical Journal-Review*, 2(2), 46-53.
- Aldabib, J. M. (2025). The Effect of Planetary Ball Milling Technique on Physical and Mechanical Properties of Reinforced Poly (Methyl Methacrylate) Denture Base. *Medical Technology Journal of Applied Science*, 46-53.
- Aldabib, J. M. Effect of silane coupling agent content on mechanical properties of hydroxyapatite/poly (methyl methacrylate) denture base composite. *JOURNAL OF SCIENTIFIC PERSPECTIVES*, 5(1), 37-45.
- Aldabib, J. M., & Ishak, Z. A. M. (2020). Effect of hydroxyapatite filler concentration on mechanical properties of poly (methyl methacrylate) denture base. *SN Applied Sciences*, 2(4), 732.
- Aldabib, J. M., & Ishak, Z. A. M. (2021). Fracture Toughness of Poly (Methyl Methacrylate)/Hydroxyapatite Denture Base Composite: Effect of Planetary Ball Milling Mixing Time. *Journal of Physical Science*, 32(3), 103-116.
- Ali Sabri, B., Satgunam, M., Abreeza, N., & N. Abed, A. (2021). A review on enhancements of PMMA denture base material with different nano-fillers. *Cogent Engineering*, 8(1), 1875968.
- Alqutaibi, A. Y., Baik, A., Almuzaini, S. A., Farghal, A. E., Alnazzawi, A. A., Borzangy, S., . . . Zafar, M. S. (2023). Polymeric denture base materials: a review. *Polymers*, 15(15), 3258.
- Amin, F., Fareed, M. A., Zafar, M. S., Khurshid, Z., Palma, P. J., & Kumar, N. (2022). Degradation and stabilization of resin-dentine interfaces in polymeric dental adhesives: an updated review. *Coatings*, 12(8), 1094.
- Antonucci, J. M., Dickens, S. H., Fowler, B. O., Xu, H. H., & McDonough, W. G. (2005). Chemistry of silanes: interfaces in dental polymers and composites. *Journal of research of the National Institute of Standards and Technology*, 110(5), 541.
- Babeer, W. A. (2025). Fracture toughness of three-dimensional printed and milled denture bases. *PLoS One*, 20(8), e0329556.
- Bettencourt, A. F., Neves, C. B., de Almeida, M. S., Pinheiro, L. M., e Oliveira, S. A., Lopes, L. P., & Castro, M. F. (2010). Biodegradation of acrylic based resins: A review. *Dental Materials*, 26(5), e171-e180.
- Bettencourta, A. F., Neves, C., de Almeida, M., Pinheiro, L., Oliveira, S., Lopes, L., & Castro, M. (2010). Biodegradation of acrylic based resins: A review. *Dent. Mater*, 26, 171-180.
- Billingham, N., Knight, B., Garside, P., & Mills, D. (2023). *Polymers and Their Degradation*. In *Conservation of Books* (pp. 385-416): Routledge.
- Čekalović Agović, S., Klarić, E., Ivanišević, A., Soče, M., Grego, T., & Radin Nujić, I. (2025). Water Absorption and Solubility of Fluoride-Based Restorative Materials Exposed to Ionizing Radiation. *Polymers*, 17(20), 2736.
- Cervino, G., Cicciù, M., Herford, A. S., Germanà, A., & Fiorillo, L. (2020). Biological and chemo-physical features of denture resins. *Materials*, 13(15), 3350.
- Chen, H., Wang, R., Qian, L., Ren, Q., Jiang, X., & Zhu, M. (2018). Dental restorative resin composites: modification technologies for the matrix/filler interface. *Macromolecular Materials and Engineering*, 303(10), 1800264.
- Chen, S., Arola, D., Ricucci, D., Bergeron, B. E., Branton, J. A., Gu, L.-s., & Tay, F. R. (2023). Biomechanical perspectives on dentine cracks and fractures: implications in their clinical management. *Journal of dentistry*, 130, 104424.
- Chojnowska, S., Baran, T., Wilińska, I., Sienicka, P., Cabaj-Wiater, I., & Knaś, M. (2018). Human saliva as a diagnostic material. *Advances in medical sciences*, 63(1), 185-191.

- Coca-Gonzalez, M., & Jimenez-Martinez, M. (2025). Warpage: Causes, manufacturing processes and future challenges: A review. *Proceedings of the Institution of Mechanical Engineers, Part L: Journal of Materials: Design and Applications*, 239(6), 1201-1217.
- Demir, H., Murat Dogan, O., & Dogan, A. (2010). Water sorption of denture base resin reinforced with different fibres. *Materials Research Innovations*, 14(4), 332-337.
- Drummond, J. L. (2008). Degradation, fatigue, and failure of resin dental composite materials. *Journal of dental research*, 87(8), 710-719.
- Durkan, R. K., Oezdemir, T., Pamir, A. D., & Usanmaz, A. (2010). Water absorption of two different denture base resins reinforced with dental fiber systems. *Journal of Applied Polymer Science*, 117(3), 1750-1753.
- Gauthier, R., Abouelleil, H., Boussès, Y., Brulat-Bouchard, N., Colon, P., Chenal, J.-M., . . . Grosgeat, B. (2023). Experimental investigation of dental composites degradation after early water exposure. *Journal of Biomechanical Engineering*, 145(5), 051001.
- Guo, X., Yu, Y., Gao, S., Zhang, Z., & Zhao, H. (2022). Biodegradation of dental resin-based composite—A potential factor affecting the bonding effect: A narrative review. *Biomedicines*, 10(9), 2313.
- Halib, N., Perrone, F., Cemazar, M., Dapas, B., Farra, R., Abrami, M., . . . Pozzato, G. (2017). Potential applications of nanocellulose-containing materials in the biomedical field. *Materials*, 10(8), 977.
- Hanno, K. I., & Metwally, N. A. (2024). The wettability of complete denture base materials constructed by conventional versus digital techniques: an in-vitro study. *BMC Oral Health*, 24(1), 1081.
- Hany, R. A., & Habib, A. (2022). Polymers degradation. *Biomaterials Journal*, 1(11), 47-60.
- Kim, Y.-H., Kwon, D., & Lee, S. (1994). KIC modelling for a critical strain criterion involving the stress triaxiality effect. *Acta metallurgica et materialia*, 42(6), 1887-1891.
- Lacoste-Ferré, M.-H., Demont, P., Dandurand, J., Dantras, E., Duran, D., & Lacabanne, C. (2011). Dynamic mechanical properties of oral mucosa: comparison with polymeric soft denture liners. *Journal of the Mechanical Behavior of Biomedical Materials*, 4(3), 269-274.
- Lakhyani, R., & Wagdargi, S. S. (2012). Saliva and its importance in complete denture prosthodontics. *Natl J Integr Res Med*, 3(1), 139-146.
- Lau, K., Vaughan, A., Chen, G., Hosier, I., & Holt, A. (2013). On the dielectric response of silica-based polyethylene nanocomposites. *Journal of Physics D: Applied Physics*, 46(9), 095303.
- MAROM, G. (1989). Environmental effects on fracture mechanical properties of polymer composites. In *Composite Materials Series (Vol. 6, pp. 397-424)*: Elsevier.
- Moghbelli, E., Banyay, R., & Sue, H.-J. (2014). Effect of moisture exposure on scratch resistance of PMMA. *Tribology International*, 69, 46-51.
- N'diaye, M., Pascaretti-Grizon, F., Massin, P., Baslé, M. F., & Chappard, D. (2012). Water absorption of poly (methyl methacrylate) measured by vertical interference microscopy. *Langmuir*, 28(31), 11609-11614.
- Qiao, Y., Zhang, Z.-X., & Zhang, S. (2023). An Experimental Study of the Relation between Mode I Fracture Toughness, K_{Ic}, and Critical Energy Release Rate, G_{Ic}. *Materials*, 16(3), 1056.
- Ritchie, R., Gilbert, C., & McNaney, J. (2000). Mechanics and mechanisms of fatigue damage and crack growth in advanced materials. *International Journal of Solids and Structures*, 37(1-2), 311-329.
- Sahu, P., & Gupta, M. (2022). Water absorption behavior of cellulosic fibres polymer composites: A review on its effects and remedies. *Journal of Industrial Textiles*, 51(5_suppl), 7480S-7512S.
- Saini, R. S., Vaddamanu, S. K., Dermawan, D., Mosaddad, S. A., & Heboyan, A. (2024). Investigating the role of temperature and moisture on the degradation of 3D-printed polymethyl methacrylate dental materials through molecular dynamics simulations. *Scientific Reports*, 14(1), 26079.
- Sasaki, H., Hamanaka, I., Takahashi, Y., & Kawaguchi, T. (2016). Effect of long-term water immersion or thermal shock on mechanical properties of high-impact acrylic denture base resins. *Dental materials journal*, 35(2), 204-209.

- Shirangi, M., & Michel, B. (2010). Mechanism of moisture diffusion, hygroscopic swelling, and adhesion degradation in epoxy molding compounds. In *Moisture sensitivity of plastic packages of IC Devices* (pp. 29-69): Springer.
- Sideridou, I. D., & Karabela, M. M. (2009). Effect of the amount of 3-methacyloxypropyltrimethoxysilane coupling agent on physical properties of dental resin nanocomposites. *Dental Materials*, 25(11), 1315-1324.
- Singh, M. (2019). The Comparative Evaluation of the Effect of Nanoparticles of Titanium Dioxide, Zirconium Oxide & Fibers of Glass and Nylon on the Flexural Strength of Conventional Heat Cured Polymethyl Methacrylate Denture Base Resin—An in Vitro Study. *Rajiv Gandhi University of Health Sciences (India)*,
- Söderholm, K.-J. (2012). Fracture of dental materials. *Applied fracture mechanics: InTech*, 109-142.
- Söderholm, K.-J. M. (1984). Hydrolytic degradation of dental composites and effects of silane-treatment and filler fraction on compressive strength and thermal expansion of composites. *Umeå universitet*,
- Šupová, M., Martynková, G. S., & Barabaszová, K. (2011). Effect of nanofillers dispersion in polymer matrices: a review. *Science of Advanced Materials*, 3(1), 1-25.
- Tham, W., Chow, W., & Ishak, Z. M. (2010). Simulated body fluid and water absorption effects on poly (methyl methacrylate)/hydroxyapatite denture base composites. *Express Polymer Letters*, 4(9).
- Toriello, M., Afsari, M., Shon, H. K., & Tijing, L. D. (2020). Progress on the fabrication and application of electrospun nanofiber composites. *Membranes*, 10(9), 204.
- Yao, X., Yang, X., Lu, Y., Qiu, Y., & Zeng, Q. (2024). Review of the synthesis and degradation mechanisms of some biodegradable polymers in natural environments. *Polymers*, 17(1), 66.