The Difference and Correlation of Modulus of Elasticity and Surface Hardness of PMMA and Thermoplastic Nylon Denture Base Materials

Anggini Anha Fitri[1], Hubban Nasution[2]*, Ika Andryas[2], Siti Wahyuni[2], Putri Welda Utami Ritonga[2], Ricca Chairunnisa[2], Ariyani Dallmer[2]

1. Clinical Student, Faculty of Dentistry, Universitas Sumatera Utara, Medan, Indonesia.
2. Lecturer, Department of Prosthodontics, Faculty of Dentistry, Universitas Sumatera Utara, Medan, Indonesia.

Abstract

Mechanical properties of materials are necessary to be considered in manufacturing denture base. Some parameters of mechanical properties are modulus of elasticity and surface hardness, which can be the factors that affect the resistance of a denture.

PMMA (Huge) and thermoplastic nylon (Bio-Tone, Vertex thermosens and TCS) denture base materials with the size 64x10x3.3 mm3 for the modulus of elasticity (n=6) and 10x10x3 mm3 for surface hardness (n=6) were evaluated. The modulus of elasticity was measured by using Universal Testing Machine and surface hardness was measured by using Vickers Hardness Testing Machine. Data were statistically analyzed with one-way ANOVA test and followed by Tukey's post hoc test (P<.05). Pearson correlation test was used to found correlation between modulus of elasticity and surface hardness (P>.01).

Based on the one-way ANOVA test there was significant difference of modulus of elasticity between PMMA and thermoplastic nylon, and there was significant difference of surface hardness between PMMA and thermoplastic nylon as well. The Pearson correlation test showed a positive correlation between modulus of elasticity and surface hardness.

PMMA showed higher modulus of elasticity and higher surface hardness than thermoplastic nylon. A positive correlation was found between modulus of elasticity and surface hardness.

Review (J Int Dent Med Res 2020; 13(4): 1598-1603)

Keywords: Modulus of elasticity, PMMA, surface hardness, thermoplastic nylon.

Received date: 29 February 2020 **Accept date:** 08 April 2020

Introduction

Denture base is a part of a denture which rests on the soft tissue and to which teeth are attached.[1] Polymethylmethacrylate (PMMA) has been used as a denture base material in dentistry since 1937, and became the major denture base to be used.[2,3] PMMA is a thermoset polymer which contains cross-linking agent, and this polymer do not undergo softening upon heating.[4] The cross-linking agent could increase the modulus of elasticity and the surface hardness of a material.[5,6] The advantages of PMMA i.e., good aesthetics as it can mimic the colour of the gingiva, good dimensional stability and excellent adhesion to artificial teeth.[7] However, PMMA have disadvantages, i.e., high probability of fracture, high water absorption, allergic reaction caused by residual monomer, poor resistance to fatigue fracture, low impact strength, hypersensitivity and mucosal irritation, and if denture or fragment swallows or inhales it is difficult to detect by using simple radiological techniques.[8,9,10]

In 1956, thermoplastic nylon was developed and used as a denture base material.[11] Thermoplastic nylon denture base material have advantages including higher elasticity than PMMA, and safety for patient with resin monomer and metal allergy.[12] Therefore, thermoplastic nylon denture base material could be a useful alternative to PMMA in special circumstances.[13] Thermoplastic nylon has a wide variety of material modifications, such as polyamide 12 and polyamide microcrystalline.[14] Polyamide 12 developed from polylaurolactam whereas polyamide microcrystalline is made from high-level microcrystalline.[14] Polyamide microcrystalline material represents the next generation that can overcome some polyamide 12 deficiencies.[15]

***Corresponding author:**
Hubban Nasution,
Lecturer, Department of Prosthodontics, Faculty of Dentistry, Universitas Sumatera Utara, Medan, Indonesia.
E-mail: hubban.nasution@gmail.com

Modulus of elasticity and surface hardness are the two essential parameters of structural materials and the correlations between them are of keen interest to material scientists.[16,17,18] The Microhardness test was used to measure the surface hardness in this study. Microhardness is regularly used to predict the degree of conversion of the polymer materials due to the strong relation between hardness value and the percentage of polymerization degree.[19] Modulus of elasticity and surface hardness may affect the wear resistance. It was found that thermoplastic resin with low modulus of elasticity and nanohardness was easily worn under the wear scratch test.[20]

Nowadays, a wide variety of dental materials have been found in the market and there is a lack of study of thermoplastic nylon. Therefore, the purposes of the present study were to compare the difference of modulus of elasticity and surface hardness of PMMA and thermoplastic nylon denture base materials and to found the correlation between modulus of elasticity and surface hardness of PMMA and thermoplastic nylon denture base materials. The null hypotheses were that there would be no difference of modulus of elasticity and surface hardness of acrylic resin and thermoplastic nylon denture base materials, and there would be no correlation of modulus of elasticity and surface hardness.

Materials and methods

Three thermoplastic nylon denture base materials (TCS, Bio-Tone and Vertex Thermosens) and one PMMA (Huge) were selected for this present study (table 1).

The specimens for modulus elasticity test were 64x10x3.3 mm^3 (n=6) according to International Organization for Standard (ISO) 20795-1:2013, and the specimens for surface hardness test were 10x10x3 mm^3 (n=6).

Each specimen was polished with SiC abrasive paper grit size 340, 500, 800, 1200 using rotary grinder machine (Metaserv 3000, Buehler Ltd, USA) under constant water irrigation. The specimens were stored in distilled water at 37^0C for 24 hours before testing.

Material	Constituent	Manufacturer	Processing Methods
Huge	PMMA	Huge, Huge Dental Material Co., Ltd., China	Compression molding technique; heat-processed at 100^0C for 20 min
TCS	Polyamide 12	TCS Dental Inc., Signal Hill, CA	Injection molding technique; heat processed at 288^0C for 11 min
Bio-Tone	Polyamide microcrystalline	Denken-Highdental Co., Ltd., Japan	Injection molding technique; heat processed at 300^0C for 15 min
Vertex Thermosens	Polyamide microcrystalline	Vertex-Dental B.V., Netherland	Injection molding technique; heat processed at 290^0C for 18 min

Table 1. Denture base materials used in the present study.

Modulus of Elasticity

The modulus of elasticity test was performed with Universal Testing Machine (RTF-1350, Tensilon., Japan). A continuous load was applied on the center of the specimen until it reached maximum load (Figure 1). The loading speed was 5 mm/min.

The modulus of elasticity (MPa) was calculated according to the following formula: [21]

$$E=L^3m/4bd^3$$

Where, E=Elastic modulus (MPa), L=the length of the support span (50 mm), m=the slope of the modulus line (N/mm), b=the width of the specimen (mm), and d=the height of the specimen (mm).

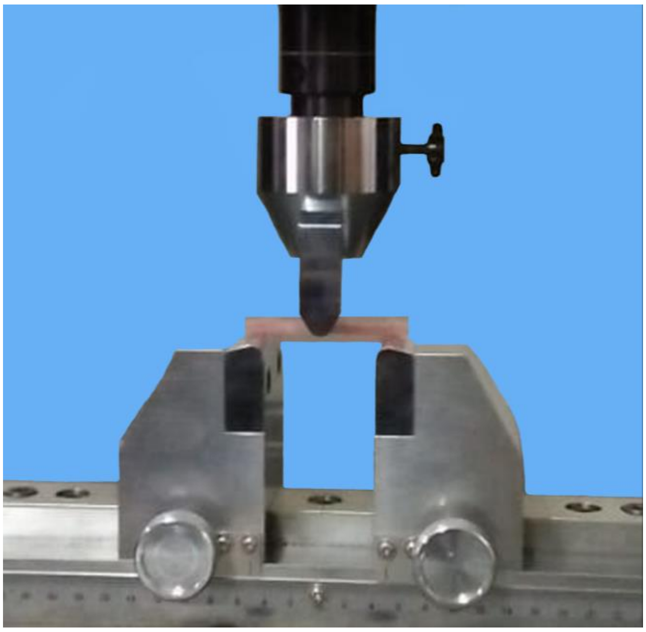

Figure 1. Three point bending test of modulus of elasticity.

Surface Hardness

The surface hardness test was performed with Micro Vickers Hardness Testing Machine (FM-800 FMS8133, Future-Tech Corp., Japan). The load was applied to the surface of each specimen by diagonal tip at 100 gf for 30 seconds (Figure 2). Then, the diagonal curves that remain after load removal were measured by microscope.

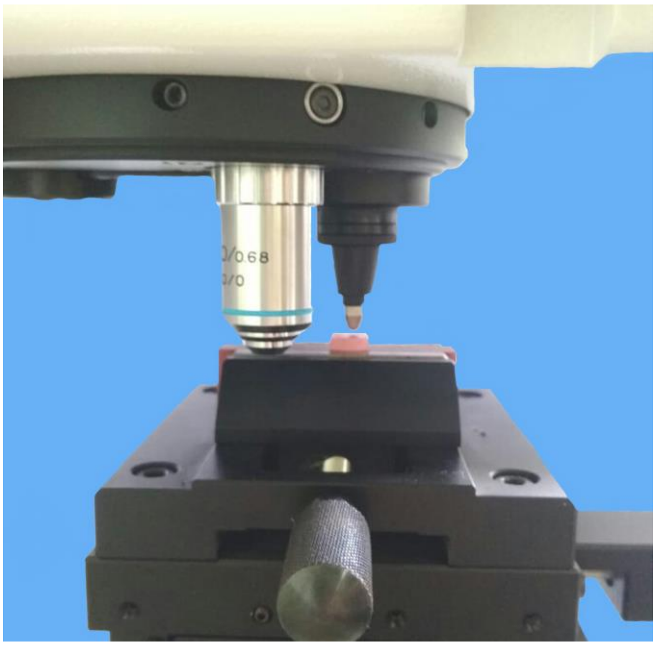

Figure 2. Surface hardness test.

The surface hardness (HV) was calculated according to the following formula: [22]

$$HV = 1854{,}4 \times P/d^2$$

Where, HV=Surface hardness, P=force (gf), and d=mean diagonal length of the indentation (μm)

Modulus of elasticity and surface hardness data were analyzed by using one-way ANOVA (*P*<0.05). Pearson correlation test was used to analyze the correlation of modulus of elasticity and surface hardness (*P*>.01).

Results

Modulus of elasticity

The results shown in Table 2 indicated that the highest modulus of elasticity (2508.62±114.92 MPa) was in PMMA and the lowest modulus of elasticity (733.58±8.14 MPa) was in TCS. The results of the one-way ANOVA shown in Table 2 indicated a significant difference among the denture base materials in modulus of elasticity between PMMA and thermoplastic nylon (*P*=.001). However, among the nylon thermoplastic denture base materials, TCS has a significant difference with Bio-Tone and Vertex Thermosens (*P*=.001), but there was no significant difference between Bio-Tone and Vertex Thermosens (*P*=,566). The differences of modulus of elasticity between PMMA (Huge) and thermoplastic nylon TCS, Bio-Tone and Vertex Thermosens are shown in Figure 3.

Denture Base Materials	Modulus of Elasticity (MPa)		p value	Surface Hardness (HV)		p value
	Mean	SD	(P<0.05)	Mean	SD	(P<0.05)
Huge	2508.62	92.25	0.001	16.93	0.04	0.001
TCS	733.58	6.42	0.001	7.73	0.07	0.001
Bio-Tone	1358.55	50.46	0.566	8.93	0.03	0.001
Vertex Thermosens	1402.07	45.97	0.566	6.47	0.21	0.001

Table 2. Mean and standard deviation of modulus of elasticity and surface hardness test of each denture base materials and its *p* value.

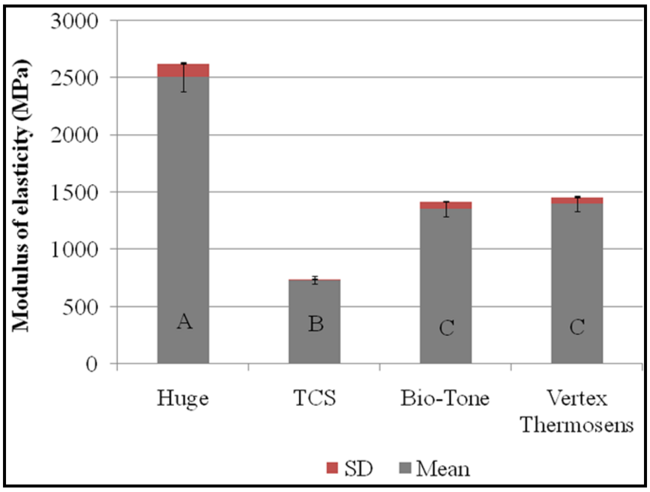

Figure 3. Mean and standard of deviatiation of modulus of elasticity (MPa) between each denture base materials (different letters between groups indicate significant differences).

Surface Hardness

The results shown in Table 2, indicated that the highest surface hardness (16.93±0.05 HV) was in PMMA and the lowest surface hardness (6.47±0.26 HV) was in TCS. The results of the one-way ANOVA shown in Table 2 indicated significant differences among the denture base materials in surface hardness between PMMA and thermoplastic nylon denture base materials (*P*=.001). The differences of surface hardness between PMMA (Huge) and thermoplastic nylon TCS, Bio-Tone and Vertex Thermosens are shown in Figure 4.

Correlation between Modulus of Elasticity and Surface Hardness

The Pearson correlation indicated significant correlation between modulus of elasticity and surface hardness (*P*=.964). The higher modulus of elasticity, the higher surface hardness was (Table 3).

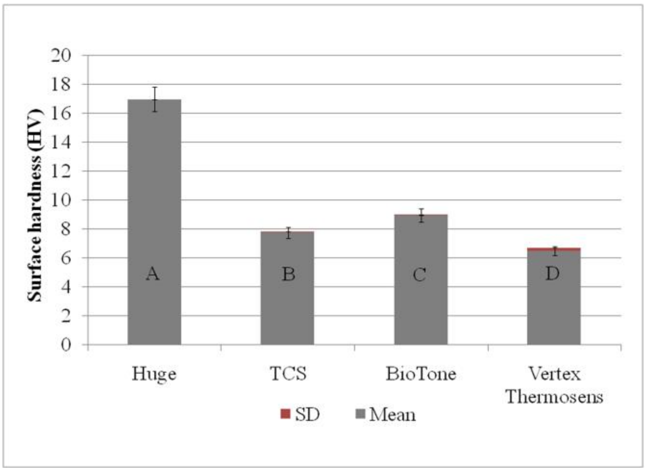

Figure 4. Mean and standard of deviatiation of surface hardness (HV) between each denture base materials (different letters between groups indicate significant differences).

Groups	Modulus of Elasticity	Surface Hardness	*p* value
Modulus of Elasticity		0.964	p>0.01
Surface hardness	0.964		

Table 3. Pearson correlation test result of modulus of elasticity and surface hardness.

Discussion

The null hypotheses of this present study was rejected since there were significant differences of modulus of elasticity and surface hardness of acrylic resin and thermoplastic nylon denture base materials, and there was a positive correlation between modulus of elasticity and surface hardness.

Modulus of Elasticity

In this present study, the highest modulus of elasticity was observed in PMMA denture base material, which corresponded to the previous study.[20] Cross-linking agent in PMMA lead to interlinking the polymer chains covalently where primary linkages occur between chains and the polymer actually becomes a single giant macromolecule.[4] Cross-linking agent material commonly used in PMMA is glycol dimethacrylate. If sufficient glycol dimethacrylate is included in the mixture, several interconnections can be formed and solvent swelling may occur. These interconnections yield a netlike structure that provides resistance to deformation. Cross-linking agents are incorporated into the liquid component at a concentration of 1% to 2% by volume.[12] The denture base material which contain cross-linking agent will have outstanding mechanical properties as high modulus of elasticity, stiffness, and good abrasion resistance.[6]

Thermoplastic nylon groups have lower modulus of elasticity, which were in line to the previous study.[17] Thermoplastic nylon is a crystalline polymer, where the material with high degree of crystalline will produce an atomic arrangement that is regular, strong and stiff. [12, 14] Polyamide microcrystalline has more degree of crystalline than polyamide 12.[14] Therefore, polyamide microcrystalline is more rigid than polyamide 12.[14] Polyamide 12 has low modulus of elasticity means that the denture is lacking in rigidity.[15] However, it can be improved by using it in combination with metal frame to expand its indication.[15]

Surface Hardness

Surface hardness is an important property on denture base material which refers to resistance of material to occlusal forces, scratching and abrasion.[2] In the present study, the highest surface hardness was observed in PMMA denture base material, which was similar to the previous studies.[2,5,10,20] This results were caused by high monomer-polymer ratio, presences of methyl-methacrylate monomer and cross-linking agent.[10] The cross-linking agent (glycol dimethacrylate) can increased surface hardness and reduced water sorption in denture base material.[5] Thermoplastic nylon are made of linear chain, that are hexamethylenadiamine and carboxylic acid forming polyamide bonds, these linear bonds are not resistance enough to solvent and cause low resistance to surface pressure.[10] The degree of crystalline in thermoplastic nylon also affects the surface hardness, rigidity and resistance to abrasion.[13] Polyamide microcrystalline has higher surface hardness than polyamide 12, because polyamide microcrystalline has more degree of crystalline than polyamide 12.[14]

Correlation between Modulus of Elasticity and Surface Hardness

A positive correlation between modulus of elasticity and surface hardness was observed in this present study. The higher modulus of elasticity, the higher surface hardness was. Modulus of elasticity considered to increase surface hardness, but not all studies were in line with this statement.[16,17] Modulus of elasticity and surface hardness was claimed can affect the wear resistance of denture.[20] Several authors have reported positive correlation between modulus of elasticity and surface hardness.[20] However, modulus of elasticity cannot fully describe surface hardness of a material.[20] Surface hardness is a complex parameter which involves the elasticity and plasticity and affected by both intrinsic and extrinsic properties of the material.[18] The material is considered to be rigid if it reject plastic deformation.[18] The more rigid a material, the smaller or no plastic deformation will be.[18]

The limitations of the present study were that modulus of elasticity and surface hardness was evaluated only on three thermoplastic nylon denture base materials and without thermocycling procedure. Thermoplastic nylon is a chemical resistant material that can be easily modified to increase stiffness and wear resistance. Therefore, future studies using varying thermoplastic nylon materials and imitate the oral environment were recommended.

Conclusions

Within the limitations of this study, it can be concluded that:

1. PMMA showed significantly higher modulus of elasticity and surface hardness among four types of denture base materials ($P<.05$).
2. Vertex Thermosens showed significantly higher modulus of elasticity and surface hardness among three types of thermoplastic nylon denture base materials ($P<.05$).
3. TCS showed significantly lower modulus of elasticity and surface hardness among four types of denture base materials ($P<.05$).
4. A positive correlation between modulus of elasticity and surface hardness was observed ($P>.01$).

Declaration of Interest

The authors report no conflict of interest.

References

1. McCabe JF, Walls AWG. Applied dental materials. 9th ed. Oxford: Blackwell Publishing Ltd; 2008:110.
2. Ayaz EA, Bagis B, Turgut S. Effect of thermal cycling on surface roughness, hardness and flexural strength of polymethylmethacrylate and polyamide denture base resin. J Appl Biomater Funct Mater 2015; 13(3):280-6.
3. Tandon R, Gupta S, Agarwal SK. Denture base materials: from past to future. Ind J Dent Sci 2010; 2(2):33-9.
4. O'brien WJ. Dental material and their selection. 3th ed. Michigan: Quintessence Books; 2002:142.
5. Utami M, Febrida R, Djustiana N. The comparison of surface hardness between thermoplastic nylon resin and heat-cured acrylic resin. Padjadjaran J Dent 2009; 21(3):200-3.
6. Albeladi HK, Al-Romaizan AN, Hussein MA. Role of cross-linking process on the performance of PMMA. Int J Biosen Bioelectron 2017; 3(3):279-284.
7. Wan Ali WNS, Sapon MS, Rosdi NM, Halib N, Mohamed N. The two-dimensional effects of *salvadora persica* mechanical brushing on the surface of polymethyl methacrylate denture base material. J Int Dent Med Res 2019; 12(2):448.
8. Anusavice KJ, Shen C, Rawls R. Phillip's science of dental materials. 12th ed. Riverport Lane: Elsevier Saunders; 2013:475.
9. Okeke KN, Vahed A,Singh S. Improving the strength properties of denture base acrylic resins using hibiscus sabdariffa natural fiber. J Int Dent Med Res 2018; 11(1):248.
10. Shah J, Bulbule N, Kulkarni S, Shah R, Kakade D. Comparative evaluation of sorption, solubility and microhardness of heat cure polymethylmethacrylate denture base resin & flexible denture base resin. J Clin Diagn Res 2014; 8(8):1-4.
11. Fueki K, Ohkubo C, Yatabe M, Arakawa I, Arita M, Ino S, et al. Clinical application of removable partial dentures using thermoplastic resin-Part I: definition and indication of non-metal clasp dentures. J Prosthodont Res 2014; 58(1):3-10.
12. Vojdani M, Giti R. Polyamide as a denture base material: a literature review. J Dent Shiraz Univ Med Sci 2015; 16(1):1-9.
13. Sagsoz NP, Yanikoglu N, Ulu H, Bayindir F. Color changes of polyamide and polymetyhl methacrylate denture base materials. Open J Stomatology 2014; 4(10):489-96.
14. Sari W, Fardaniah S, Masulili C. Color changing in denture base polyamide 12 and polyamide microcrystalline after polishing in laboratory and dental clinic.J Phys 2017;884(1):1-6.
15. Fueki K, Ohkubo C, Yatabe M, Arakawa I, Arita M, Ino S, et al. Clinical application of removable partial dentures using thermoplastic resin. Part II: material properties and clinical features of non-metal clasp dentures. J Prosthodont Res 2014; 58(2):71-84.
16. Bao YW, Wang W, Zhou YC. Investigation of the relationship between elastic modulus and hardness based on depth-sensing indentation measurements. J Actamat 2004; 52(18):5397–404.
17. Hamanaka I, Iwamoto M, Lassila LVJ, Vallittu PK, Takahashi Y. Wear resistance of injection-molded thermoplastic denture base resins. Acta Biomater Odontol Scand 2016; 2(1): 31-7.
18. Chung HY, Weinberger MB, Yang JM, Tolbert SH, Kaner RB. Correlation between hardness and elastic moduli of the ultraincompressible transition metal diborides RuB_2, OsB_2, and ReB_2. Appl Phys Lett 2008; 92(26):1-3.
19. Karawatthanaworrakul J, Aksornmuang J. Effect of post-polymerization microwave treatment on mechanical properties and dimensional change of provisional self-cure PMMA. J Int Dent Med Res 2020; 13(1):33.
20. Nasution H, Kamonkhantikul K, Arksornnukit M, Takahashi H. Pressure transmission area and maximum pressure transmission of different thermoplastic resin denture base materials under impact load. J Prosthodont Res 2018; 62(1):44-9.

21. Lee HH, Lee JH, Yang TH, Kim YJ, Kim SC, Kim GR, et al. Evaluation of the flexural mechanical properties of various thermoplastic denture base polymers. Dent Mater J 2018; 37:953-4.
22. American Society for Testing and Materials. Standard test method for microindentation hardness of materials. E384-17.West Conshohocken 2017: 1-7.