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COLORATION STUDY HEAT-CURED POLYMER MATERIALS FOR DENTURE BASE

STUDI PEWARNAAN MATERIAL HEAT CURE POLYMERS UNTUK GUSI TIRUAN

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ABSTRAK

Warna material gusi tiruan penting dalam kedokteran gigi untuk mencapai estetika gusi tiruan yang alami. Tidak ada standar universal untuk warna gusi tiruan, menjadikan sulit bagi dokter gigi dan teknisi laboratorium gigi untuk mencapai hasil yang konsisten. Penelitian ini mengusulkan suatu metode untuk mengidentifikasi warna gusi tiruan yang terbuat dari resin polimer yang dipanaskan dengan zat pewarna. Penelitian ini juga meneliti pengaruh penambahan zat pewarna terhadap kekerasan bahan gusi tiruan dan pengaruh perendaman saliva buatan terhadap pewarnaan. Zat pewarna baru, yaitu merah muda (P), merah (M), dan ungu (U), ditambahkan untuk menciptakan warna baru dalam penelitian ini. Tujuh spesimen dari warna terang hingga gelap dibuat. Spesimen yang dihasilkan difoto dan dianalisis menggunakan perangkat lunak Adobe Photoshop untuk mendapatkan nilai L, a*, dan b* untuk setiap spesimen, yang kemudian dianalisis menggunakan rumus CIELAB. Hasil uji kekerasan material menunjukkan perubahan signifikan antara kelompok perendaman dan tanpa perendaman (p-value 0,00<0,05), sedangkan perubahan antara kelompok perendaman 10 hari dan 20 hari tidak signifikan (p-value 0,65>0,05). Pada bahan tanpa penambahan pewarna, nilai kekerasannya adalah 85,3 - 86,3 HSD, sedangkan pada bahan dengan penambahan pewarna, nilai kekerasannya meningkat menjadi 85,5 - 87,7 HSD. Hasil uji perendaman saliva menunjukkan perubahan pada kisaran 2,51 - 5,98 untuk perendaman 10 hari dan 0,85 - 4,22 untuk perendaman 20 hari. Dari hasil tersebut menunjukkan sebagian besar perubahan warna masih di bawah ambang batas penerimaan klinis yaitu kurang dari 4,1, sehingga dapat disimpulkan bahwa perubahan warna yang terjadi setelah dilakukan perendaman masih dapat diterima secara klinis.*

Kata kunci: *Gusi Tiruan; Stabilitas Warna; Kekerasan Material.*

ABSTRACT

The color of denture base material is important in dentistry to achieve a natural gingival aesthetic. No universal standard for denture base color, due to it difficult for dentists and dental laboratory technicians to achieve consistent results. This study proposes a method for identifying the color of artificial gums made from heated

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cure polymers with coloring agents. This study also examined the effect adding color agent on the hardness of denture base material and the effect of artificial saliva immersion on coloring. New coloring agents, namely pink (P), red (M), and purple (U), were added to create new colors in this study. Seven specimens from light to dark colors were made. The resulting specimens were photographed and analyzed using Adobe Photoshop software to obtain the L, a*, and b* values for each specimen, which were then analyzed using the CIELAB formula. The results of the material hardness test showed a significant change between the immersion and non-immersion groups (p-value 0.00<0.05), while the group between 10-day and 20-day immersion showed no significant change (p-value 0.65>0.05). In materials without added color, the hardness value is 85.3 - 86.3 HSD, while in materials with added color, the hardness value increases to 85.5 - 87.7 HSD. The results of the saliva immersion test showed changes in the range of 2.51 - 5.98 for 10 days of immersion and 0.85 - 4.22 for 20 days of immersion. Based on these results, most of the color changes are still below the clinical acceptance threshold of less than 4.1. Therefore, it can be concluded that the color changes that occur after soaking are still clinically acceptable.*

Keywords: *Denture Base; Color Stability; Material Hardness.*

INTRODUCTION

An attractive smile enhances aesthetic satisfaction and positively influences social interactions, happiness, success, and health (Abdurachman, 2018). In dentistry, accurate color matching of restoration materials, including denture bases, is crucial for achieving aesthetic harmony between white teeth and pink gums (Montero et al., 2014). Since approximately 80% of the population displays their gums when smiling (Tjan et al., 1984), gum color plays a significant role in overall aesthetics.

However, gum color varies widely due to keratinization, pigmentation, medication, smoking habits, age, and race (Gómez-Polo et al., 2024). An unnatural denture base color can lead to an unsatisfactory appearance, affecting patient confidence. Mimicking natural gum color remains a complex challenge, further complicated by the absence of standardized color guides for gum shades (Gómez-Polo et al., 2023).

Dental color guides, such as the Vita Classical guide, are essential for selecting and communicating colors in dental restorations, offering an international standard that increases efficiency among dental professionals (Pascal et al., 2016). Although dental color guides are well-established, gingival color guides are still limited, varying across manufacturers without universally accepted standards, which makes it difficult to achieve consistent results (Díaz Hernández et al., 2023).

A standardized denture-based color reference hinders communication between dentists and technicians (Hernández et al., 2023). This forces subjective visual selection with low accuracy (Gómez-Polo et al., 2024; Mokashi et al., 2024). Although studies have explored gingival color space for diverse populations, they often only provide color coordinates without translating them into usable physical color guides, leaving gaps in subjective color-matching procedures. Developing a comprehensive gingival color guide that includes natural color variations is essential for producing restorations that closely resemble the patient's natural gum color.

The standard often used for color analysis in dentistry is the CIELAB color space from CIE. CIELAB color space is a Cartesian coordinate system defined by three colorimetric coordinates: L*, a*, and b*. The L* coordinate indicates brightness, with values ranging between 0 and 100 (vertical axis), while the a* coordinate indicates the amount of red/green (horizontal axis), and the b* coordinate indicates the amount of blue/yellow (horizontal axis) (Díaz Hernández et al., 2023).

Heat cure polymer acrylic resin is the most used material for denture bases due to its ease of availability, simple manufacturing process, biocompatibility, sufficient strength to withstand chewing forces, and ease of repair in case of damage or fracture (Budiharjo et al., 2014). However, it has several drawbacks, including its tendency to absorb liquids, susceptibility to porosity, low impact and pressure strength, and limited flexibility, leading to breakage if dropped (Somani et al., 2019). Adding colorants to the resin can alter its functional groups and hardness, depending on the type and amount of colorant used. FTIR and hardness testing are essential to assess these effects. Color stability is also crucial, as continuous exposure to saliva, which contains enzymes, proteins, and ions, may trigger chemical reactions that affect the color and physical properties of the material (Nowakowska-Toporowska et al., 2016). The lack of a standardized gum color reference guide complicates communication between dentists and laboratory technicians, leading to inconsistent restoration results.

The main objective of this study was to determine the process and composition of coloring heat-cure polymers for denture bases. Additionally, this study aimed to determine the effect of coloring on material hardness and the impact of artificial saliva immersion on the stability of the color that has been produced.

The coloring results obtained are expected to increase the choice of color shades already present in heat-cured polymers. The increase in color shade will result in a high aesthetic adjustment, resulting in an increase in the quality and patient satisfaction of the denture prosthesis produced.

Materials and Methods

The first stage of this research starts with preparing tools and materials, including making molds on cuvettes using plaster casts. After the mold is formed, specimens are made by mixing denture-based polymers with HUGE heat-cured acrylic powder with liquid heat cure and coloring materials. The coloring agents are oil-based food colorants (pink, red, and purple). These dyes have the same mode of action as dyes made for resins (Levintsa, 2021). The colors used in this study are pink, red, and purple. Specimens were made in seven colors with 54 x 26 x 6 mm dimensions. The detailed compositions of the polymer powders, monomer liquids, and colorants used in this study are presented in Table 1.

The next stage is the curing process, which is carried out in a water bath for 90 minutes. The last stage is the finishing process, which is the process of smoothing the specimen using sandpaper (no. 400).

Seven specimens were tested using Fourier Transform Infrared Spectroscopy (FTIR) type Shimadzu IRAffinity-1S (Japan) and hardness testing using durometer type shore D (China) with the loading force of 10 lb (4536 g) at an angle perpendicular to the specimen. After that, the specimen was cut into two parts and tested for immersion in artificial saliva for 20 days. The results of this test are used for the data analysis process.

Table 1.
Coloring composition table

Color Code	Composition				
	Powder (gr)	Liquid (ml)	Pink (drops)	Red (drops)	Purple (drops)
A	14.04	6			
B	14.04	6	1		
C	14.04	6	2		
D	14.04	6		1	
E	14.04	6		1	1
F	14.04	6	3		1
G	14.04	6	1		1

Source: Research documetation (2025)

The curing process involves placing the cuvette and pressing it in a heating pot filled with water from a cold state, bringing it to a boil for 30 minutes, and maintaining boiling conditions for 60 minutes. Afterward, the heater is turned off, and the cuvette can cool naturally before carefully removing the specimen. After removal, the specimens underwent a finishing process in which the hardened resin was removed using a small drill, and the surface was polished or sanded to achieve smoothness.

FTIR testing was performed on each specimen for chemical group analysis to evaluate the changes before and after adding the color mixture (Fadlelmoula et al., 2022). Hardness testing, following the ASTM D2240 standard, was performed using a type D hardness tester to assess the hardness of the specimens under three conditions: without immersion, after 10 days of saliva immersion, and after 20 days (Beer Mohamed et al., 2022; Broitman, 2017). Saliva immersion testing was conducted in artificial saliva for 20 days to evaluate the resin's weight change and color stability. The composition of artificial saliva is shown in Table 2 (Zheng et al., 2003).

Table 2.
Compositions of artificial salivary fluid

Composition	Quantity
NaCl	0.4 g
KCl	0.4 g
CaCl2.2H2O	0.795 g
NaH2PO4.2H2O	0.78 g
Na2S.9H2O	0.005 g
Urea	1 g
Distilled water	1000 ml

Source: Research documetation (2025)

Photographs of specimens were taken in a mini studio with lighting conditions according to dental room standards (500-1000 lux) and a white background (Nurcahyo, 2023). The mini studio is a square room with dimensions 24.5 cm long, 24.5 cm wide, and 22.5 cm high. The lighting used is a ring light lamp measuring 26 cm, with a color temperature of 6500-7000K (Annisa et al., 2023). Specimens were photographed using a Samsung Note 10+ cellphone camera (12 MP camera, 1080 x 2280pixel resolution) with adjusted pro settings, ISO50, aperture F1.5, WB 5200K, focal length 4.32, and shutter speed 1/180 at a distance of 30 cm from the object (Listari & Siham, 2024). Photos were taken sequentially, comparing specimens without immersion, after 10 days of immersion, and after 20 days. Figure 1 illustrates the photography settings.

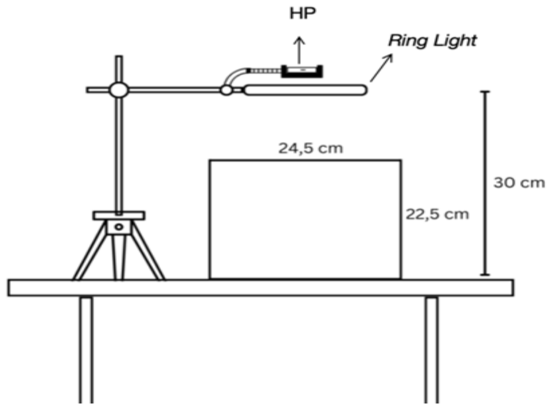


Figure 1
Schematic illustration of photo capturing process of the specimens
Source: Research documetation (2025)

Data analysis was performed using Microsoft Excel and Adobe Photoshop CC 2021, software that claims to recognize colors (Adobe, 2024). The T-test: Paired Two Samples for Means analyzed the change in hardness among the different immersion groups, while the photo analysis provided L*, a*, and b* color values (Listari & Siham, 2024). These values were evaluated using the CIELAB formula in Equation 1.

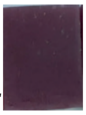
$$\Delta E_{ab} = (\Delta L^2 + \Delta a^2 + \Delta b^2)^{1/2} \quad \text{................(1)}$$

RESULT AND DISCUSSION

Coloring

Seven specimens with different colors were obtained from the coloring results, resulting in a color catalog and its composition, as shown in Table 3.

Table 3.
Color catalog and its composition

Color Code	Composition				
	Powder (gr)	Liquid (ml)	Pink (ml)	Red (ml)	Purple (ml)
 A	14.04	6			
 B	14.04	6	0.03		
 C	14.04	6	0.06		
 D	14.04	6		0.03	
 E	14.04	6		0.03	0.03
 F	14.04	6	0.09		0.03
 G	14.04	6	0.03		0.03

Source: Research documetation (2025)

Seven specimens that have been obtained are then analyzed for color L*, a*, and b*, with detailed results shown in Table 4.

The L* value represents brightness, where zero indicates black and 100 indicates white. The data shows that darker specimens exhibit lower L* values. The* value represents a green-to-red scale, with negative values indicating green and positive values red. The analysis shows a predominant red color in all specimens, with darker specimens exhibiting lower a* values. Similarly, b* values represent the blue-to-yellow scale, where negative values indicate blue and positive values yellow (Díaz Hernández et al., 2023). Darker specimens have lower b* values, tending to be blue. The ΔE value, which is calculated based on the reference color (lightest specimen), increases as the specimen becomes darker, reflecting a greater color difference.

Table 4.
L*, a*, b* values of seven specimens

Color Code	Composition			ΔE
	L*	a*	b*	
A	35.8	44.2	23.2	0.0
B	36.2	45.2	22.4	1.3
C	37.6	45	20.2	3.6
D	32.8	45.6	20.8	4.1
E	29.6	34.4	12.2	16.0
F	24.2	15.2	-3.2	40.9
G	25.4	13.4	-3.2	41.9

Source: Research documetation (2025)

Saliva Immersion Testing

The results of the specimen immersion test on weight change can be seen in Figure 2. Acrylic resin, used as gingival material, absorbs water gradually over time. Figure 2 is the result of weight gain in specimens A and F.

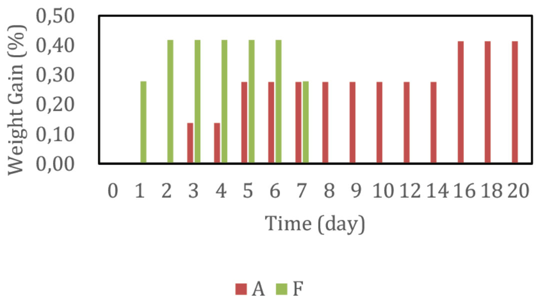


Figure 2.
Graph of Weight Change for 20 Days
Source: Research documetation (2025)

In specimen A, the weight gain experienced an exponential increase from the initial weight of 7.25 grams to 7.28 grams. In specimen F, there was a spike in weight gain from the beginning of immersion until the sixth day, from the initial weight of 7.18 grams to 7.21 grams, which then decreased on the seventh day and thereafter to 7.18 grams again. This can occur because specimen F gets the most coloring material, so more monomers do not bond with each other, and they absorb more water at the beginning of immersion.

Overall, water absorption ranged from 0% to 0.41%, with a maximum weight gain of 0.3 grams, categorized as minimal. This is in line with the findings of (Al-Nori et al., 2007), where acrylic resins immersed in distilled water for 7 days and 1 month showed weight increases of 1.0168 grams and 1.8221 grams, respectively. In addition, the water absorption rate remained below the standard value of 0.69 mg/cm² set by (Anusavice, 2003), possibly due to effective polymerization during curing, thus minimizing the path of liquid absorption.

FTIR Testing

FTIR testing is done to determine the type of material used. Based on the data obtained from the test results, it is known that the material belongs to the PMMA material type. This can be seen from the absorption value of the compounds in the material, as shown in Figure 3 (Sadeq et al., 2020). Based on (Arifiyanto et al., 2020) wavelengths to determine functional groups in infrared waves, we can know the bonds in PMMA compounds shown in Table 5.

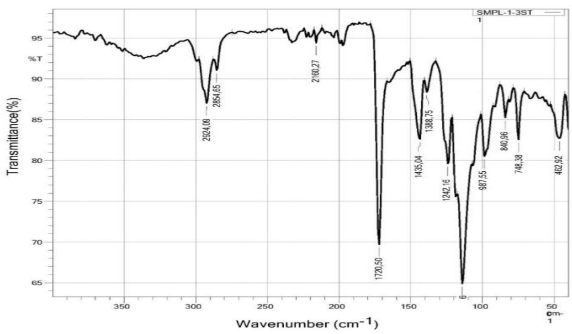


Figure 3.
Figure Analysis of Functional Groups in FTIR Results
Source: Research documetation (2025)

Table 5.
Bonds contained in PMMA compounds

Wave Numbers (cm-1)	Chemical Group
987,55	C-H
1141,86	C-O
1242,16	C-O
1388,75	C-H
1435,04	C-H
1720,50	C=O
2854,65	C-H
2924,09	C-H

Source: Research documetation (2025)

In addition to determining the type of material, the FTIR test also aims to determine the effect of the addition of coloring on the material. The results of the FTIR test on the seven specimens can be seen in Figure 4.

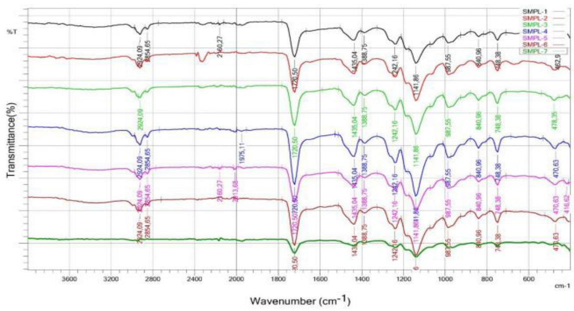


Figure 4.
FTIR test results of seven specimens
Source: Research documetation (2025)

The graph in Figure 4 shows that the seven specimens have similar Infrared transmittance peaks. This indicates that there is no change in functional groups (identical). Therefore, it can be concluded that the added coloring material does not affect the PMMA material of each specimen.

Hardness Testing

Figure 5 shows the results of hardness testing in the non-immersion, 10-day immersion and 20-day immersion groups.

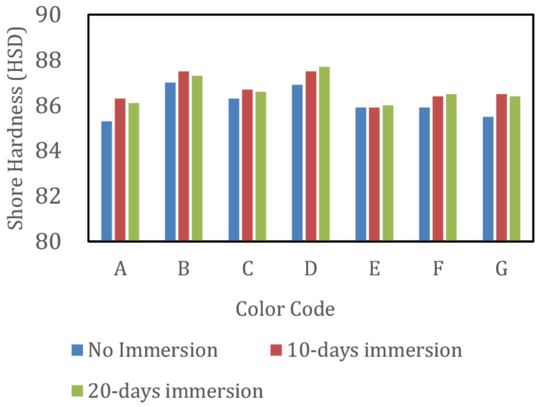


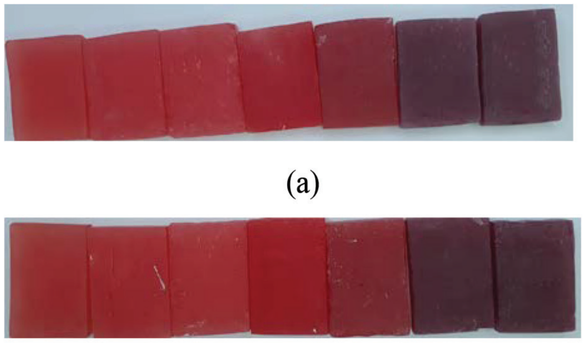
Figure 5.
Hardness Test Results on Seven Specimens
Source: Research documetation (2025)

Figure 5 illustrates the average hardness of the specimens, ranging from 85.3 HSD to 87.7 HSD. Statistical analysis using the t-test: Paired Two Sample for Means showed a significant change in hardness between the immersion and no immersion groups ($p<0.05$), while the change between the 10-day and 20-day immersion groups was not significant ($p>0.05$). Despite these variations, all hardness values remained within the standard range for PMMA resins (80-90 HSD) (Sadeq et al., 2020). These findings align with (Badran et al., 2022), who reported an increase in the hardness of PMMA from 81.2 HSD to 87.1 HSD by incorporating graphene and TiO_2 hybrid nanoparticles.

Notably, the 10-day immersion results showed no increase in hardness for specimen E, while specimens A and G showed the highest increase of 1 HSD. The change between 10 and 20 days of immersion was minimal (0.1-0.2 HSD). The observed increase in hardness likely stems from continued curing, increasing monomer conversion, and completing polymerization in the heat-cured resin, which results in a denser structure with reduced porosity. In addition, liquid absorption during immersion may trigger chemical reactions that further strengthen the resin structure.

Color Stability

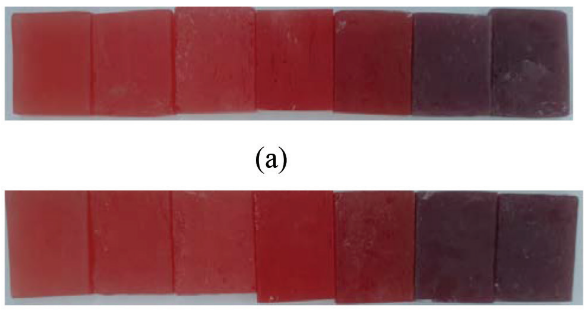
In denture base aesthetics, color stability is an important aspect to consider. In general, denture bases require 17 days to become saturated with water and show the effect of water absorption on color change (Ferracane, 2006). In saliva immersion, color measurements were made on the material after the saturation phase, namely on day 10 and day 20 of immersion. The results of color changes before and after immersion for 10 days and 20 days can be seen in Figure 6 and Figure 7.



(a)

(b)

Figure 6.
Color comparison (a) before immersion and (b) after 10 days of immersion
Source: Research documetation (2025)



(a)

(b)

Figure 7.
Color comparison (a) before immersion and (b) after 20 days of immersion
Source: Research documetation (2025)

Figure 6 shows color photographs of specimens without immersion (a) and after immersion in artificial saliva for 10 days (b). The results of the photos were analyzed for the L*, a*, b* value of the color after immersion, and then the value of the color change or ΔE against the L*, a*, b* color was calculated without immersion. Figure 7 shows photos of the specimen's color without immersion (a) and after immersion in artificial saliva for 20 days (b). The photo results were analyzed for the color's L*, a*,b* value after 20 days of immersion, and then, the color change value or ΔE was calculated against the L*, a*,b* color without immersion. The color change value was carried out on the specimen without immersion in both photos, with the analysis results shown in Table 6.

Table 6.
ΔE values of 10- and 20-days immersion versus no immersion

Color Code	ΔE 10 days immersion	ΔE 20 days immersion
A	2.54	4.22
B	2.51	2.73
C	3.87	2.07
D	5.98	3.52
E	3.68	0.85
F	4.85	1.57
G	5.02	1.66

Source: Research documetation (2025)

The color difference measured in dentistry refers to the 50:50% clinical acceptance threshold value, which is 50% of the color considered acceptable by 50% of observers and 50% not perceived by observers. The clinical acceptance threshold used in this study is based on Gomez-Polo's research, which is 4.1 (Gómez-Polo et al., 2020) and 4.0 (Ren et al., 2015).

Based on Table 6, the analysis results of the ΔE value of each immersion specimen against the specimen without immersion show a change, namely in the range of 2.51 - 5.98 for 10 days of immersion and 0.85 - 4.22 for 20 days of immersion. These results show that most color changes are below the clinical acceptance threshold of less than 4.1, as seen in Figure 8. Therefore, it can be concluded that the color changes that occur after immersion are still clinically acceptable. The

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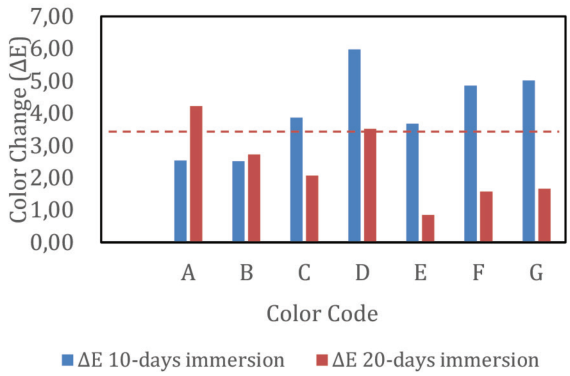

Figure 8.
Color change in 10 and 20days immersion
Source: Research documetation (2025)

Another thing that can be taken from the analysis results in Table 6 is that the value of the color change obtained is inconsistent. Namely, the value of color change is higher in the 10-day immersion than in the 20-day immersion. Several possibilities can cause this. The first is the color change that occurs in specimens without immersion. The second is photo-taking factors related to variations in lighting, photo-taking angles, and camera quality.

CONCLUSION

This study produced seven heat cure polymer resin samples with various colors for denture applications, ranging from light colors (color code A) as a reference to dark colors (color code G). The hardness test results showed that adding colorants did not affect the hardness quality of the material, with hardness values in materials without colorants ranging from 85.3-86.3 HSD and in materials with colorants increasing to 85.5-87.7 HSD. Color stability tests on artificial saliva immersion showed very small color changes and were still clinically acceptable.

Color reading using the photo method analyzed with Adobe Photoshop has limitations in producing accurate data. This is due to lighting factors, the angle of the photo, the quality of the camera, and the software's limitations in providing precise quantitative values. Although this method is practical, the results are less reliable, so it is recommended that future studies use more accurate measuring instruments such as Colorimeters or Spectrophotometers.

BIBLIOGRAPHY

Abdurachman. (2018). *Anatomi Senyum Kajian Kinesiologi*. Airlangga University Press.

Adobe. (2024). *Adobe Photoshop untuk Mac*. Softonic. https://adobe-photoshop.softonic-id.com/mac

Al-Nori, A., Hussain, A., & Rejab, L. (2007). Water sorption of heat–cured acrylic resin. *Al-Rafidain Dental Journal*, *7*(2), 186–194. https://doi.org/10.33899/rden.2007.8961

Annisa, M., Harsini, H., & Nuryanti, A. (2023). The comparison of two programmes to measure color difference (ΔE) from tooth sample photo. *Odonto : Dental Journal*, *10*(2), 257. https://doi.org/10.30659/odj.10.2.257-267

Anusavice, K. (2003). *Philips' science of dental materials* (11th ed.). Elsevier Saunders.

Arifiyanto, M. R., Siswanto, B. D., & Hotsan, B. (2020). Analisa Pengaruh Temperatur dan Kelembaban Terhadap Perubahan Panjang dan Gugus Fungsi Pada Material Plastik PMMA (Polymethymethacrylate)., *4*(2), 159–174. https://doi.org/10.31289/jmemme.v4i2.4057

Badran, A., Hamdy, K., & Rashed, A. (2022). Hardness And Tribological Properties Of Pmma Composite Reinforced By Hybrid Graphene And Tio2 Nanoparticles Used In Dental Applications. *Journal of the Egyptian Society of Tribology*, *19*(2), 36–47. https://doi.org/10.21608/jest.2022.231178

Beer Mohamed, S., Anandhavasan, S., Basheer Ahamed, S., Ajayharish, R., Barathraj, B., Hariprakash, R., Ravichandran, M., & Kaviarasu, C. (2022). Investigation on mechanical properties of hybrid polymer composites for automobile applications. *Materials Today: Proceedings*, *74*, 73–79. https://doi.org/10.1016/j.matpr.2022.11.239

Broitman, E. (2017). Indentation Hardness Measurements at Macro-, Micro-, and Nanoscale: A Critical Overview. *Tribology Letters*, *65*(1), 23. https://doi.org/10.1007/s11249-016-0805-5

Budiharjo, A., Wahyuningtyas, E., & Sugiatno, E. (2014). Pengaruh Lama Pemanasan Pasca Polimerisasi dengan Microwave terhadap Monomer Sisa dan Kekuatan Transversal pada Reparasi Plat Gigi Tiruan Resin Akrilik. *Jurnal Kedokteran Gigi*, *5*(2), 1–13.

Díaz Hernández, A., Celemín Viñuela, A., Gómez-Polo, M., Martín Casado, A. M., & Gómez-Polo, C. (2023). Coverage error and shade-match accuracy in three ceramic gingival systems. *Journal of Prosthetic Dentistry*. https://doi.org/10.1016/j.prosdent.2023.09.002

Fadlelmoula, A., Pinho, D., Carvalho, V. H., Catarino, S. O., & Minas, G. (2022). Fourier Transform Infrared (FTIR) Spectroscopy to Analyse Human Blood over the Last 20 Years: A Review towards Lab-on-a-Chip Devices. *Micromachines*, *13*(2). https://doi.org/10.3390/mi13020187

Ferracane, J. L. (2006). Hygroscopic and hydrolytic effects in dental polymer networks. *Dental Materials*, *22*(3), 211–222. https://doi.org/10.1016/j.dental.2005.05.005

Gómez-Polo, C., Martín-Casado, A. M., & Montero, J. (2023). Fifteen ceramic gingival samples: A proposed gingival shade guide. *Journal of Dentistry*, *138*. https://doi.org/10.1016/j.jdent.2023.104648

Gómez-Polo, C., Martín Casado, A. M., Gómez-Polo, M., & Montero, J. (2020). Colour thresholds of the gingival chromatic space. *Journal of Dentistry*, *103*. https://doi.org/10.1016/j.jdent.2020.103502

Gómez-Polo, C., Montero, J., Quispe, N., Flores-Fraile, J., Portillo Muñoz, M., & Martín Casado, A. M. (2024). Level of Agreement in Subjective Selection of Gingival Colour. *Applied Sciences (Switzerland)*, *14*(10). https://doi.org/10.3390/app14104025

Hernández, A. D., Martín Casado, A. M., Gómez-Polo, M., Viñuela, A. C., & Gómez-Polo, C. (2023). Degree of Standardisation in Ceramic Gingival Systems. *Materials*, *16*(20). https://doi.org/10.3390/ma16206710

Levintsa, T. (2021). *Food Coloring in Resin? All You Need to Know!* www.3dprinternasional.com

Listari, K. M., & Siham. (2024). Potential of Virgin Coconut Oil Paste As Extrinsic Dental Stain Removal. *Interdental Jurnal Kedokteran Gigi (IJKG)*, *20*(1), 83–89. https://doi.org/10.46862/interdental.v20i1.8634

Mokashi, K., Adhapure, P., Sahu, N., Yeshwante, B., & Bhatkar, S. (2024). Manual Method for Gingival Shade Selection- a Literature Review. *International Journal of Advanced Research*, *12*(01), 763–766. https://doi.org/10.21474/ijar01/18184

Montero, J., Gómez-Polo, C., Santos, J. A., Portillo, M., Lorenzo, M. C., & Albaladejo, A. (2014). Contributions of dental colour to the physical attractiveness stereotype. *Journal of Oral Rehabilitation*, *41*(10), 768–782. https://doi.org/10.1111/joor.12194

Nowakowska-Toporowska, A., Raszewski, Z., & Wieckiewicz, W. (2016). Color change of soft silicone relining materials after storage in artificial saliva. *Journal of Prosthetic Dentistry*, *115*(3), 377–380. https://doi.org/10.1016/j.prosdent.2015.08.022

Nurcahyo, R. E. (2023). Analisis Kualitas Pencahayaan Ruang Dokter Gigi Sesuai Peraturan Indonesia di Klinik. *Jurnal Lentera Kesehatan Masyarakat*, *2*(1), 38–42. https://jurnalkesmas.co.id/index.php/jlkm/article/view/25/38%0Ahttps://jurnalkesmas.co.id/index.php/jlkm/article/view/25

Pascal, M., Pinto, G., Carvalho, A. O., Giannini, M., & Maia, H. P. (2016). Evaluation of an anatomic dual-laminate composite resin shade guide. *Dental Materials*, *32*, e18. https://doi.org/10.1016/j.dental.2016.08.034

Ren, J., Lin, H., Huang, Q., Liang, Q., & Zheng, G. (2015). Color difference threshold determination for acrylic denture base resins. *Bio-Medical Materials and Engineering*, *26*, S35–S43. https://doi.org/10.3233/BME-151287

Sadeq, H. M., Salih, S. I., & Braihi, A. J. (2020). Development on mechanical properties of pmma by blending it with natural rubber or silicone rubber and reinforced by nanoparticle. *Interna-*

tional Journal of Nanoelectronics and Materials, *13*(1), 131–144.

Somani, M. V., Khandelwal, M., Punia, V., & Sharma, V. (2019). The effect of incorporating various reinforcement materials on flexural strength and impact strength of polymethylmethacrylate: A meta-analysis. *The Journal of Indian Prosthodontic Society*, *19*(2), 101–112. https://doi.org/10.4103/jips.jips_313_18

Thirumalvalavan, S., Senthilkumar, N., Deepanraj, B., & Syam Sundar, L. (2023). Assessment of mechanical properties of flax fiber reinforced with Delrin polymer composite. *Materials Today: Proceedings*. https://doi.org/10.1016/j.matpr.2023.03.087

Tjan, A. H. L., Miller, G. D., & The, J. G. P. (1984). Some esthetic factors in a smile. *The Journal of Prosthetic Dentistry*, *51*(1), 24–28. https://doi.org/10.1016/S0022-3913(84)80097-9

Zheng, J., Zhou, Z. R., Zhang, J., Li, H., & Yu, H. Y. (2003). On the friction and wear behaviour of human tooth enamel and dentin. *Wear*, *255*(7–12), 967–974. https://doi.org/10.1016/S0043-1648(03)00079-6