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In Vitro Study of the Surface Roughness, Hardness, and Absorption of an Injection-Molded Denture Base Polymer, Manufactured under Insufficient Mold Solidification

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Abstract: The current study sought to investigate the changes in surface hardness, roughness, and moisture absorption of the Vertex ThermoSens polymer (Vertex Dental, 3D Systems, The Netherlands) following immersion in artificial saliva for various periods (7, 14, and 28 days). A total of 60 rectangular specimens with dimensions of 20 mm in length, 20 mm in width, and 3 mm in thickness were made. Due to insufficient mold solidification, these specimens were made utilizing the injection molding process. A Mitutoyo Surftest 4 roughness meter (Mitutoyo, Aurora, IL, USA) was used to measure the surface roughness of the test materials. The ThermoSens polymer hardness was assessed using the Shor method and D—HSD scale, while absorption was measured with a Sartorius analytical balance. Results indicated the highest mean hardness after 28 days (M = 77.6) (Surface 1) and the lowest for the control group (M = 59) (Surface 2). The maximum surface roughness occurred in direction 2.2 pre-immersion (Ra = 2.88 μm) and 7 days post-removal (Ra = 2.95 μm). The control group exhibited the lowest absorption (Wsp = 1.524 mg/mm^3), with the highest mean values over 28 days (Wsp = 1.541 mg/mm^3). The elevated flask and plaster temperature slowed polymer solidification, resulting in longer macromolecules and improved mechanical properties and surface features.

Keywords: thermoplastic polymer; injection-molded; surface hardness; surface roughness; absorption; denture base polymers; solidification

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1. Introduction

Polymethyl methacrylate (PMMA) holds numerous advantageous attributes, positioning it as the most pertinent material for the fabrication of removable prostheses [1]. Nevertheless, certain drawbacks are associated with its suboptimal surface characteristics [2]. The attainment of polished surfaces for denture bases is imperative to mitigating microbial adhesion and unsightly discolorations, aligning with esthetic requirements [3–6]. Additionally, denture base resins possessing abrasion resistance provide the dentures with a robustness that can withstand mechanical brushing and the consumption of hard foods [7]. In contrast, denture base materials exhibiting limited abrasion resistance might result in heightened surface roughness, the propagation of cracks within deep scratches, and potential dimensional alterations [8]. Consequently, the incorporation of denture base resins featuring commendable surface attributes contributes to the durability of dentures while addressing aesthetic considerations, even in the context of advancing digital technologies for crafting removable prostheses.

Methacrylate polymers have gained substantial popularity within dentistry as denture base materials due to their several advantages [9]. Polymethyl methacrylate base materials offer numerous advantages in dental applications, including easy processing, favorable

aesthetics, resistance to chemical degradation, and cost-effectiveness. Additionally, a significant advantage of PMMA base materials is their excellent bonding to denture teeth, which ensures a secure fit and enhances the durability of the denture [10]. Moreover, PMMA allows for easy repair and reline procedures, enabling clinicians to quickly address any issues that may arise during the lifespan of the denture, thereby minimizing patient inconvenience and maximizing longevity. This ease of repair and reline contributes to the overall cost-effectiveness of PMMA-based dentures, making them a preferred choice for both patients and dental professionals [11]. Various methods have been employed for denture base fabrication. Heat activation, involving heat injection techniques and polymerization using a water bath or microwave oven, has been used [12]. Polymethyl methacrylate denture base material was typically supplied in powder and liquid forms [13]. A recent innovation in denture base materials is the VertexTM ThermoSens thermoplastic material, which employs thermal energy for curing [14].

"Thermoplastic" refers to polymers that soften when heated and solidify upon cooling [15]. These polymers, composed of linear and/or branched chains, exhibit molecular movement beyond their glass transition temperature, allowing for molding and shaping while softening [16,17]. Upon cooling, they retain their formed shape. Reheating enables reshaping due to the reversible setting reaction, owing to weak bonds between molecular chains. The hardness of thermoplastic polymers indicates their abrasion resistance and surface strength [18,19]. Lower hardness levels increase susceptibility to scratches, surface damage, and potential dimensional changes from mechanical brushing or chewing hard foods [20].

Flexible denture base materials are conveniently packaged in cartridges of various sizes [21]. These thermoplastic materials are typically polyacetal or polyamide-nylon, specifically belonging to the super polyamide category within the nylon family. Nylon, derived from dicarboxylic acid, amino acid, diamine, and lactams, is the foundation for these resins. The fabrication of flexible denture base prostheses relies on the injection molding technique [22].

The Vertex ThermoSens stands as an innovative, virtually unbreakable, rigid thermoplastic denture base material, devoid of monomers [23–25]. It is designed for use in complete or partial denture bases, bridge constructions, and temporary crowns. Comprising microcrystalline polyamide material with pigments, it becomes a suitable option for patients with monomer allergies [26,27]. The molding process for Vertex ThermoSens involves an injection technique, which can be performed using automatic or manual injection machines [28,29]. The inherent flexibility of these thermoplastic denture base materials makes them particularly suitable for removable partial dentures, producing durable and comfortable appliances [30].

While polyamide materials boast robust mechanical attributes, there is potential for enhancing their texture by modifying the technological parameters of their injection process [31,32]. This altered surface must also be able to withstand impacts that might escalate roughness or compromise material quality [33]. Achieving these objectives could lead to an improved material surface that resists microbial adhesion and retains its structural integrity. This deduction supports the notion that Surface 1 absorbed many of the gases, thereby fostering the creation of numerous pores [34,35]. Consequently, it can be inferred that Surface 1 predominantly absorbs the artificial saliva, which corresponds to the lower side of the casting or the side that encounters the oral mucosa. This scenario is undesirable due to its potential to facilitate contamination of the polymer with pathogenic microorganisms and the subsequent development of colonies [36,37].

Thermoplastic resins offer numerous advantages compared to traditional powder or liquid resin systems. These include elevated flexural and impact strength, remarkable flexibility, transparency, significant resistance to creep and fatigue, exceptional wear properties, and solvent resistance [38]. They also exhibit low water absorption, minimal residual monomer content, limited porosity, reduced accumulation of biological materials, and diminished odor and staining [39]. Additionally, they demonstrate heightened dimensional

and color stability. With a metal-free microcrystalline structure, finishing and polishing processes are simplified, akin to acrylic resins [40]. Their flexibility reduces stress transmission to adjacent teeth and surrounding tissues, thus lowering the risk of trauma [41]. Moreover, their esthetic appearance closely resembles oral tissues, eliminating the need for the metal clasps commonly used in traditional metallic partial dentures [42]. Notably, Vertex ThermoSens exhibits a lower flexural modulus and a higher flexural strength compared to conventional denture base materials after a year of water storage [43].

Water absorption, a characteristic of dental materials, causes changes in size and weight [44]. Acrylic polymers tend to absorb water, gradually expanding over time. This expansion occurs in three dimensions and is influenced by the duration of water immersion until equilibrium is reached [45]. However, the equilibrium water content must stay below 32 $\mu g/mm^3$. Water absorption can release internal stresses developed during manufacturing [46], potentially altering the shape of removable dentures [34]. Frequent wetting and drying should be avoided to prevent material aging and deformation in prosthetic restorations [47]. As dental resin dries, it expels water, causing polymer chains to revert to their original state [48]. Rehydration leads to chain expansion, creating minor fluctuations that can result in microcracks and, under mechanical stress, fractures in removable dentures. Saliva absorption prompts linear expansion, with levels assessed through specific laboratory tests according to ISO standards [49].

Several significant drawbacks associated with polyamide dentures include the propensity for plaque accumulation and substantial alveolar bone resorption in edentulous regions. These issues stem from the absence of a conventional removable partial denture design, which is a primary factor contributing to the limited duration of oral use for polyamide dentures [50]. Plaque buildup poses a concern for oral hygiene and can lead to various dental problems, while the high degree of alveolar bone resorption in areas lacking teeth compromises the structural integrity of the denture's foundation. Consequently, these factors collectively contribute to the relatively short lifespan of polyamide dentures within the oral cavity [51].

A surface hardness test is essential since it determines a material's susceptibility to scratching [52]. The chemical composition of thermoset elastomers differs significantly from that of thermoplastic elastomers, owing to their different cross-linking mechanisms [53]. Cross-linking in thermoset polymers includes the creation of covalent bonds during the polymerization process [54]. This cross-linking is a critical structural ingredient that gives the material notable elastic properties. When compared to high-impact acrylic resin, thermoplastic materials have superior flexural strength [55].

The purpose of this study was to investigate the surface roughness, hardness, and absorption of ThermoSens denture base material after three different times of immersion in artificial saliva. The null hypothesis is that there is no significant difference in the investigated properties between the selected surfaces and time frames of observation.

2. Materials and Methods

The objective of this present study was to examine alterations in surface hardness, roughness, and absorption of the denture base polymer Thermosens (Vertex Dental, 3D Systems, Soesterberg, The Netherlands) following immersion in artificial saliva for varying durations (7, 14, 28 days).

The sample size calculation and study design were determined prior to the experiment. An a priori power analysis was conducted using the specialized software G*Power version 3.1.9.7. (Heinrich—Heine University, Dusseldorf, Germany), setting a significance level (p value) of 0.05 and a power of 0.70 for a balanced 2-group design. The analysis indicated that 20 specimens were needed per testing group, to meet the specified criteria.

The specimens (n = 20) were fabricated in a rectangular shape (dimensions: length—20 mm, width—20 mm, thickness—3 mm), using the injection molding technique. Dental stone Type III (Elite Model, Zhermack, Badia Polesine, Italy) was employed for investing

the experimental samples, with the flask being preheated to 30 °C before the injection molding process.

Injection processing took place at a polymer temperature of 290 °C, operating under a pressure of 6 bar, and maintaining the pressure for approximately 3–4 min for polymer solidification within the flask. The arrangement of the experimental specimens within the flask is depicted in Figure 1.

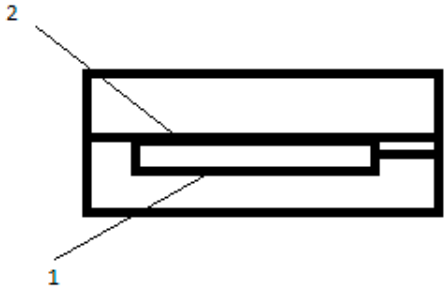

Figure 1. The position of the specimen in the injection mold.

Following the completion of the curing process, the test samples underwent a cleaning procedure to eliminate any residual particles of dental stone. Subsequently, measurements were conducted both prior to submersion in artificial saliva and after immersion periods of 7, 14, and 28 days. Additionally, measurements were performed 7 days after the removal of the test specimens from the glass container (Figure 2).

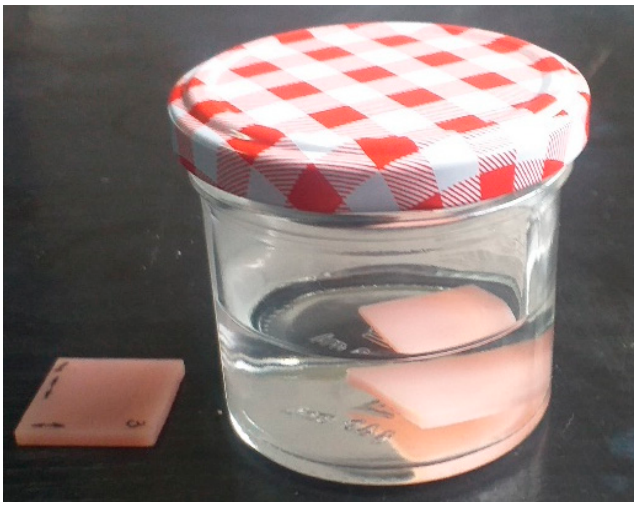

Figure 2. Test specimens before and after immersion in artificial saliva.

A Mitutoyo Surftest 4 roughness meter (Mitutoyo, Aurora, IL, USA) was applied to measure the roughness of the test samples. The Surftest® SJ-310 (Mitutoyo, Aurora, IL, USA) enhances productivity through its adaptability and efficiency, boasting precise measurements (with a resolution of 0.002 µm within a 25 µm range), rapid measurement capabilities (up to 0.75 mm/s), and a variety of 11 interchangeable detector tips. Additionally, it offers features such as the ability to detect gear tooth surfaces, further contributing to its overall versatility and increased throughput (Figure 3).

The roughness measuring instrument comes with a diamond-tipped needle that, as it moves, records changes in the surface profile by detecting the lowest and highest points. These data are then sent to the writing device, and the surface's roughness characteristics are shown on the display. Once the measurements are complete, the device calculates and displays the average roughness value based on the collected data. The surface roughness of the test specimens on Surface 1 and Surface 2 was assessed in two orientations: along the injection direction (1.1 and 2.1) and perpendicular to it (1.2 and 2.2).

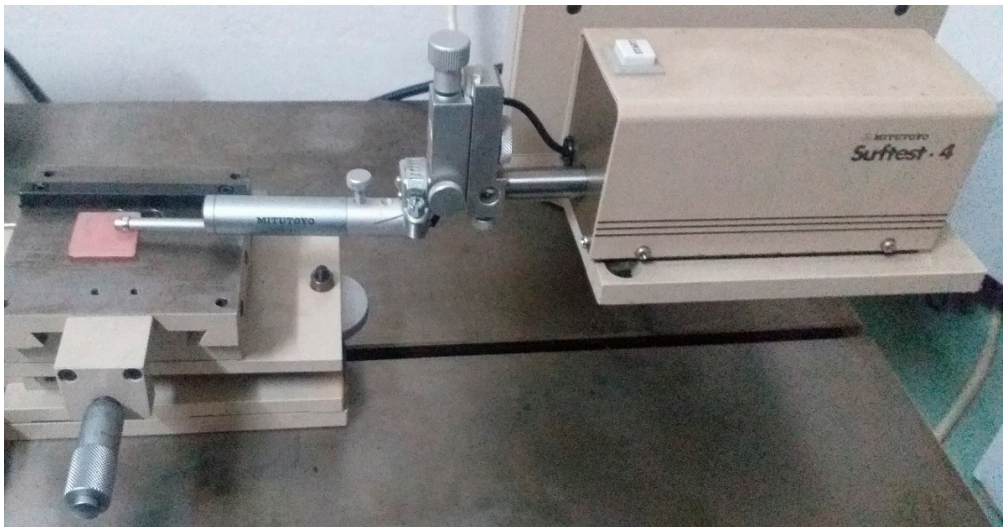

Figure 3. Measuring roughness using the Mitutoyo Surftest 4 roughness meter.

The hardness evaluation of the ThermoSens polymer test samples, was conducted using the Shor method, employing the D—HSD scale. This technique, classified as elastic-dynamic, involves dropping a tip from a specific height and then measuring the rebound distance (Figure 4).

Figure 4. Hardness measurement using the EQUOTIP hardness tester (Screening Eagle Technologies AG, Zurich, Switzerland).

The measurements were executed utilizing an EQUOTIP hardness testing device (Screening Eagle Technologies AG, Zurich, Switzerland) as illustrated in Figure 4. This device allows for convenient assessment of hardness in various items, including polished components and surfaces that have undergone heat treatment. Hardness evaluations are conducted through three techniques: dynamic rebound testing based on the Leeb method, the static Portable Rockwell hardness test, and the Ultrasonic Contact Impedance (UCI) approach.

The data collected underwent statistical analysis utilizing one-way ANOVA, followed by a comparison of mean values using the Tukey post hoc test with a significance level set at $\alpha = 0.05$. This approach aimed to determine whether there was a significant relationship between the type of material used and the recorded water sorption values. By

applying this statistical technique, the study sought to elucidate any potential correlations between material characteristics and water absorption behavior over different periods, thus providing valuable insights into the performance and suitability of the materials under investigation.

3. Results

3.1. Surface Roughness

The roughness of the test specimens on Surfaces 1 and 2 was evaluated in two directions: parallel to the injection direction (1.1 and 2.1) and perpendicular to it (1.2 and 2.2). The outcomes of these measurements are presented in Tables 1 and 2.

Table 1. The average value of the roughness Ra [µm] of the investigated surfaces—before immersion, after 7 days, and after 14 days (p value < 0.05).

	Control Group (Before Immersion)				**After 7 Days (p < 0.05)**				**After 14 Days (p < 0.05)**			
Direction	1.1	1.2	2.1	2.2	1.1	1.2	2.1	2.2	1.1	1.2	2.1	2.2
Ra [µm]	0.22	0.32	1.07	1.95	0.25	0.36	1.03	1.88	0.25	0.36	1.00	1.88

Table 2. The average value of the roughness Ra [µm] of the investigated surfaces—after 28 days, 7 days after withdrawal.

	After 28 Days (p < 0.05)				**7 Days after Withdrawal (p < 0.05)**			
Direction	1.1	1.2	2.1	2.2	1.1	1.2	2.1	2.2
Ra [µm]	0.25	0.39	1.00	1.86	0.22	0.26	1.09	1.97

Figure 5 presents an interactive plot of the mean values, standard deviations (SD), and the significance of hardness for the tested groups (control group, Surface 1, and Surface 2) across different periods of observation. During the "7 days after withdrawal" period, statistically significant differences were observed for both Surface 1 and Surface 2. Notably, the mean values were comparatively higher for Surface 2.

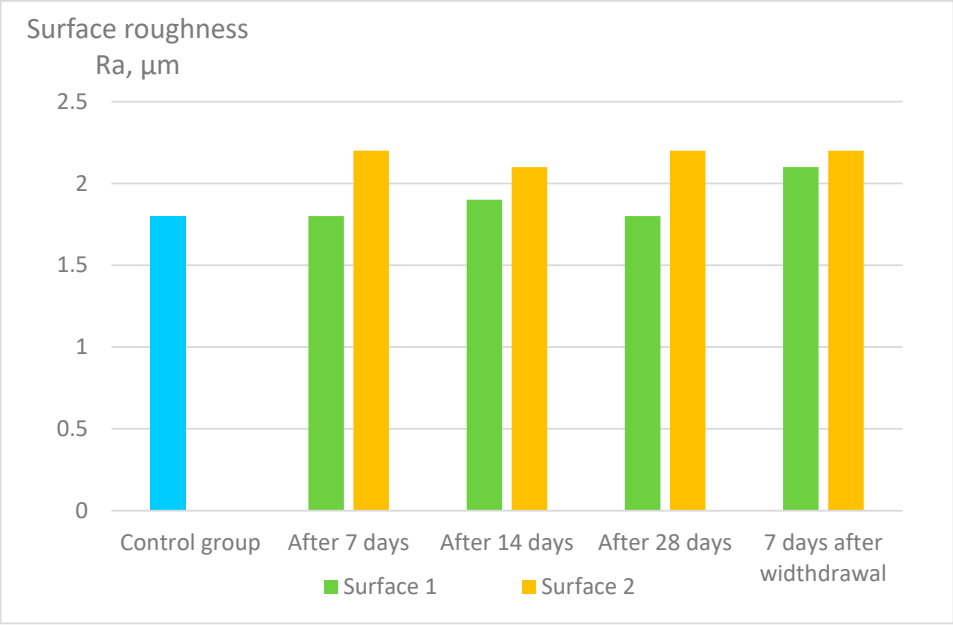

Figure 5. Mean and SD values for the investigated Surface 1 and Surface 2 for the tested periods.

Interestingly, the lowest mean values were identified within the time frames spanning 7 days and 14 days. This observation underscores the relationship between the duration of the test and the resultant mean values pertaining to surface roughness. This trend suggests that the extent of the test duration plays a role in influencing the recorded mean values for surface roughness.

3.2. Surface Hardness

The material's hardness is determined by statistical analysis (one-way ANOVA) that correlates rebound values for Surface 1 and Surface 2 with hardness levels. The outcomes of these assessments have been presented in Figure 6.

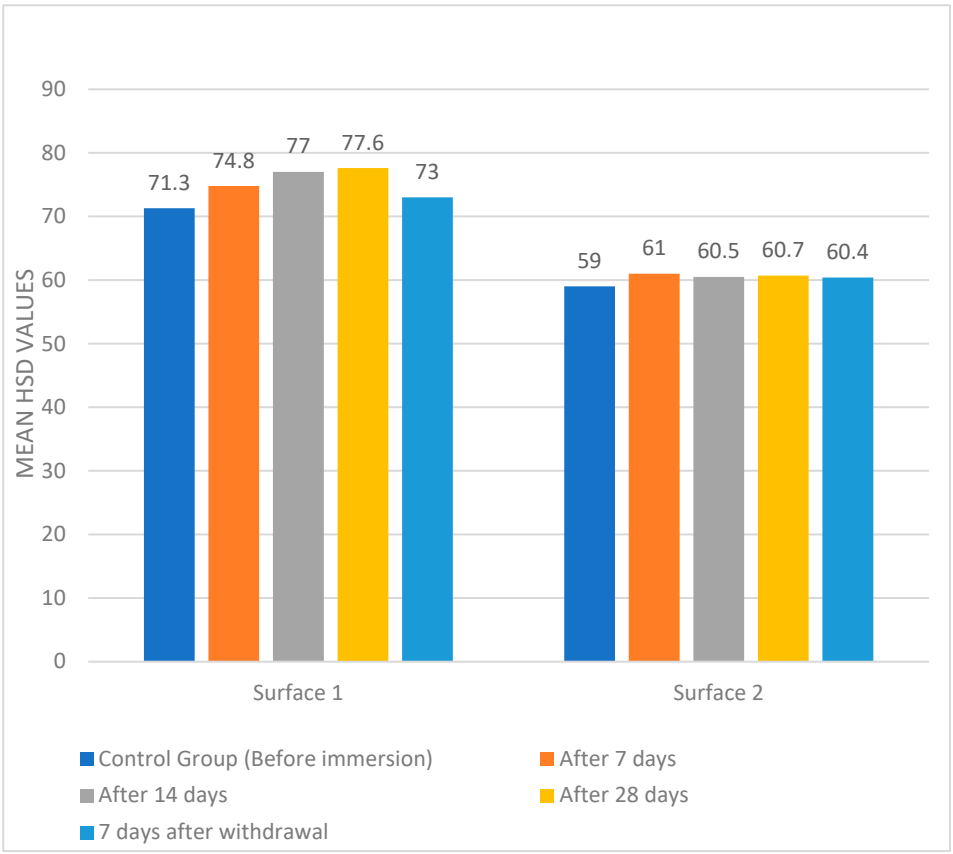

Figure 6. The mean value of the HSD hardness of the investigated surfaces.

Regarding the behavior of Surface 1, a discernible and statistically significant shift became evident within the timeframes of both 14 and 28 days. This alteration was marked by mean values of 77 and 77.6, respectively, signifying a substantial change. Delving into the characteristics of Surface 2, its mean values unveiled pronounced disparities in comparison to those exhibited by Surface 1. Notably, the mean values for Surface 2 were consistently lower. This contrast reached its zenith after the 28-day period, suggesting a particularly noteworthy divergence in behavior. Conversely, the control group registered the lowest mean value, establishing a clear benchmark for comparison.

The juxtaposition of these outcomes underscores the presence of distinctive patterns in behavior between the two surfaces as time progresses. Surface 1 displayed a notable increase in mean values over the 14- and 28-day periods, whereas Surface 2 consistently demonstrated lower mean values. This divergence implies that the surfaces react differently to the conditions, revealing the significance of the underlying characteristics and properties of each surface type.

3.3. Absorption after Immersion in Artificial Saliva

To assess the level of absorption of the test samples, the employment of highly accurate weighing scales is imperative. The specimens have been dried to their optimal mass. When measuring the mass of the analyzed Vertex Thermosens polymer and other polymer specimens investigated in our studies (Figure 7), a Sartorius balance (Sartorius Stedim Filters Inc., Yauco, Puerto Rico) was employed, capable of measuring mass up to the fourth decimal place. This is succeeded by submerging the specimens in synthetic saliva, which is formulated by a chemist using a specific recipe, for three time spans (7 days, 14 days, and 28 days). Subsequently, the updated weight of the samples is determined after they have absorbed water.

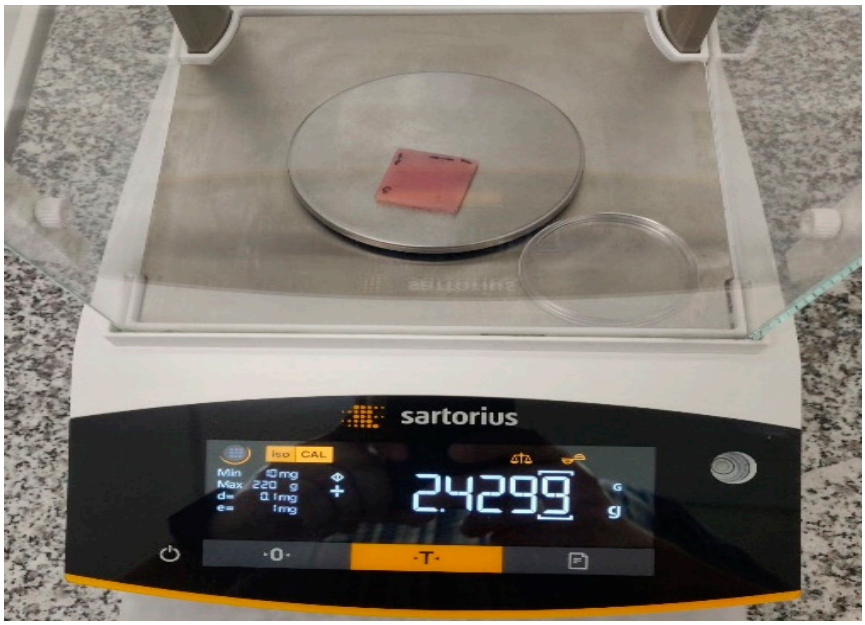

Figure 7. Measuring the mass of a test body with a Sartorius balance (Sartorius Stedim Filters Inc., Yauco, Puerto Rico).

To statistically analyze the data garnered from the investigation, a dispersion analysis statistical technique was employed (specifically, a one-way ANOVA) for the time intervals (with a confidence level of $\alpha < 0.05$). The objective was to ascertain whether a relationship exists between the material type and the observed water sorption values.

During the test that involved comparing water sorption values obtained after 7 days with the other periods, it was observed that the value obtained for parameter p was less than 0.05, which is significantly smaller than the significance interval. Consequently, it can be inferred that a clear association exists between the immersion period and the resulting water sorption values. Similarly, when the same statistical approach was applied to a 14-day period, where the obtained water sorption values were again linked to various times of immersion, the calculated p value was markedly lower than 0.05. Thus, one can deduce that a definite connection exists between the duration and the recorded water sorption values over a 14-day timeframe.

In an examination, where the acquired sorption values after 28 days were contrasted against different immersion periods, it was ascertained that the calculated p value is significantly below the threshold α of 0.05. This outcome implies a clear and direct correlation between the time and the resulting sorption values (Figure 8).

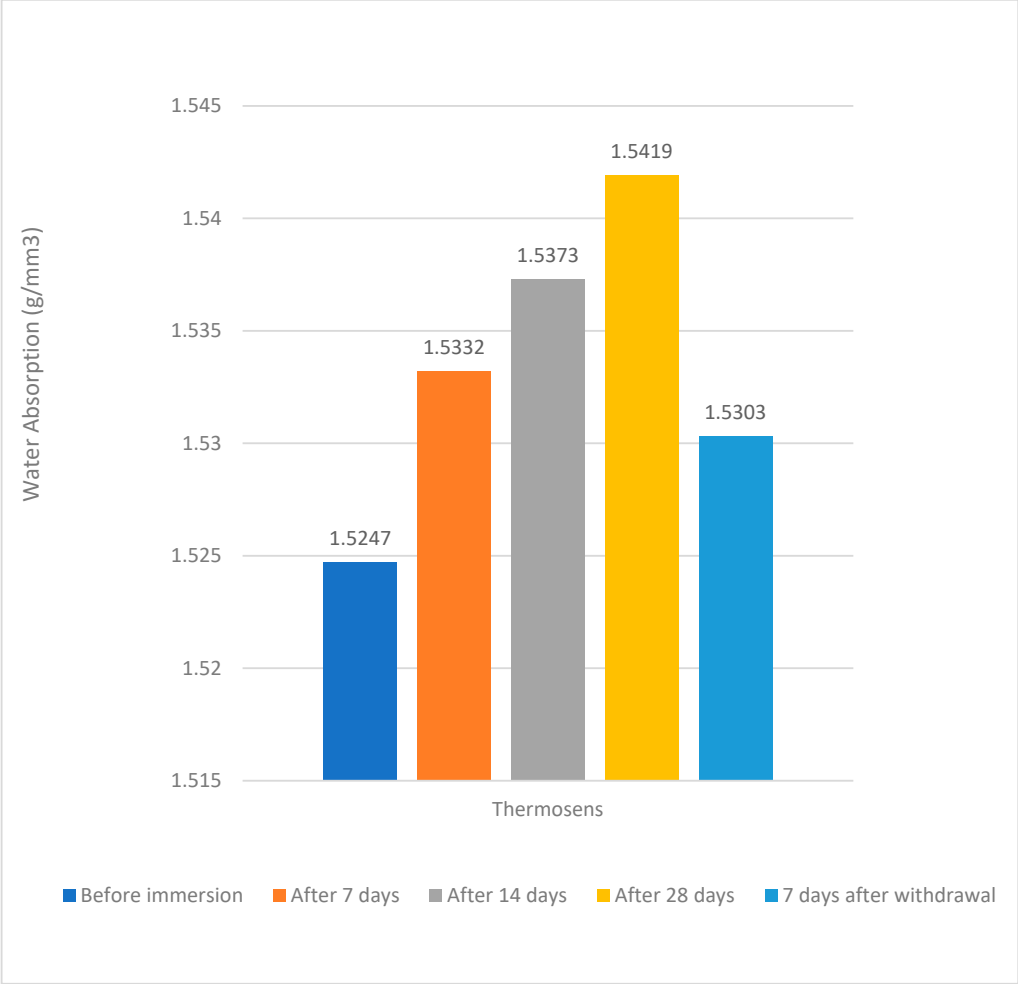

Figure 8. The water absorption of the experimental specimens after immersion in artificial saliva for different time frames.

A Tukey's Honest Significant Difference post hoc test was conducted to compare each period with the others. Table 3 presents the results of a comparative analysis of mean values, standard deviations, p values, and 95% confidence intervals for different groups and time points. The groups are categorized into a control group and various time points after withdrawal. Each cell in the table represents a comparison between two different time points within the same group or between the control group and another time point.

The observed mean difference between the group "After 7 days" and the group "After 14 days" demonstrates statistical significance, revealing a mean decrease of 0.229414. This finding indicates a notable change in the variable of interest over this period. Our confidence in this result is bolstered by the 95% confidence interval, which suggests that we can be reasonably confident that the true difference lies between −0.28645 and −0.17238.

Moreover, within the control group, the comparison with the period 7 days after withdrawal yields a substantial mean difference of −0.358741, alongside a standard deviation of 0.027897. This difference is deemed statistically significant, with a p value of less than 0.01, signifying that the observed change is highly unlikely to be a result of random chance. The corresponding 95% confidence interval, ranging from −0.44891 to −0.31034, reinforces our certainty in the magnitude and direction of this difference.

In summary, these results show that there are significant differences in the variable of interest between the specified groups and time points, providing important insights into the dynamics of the studied phenomenon.

Table 3. Tukey's Honest Significant Difference post hoc test for multiple comparisons.

(I) V2	(J) V2	Mean Values (I–J)	Standard Deviation	*p*	95%—Interval of Confidentiality	
					Lower	Upper
Control group	7 days	−0.229414 *	0.022067	<0.01	−0.28645	−0.17238
	14 days	−0.291271 *	0.022067	<0.01	−0.34831	−0.23423
	28 days	−0.349271 *	0.022067	<0.01	−0.40631	−0.29223
	7 days after withdrawal	−0.358741 *	0.027897	<0.01	−0.44891	−0.31034
After 7 days	Control group	0.229414 *	0.022067	<0.01	0.17238	0.28645
	14 days	−0.061857 *	0.022067	0.028	−0.11889	−0.00482
	28 days	−0.119857 *	0.022067	<0.01	−0.17689	−0.06282
	7 days after withdrawal	−0.120237 *	0.026717	<0.01	−0.19879	−0.06992
After 14 days	Control group	0.291271 *	0.022067	<0.01	0.23423	0.34831
	7 days	0.061857 *	0.022067	0.028	0.00482	0.11889
	28 days	−0.058000 *	0.022067	0.045	−0.11504	−0.00096
	7 days after withdrawal	−0.062013 *	0.022067	<0.01	−0.00652	0.11355
After 28 days	Control group	0.349271 *	0.022067	<0.01	0.29223	0.40631
	7 days	0.119857 *	0.022067	<0.01	0.06282	0.17689
	14 days	0.058000 *	0.022067	0.045	0.00096	0.11504
	7 days after withdrawal	0.062023 *	0.022067	<0.01	0.62096	0.15783
7 days after withdrawal	Control group	0.291661 *	0.022097	<0.01	0.23426	0.34641
	7 days	0.061637 *	0.022097	0.028	0.00192	0.11877
	14 days	−0.058020 *	0.022097	0.045	−0.11524	−0.00097
	28 days	−0.062013 *	0.022097	<0.01	−0.00562	0.11271

* The difference in means is significant at the 0.05 significance level.

4. Discussion

The current study aimed to analyze and investigate the surface hardness, roughness, and absorption of the thermoplastic denture base polymer ThermoSens after immersion in artificial saliva.

The findings from the conducted research indicate a subtle alteration in the roughness of the examined surfaces of the test specimens when exposed to artificial saliva from various angles. This phenomenon is likely attributed to the infiltration of liquid into the micro-pores formed during the polymer curing process [56]. The emergence of these pores on the contacting surfaces of the solidifying polymer with the gypsum mold's walls can be attributed to the release of water vapor as a consequence of hygroscopic moisture evaporation from the enclosed gypsum. This deduction is rooted in the fact that the gypsum mold is only heated to 30 °C before injection molding, whereas the necessary temperature to eliminate the entirety of hygroscopic moisture is a minimum of 120 °C. In contrast, the polymer's temperature before injection molding reaches 290 °C, considerably higher than the liquefaction temperature (Twt.) of polyamides, which stands at 220 °C.

Immediately after the injection molding process, the mold temperature is elevated to a level that prompts the release of gases, saturating the outermost layer of the test specimen. This notion is further supported by alterations in the weight of the test samples following exposure to artificial saliva for specific durations. Notably, a weight increase was recorded in the test specimens, with the most pronounced augmentation occurring after a 7-day immersion in the said fluid. Subsequently, a more uniform and smaller increase in weight was observed across the test samples. Helaly et al. [57] conducted a study where they assessed that the polarity of nylon material changes about the length of the chain

connecting the amide groups. Specifically, the material becomes more hydrophilic as the chain length between these amide groups becomes shorter.

Examinations of the test specimens' hardness reveal those changes in Surface 2's hardness post-immersion in a liquid environment are negligible. In contrast, Surface 1's hardness, particularly the side facing the lower plaster half-mold, demonstrates more notable variations. This hardness increase can be attributed to liquid penetrating into the formed pores, rendering the polymer's surface layer more pliable. Consequently, this pliancy leads to higher tip rebound, indicative of greater hardness. In the study of Shata M. [58], their surface hardness was evaluated using a Vickers microhardness tester with a digital display. This was performed to achieve a level and smooth reflective surface, ensuring uniform load distribution, and preventing any scratches that could affect measurement precision. Conducting the surface hardness test is crucial, as it unveils the material's resistance to scratching.

The study of Ucar et al. [59] evaluated a comparison of the hardness of a denture material based on polyamide (Deflex) with another material using injection-molded PMMA as the base, as well as a conventional PMMA material produced through compression molding. The study's findings revealed that the hardness of the Deflex specimens was notably lower than that of the other materials, indicating that the material was not as hard in comparison. Another study conducted by Shah et al. [60] demonstrated that PMMA exhibited higher hardness values when contrasted with flexible resin. This outcome could potentially be attributed to factors such as a higher monomer–polymer ratio in PMMA, the bonding characteristics of the material, and the presence of the methyl-methacrylate monomer. Furthermore, the material might contain cross-linking agents. In contrast, flexible resin showcased lower hardness values and contained fewer cross-linking agents, implying that the presence of cross-linking agents could impact the surface hardness.

Surface roughness stands as a fundamental attribute capable of influencing the durability of removable dentures. An increase in roughness can lead to heightened microbial adhesion, culminating in denture stomatitis [61]. Furthermore, rougher surfaces tend to accumulate more stains and discoloration, undermining the aesthetic appeal of dentures [62]. The surface properties of thermoplastic polymers manifest a range of imperfections and notably elevated roughness [63], creating an environment conducive to the colonization of microorganisms on their surfaces. The mechanical manipulation of thermoplastic materials presents challenges, hindering the attainment of a smooth and lustrous exterior [64]. The absence of this smoothness presents ideal conditions for the attachment of microbial cells.

Water absorption of a substance indicates its ability to attract and take in water during use. The acrylic resin's uptake of water can function as a plasticizer, resulting in softening, color changes, and a decline in its mechanical attributes like hardness, transverse strength, and fatigue threshold [65]. Nonetheless, the absorption of water leads to a three-dimensional expansion, potentially impacting the acrylic resin's ability to maintain its dimensions stably. The outcomes of our study regarding water absorption were in line with those documented by Pfeiffer et al. [66]. They indicated that water uptake in the thermoplastic category was notably lower compared to the control group of PMMA. Furthermore, another researcher [67] highlighted notable distinctions in water absorption among six thermoplastic resins and a conventional PMMA, barring one polyamide resin (Lucitone), which displayed higher water absorption surpassing the maximum ISO standard water absorption values for denture base materials set at 32 $\mu g/mm^3$ [68]. This specific material offers relief from denture-related discomfort owing to its strong flexural attributes and adaptability, ensuring it remains secured in the indentations of the remaining teeth. Moreover, the decreased water absorption and solubility of these thermoplastic resins broaden their range of applications, positioning them as a viable substitute for conventional PMMA acrylic resins in the context of denture base materials.

In addition, it becomes imperative that the flask containing the assembled denture is subjected to elevated temperatures (a minimum of 120 °C) to eliminate hygroscopic moisture [69]. This, in turn, would avert the detrimental effects of released gases on the

product's surface. The integration of a ventilation system is advisable to facilitate the expulsion of gases from the mold cavity during the injection molding procedure [70]. Whenever feasible, it is recommended to apply pastes or coatings to the contact surfaces of the mold cavity before the injection molding process. Elevating the flask and plaster's temperature will inevitably decelerate the polymer's hardening process, resulting in the creation of longer macromolecules [71–73]. This, in turn, will yield enhancements in the mechanical qualities of the polymer product and its surface configuration.

The limitations of the conducted study can be synthesized as follows:

- Due to the meticulous control inherent in this experimental investigation, it has the capacity to yield results that are both specific and pertinent, consistently. This permits the determination of surface roughness, hardness, and absorption values, facilitating the swift assessment of the characteristics of the surfaces of the test specimens of the thermoplastic dental resin when compared to alternative validation methods.
- Secondly, the data could be distorted to appear favorable. However, owing to the substantial disparity between the controlled laboratory setting and the clinical environment, replicating positive outcomes beyond experimental research becomes unattainable.

5. Conclusions

Based on the obtained findings, it can be concluded that after 28 days, Surface 1 had the highest surface hardness values, while Surface 2 (the control group) had the lowest. Surface roughness peaked at direction 2.2 before immersion and 7 days after removal. Absorption levels were lowest in the control group but highest after 28 days. These findings underscore how injection molding parameters affect the quality and surface characteristics of polymers for denture making. Higher flask and plaster temperatures slow down polymer solidification, resulting in larger macromolecule formation, which enhances mechanical properties and surface features.

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