Acta Odontologica Scandinavica. 2016; 34: 67–72

informa healthcare

ORIGINAL ARTICLE

The effect of cycling deflection on the injection-molded thermoplastic denture base resins

IPPEI HAMANAKA[1,2], MISA IWAMOTO[1,2], LIPPO VJ LASSILA[2], PEKKA K VALLITTU[2,3], HIROSHI SHIMIZU[4] & YUTAKA TAKAHASHI[1]

[1]*Division of Removable Prosthodontics, Fukuoka Dental College, Fukuoka, Japan,* [2]*Department of Biomaterials Science and Turku Clinical Biomaterials Centre-TCBC, Institute of Dentistry, University of Turku, Turku, Finland,* [3]*City of Turku, Division for Welfare, Turku, Finland, and* [4]*Division of Biomaterials, Kyushu Dental University, Fukuoka, Japan*

Abstract

Objective. The aim of this study was to evaluate the effect of cycling deflection on the flexural behavior of injection-molded thermoplastic resins. ***Materials and methods.*** Six injection-molded thermoplastic resins (two polyamides, two polyesters, one polycarbonate, one polymethyl methacrylate) and, as a control, a conventional heat-polymerized denture based polymer of polymethyl methacrylate (PMMA) were used in this study. The cyclic constant magnitude (1.0 mm) of 5000 cycles was applied using a universal testing machine to demonstrate plasticization of the polymer. Loading was carried out in water at 23ºC with eight specimens per group ($n = 8$). Cycling load (N) and deformation (mm) were measured. ***Results.*** Force required to deflect the specimens during the first loading cycle and final loading cycle was statistically significantly different ($p < 0.05$) with one polyamide based polymer (Valplast) and PMMA based polymers (Acrytone and Acron). The other polyamide based polymer (LucitoneFRS), polyester based polymers (EstheShot and EstheShotBright) and polycarbonate based polymer (ReigningN) did not show significant differences ($p > 0.05$). None of the materials fractured during the loading test. One polyamide based polymer (Valplast) displayed the highest deformation and PMMA based polymers (Acrytone and Acron) exhibited the second highest deformation among the denture base materials. ***Conclusion.*** It can be concluded that there were considerable differences in the flexural behavior of denture base polymers. This may contribute to the fatigue resistance of the materials.

Key Words: *Denture base resin, polyamide, polyester, polycarbonate, PMMA*

Introduction

Removable partial dentures (RPDs) without metal clasps have recently been reported in dental practice [1–3]. RPDs without metal clasps have been justified because metal clasps of conventional RPDs have poor esthetics, and metal allergies have been known to occur in certain situations [4,5]. Fatigue and fractures of metal clasps have also been a problem [6–9].

Injection-molded thermoplastic resins (polyamide, polyester, polycarbonate and polymethyl methacrylate) are used for denture bases of RPDs with and without metal clasps [4,10–14]. RPDs without metal clasps are retained by undercuts of the abutment teeth to the retentive arm of the denture base resin. Therefore, the flexibility and fatigue resistance of denture base resins are important properties [10–13].

In previous studies [11–13], mechanical properties (flexural strength at proportional limit, elastic modulus and impact strength) of injection-molded thermoplastic denture base resins (polyamides, polyesters and polycarbonate) were examined. Denture base resins exhibit considerable plastic deformation before fracture; however, the plastic deformation of a material beyond its proportional limit will permanently alter its dimensions. Therefore, plastic deformation is unacceptable for denture base materials, which rely on retention of RPD without metal clasps and morphological stability for their successful use. A denture material should have a proportional limit sufficiently high enough that permanent deformation does not result from the stress applied during insertion and removal of the denture. Thus, measurement of the proportional limit of a denture base material using its

Correspondence: Ippei Hamanaka, Fukuoka Dental College, 2-15-1 Tamura, Sawara-ku, Fukuoka 814-0193, Japan. Tel: +81 92 801 0411. Fax: +81 92 801 0513. E-mail: hamanaka@college.fdcnet.ac.jp

(Received 17 July 2014; accepted 8 April 2015)

ISSN 0001-6357 print/ISSN 1502-3850 online © 2015 Informa Healthcare
DOI: 10.3109/00016357.2015.1042039

Table I. Denture base resins used in this study.

Constituent	Material	Manufacturer	Processing method	Lot number
Polyamide (PA12)	Valplast	Unival Co., Ltd. Tokyo, Japan	Injection molding technique; heat processed at 215ºC for 20 min	091142
Polyamide (PACM12)	LucitoneFRS	DENTSPLY International Inc., PA, USA	Injection molding technique; heat processed at 300ºC for 17 min	100323A
Polyester (Polyethylene terephthalate copolymer)	EstheShot	i-Cast Co. Ltd., Kyoto, Japan	Injection molding technique; heat processed at 230ºC for 20 min	IKB
Polyester (Polycycloalkylene terephthalate copolymer)	EstheShot Bright	i-Cast Co. Ltd., Kyoto, Japan	Injection molding technique; heat processed at 280ºC for 20 min	2A6277240
Polycarbonate	ReigningN	Toushinyoukou Co. Ltd., Niigata, Japan	Injection molding technique; heat processed at 320ºC for 30 min	FMY31T
Polymethylmethacrylate (injection-molded PMMA)	Acrytone	High Dental Japan Co. Ltd., Osaka, Japan	Injection molding technique; heat processed at 260ºC for 25 min	1010087
Polymethylmethacrylate (conventional heart-polymerized PMMA)	Acron	GC Corp., Tokyo, Japan	Heat-polymerized, compression molding technique; heat-processed at 70ºC for 90 min, then at 100ºC for 30 min and bench cooled for 30 min	(P)1004123 (L)1003191

resistance to plastic deformation is of significant clinical value. The elastic modulus of denture base resins affects the ease of insertion and removal of the RPD without metal clasps, its retention and the stress transferred to the abutment teeth [11–13,15,16].

Injection-molded thermoplastic resins have significantly lower flexural strength at the proportional limit (FS-PL) and lower elastic modulus than the conventional heat-polymerized denture based polymer of polymethyl methacrylate. Polyamides and polycycloalkylene terephthalate copolymer have low FS-PL and low elastic modulus; polyethylene terephthalate copolymer and polycarbonate had relatively high FS-PL and high elastic modulus. These properties were tested by a static test, although it is known that in clinical conditions materials are not usually subjected to a single loading event. Stresses frequently vary and can be a result of the insertion and removal of the RPD and masticatory function.

Most fractures and deformations of prostheses develop progressively over many stress cycles [17]. Fracture and plastic deformation are typically due to crack propagation as a result of localized microscopic plastic deformation [17]. Moreover, plastic deformation is the time-dependent part of deformation that a plastic resin experiences when loaded below its proportional limit. Thus, plastic resin has the property of viscoelasticity. Viscoelasticity is the property of materials that exhibits both viscous and elastic characteristics during deformation. Therefore, a dynamic test is necessary to evaluate material performance. Part of the dynamic tests is a cyclic bending test. This test can measure change in the materials properties, e.g. deformation and flexural strength, which is due to cycling deflection. The test also provides information on the material's fatigue performance. However, little attention has been focused on injection-molded thermoplastic resins resistance to cycling deflection.

The purpose of the present study was to evaluate the effect of cycling deflection on flexural behaviors of injection-molded thermoplastic resins. The null hypothesis was that the cycling load was not changed under a cyclic bending test.

Materials and methods

Six injection-molded thermoplastic denture base resins were selected for this study and a conventional heat-polymerized denture based polymer of polymethyl methacrylate (PMMA) was used as a control (Table I).

Cyclic bending test

Test specimens ($n = 8$) for each denture base material were fabricated according to the manufacturers' instructions in gypsum molds with cavities ($65.0 \times 10.0 \times 3.3$ mm^3) [18,19]. Each specimen was wet ground with 600-grit SiC paper and the accuracy of the dimensions was verified with a caliper that was calibrated to 0.05 mm tolerance for width and height. The measurements were repeated at three locations for each dimension. The specimens were stored in water at 23 ± 1ºC for 1 month until the testing. Water sorption of the denture base polymers with the dimensions included in the present study is known to occur

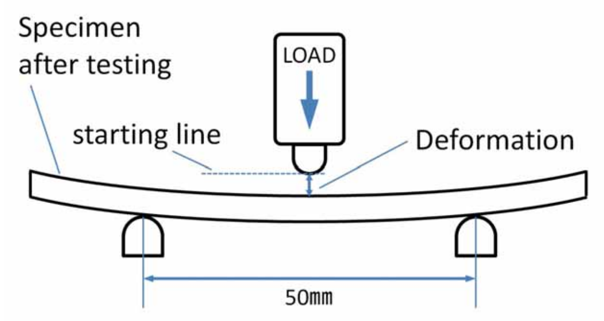

Figure 1. Measurement of specimen deformation after testing.

for a 1 month period [15]. Each specimen was placed on a 50-mm long support for a three-point bending test in water at 23 ± 1ºC (Figure 1). The constant magnitude to cycling deflection of 5000 cycles were applied using a universal testing machine (LRX, Lloyd Instruments Ltd., Hampshire, UK) at the mid-point of the specimen at a crosshead speed of 60 mm/min with a deflection of 1.0 mm and a frequency of 0.5 Hz. The cycling load to deflect the test specimens was measured during all of the loading cycles.

The cycling load (MPa) was calculated according to the following formula:

Cycling load = $3Fl/2bh^2$

where F = the maximum load (N) at deflection, l = the span distance (50 mm), b = the width (mm) of the specimen and h = the height (mm) of the specimen.

Cycling load for the first loading cycle and final loading cycle were compared. Load-cycle curves of the deflection magnitude of 1.0 mm and Load-deflection curves for 1.0 mm deflections of the first and final cycles were drawn for all test materials. Distance (mm) between the midpoints of the specimen during loading event (as a deformation) was measured for all test materials.

The data of cycling load required to deflect the specimen for the first and final time (5000 cycles) and deformation were analyzed statistically using a one-way ANOVA (STATISTICA; StatSoft, Inc., Tulsa, OK). The Newman-Keuls *post-hoc* comparison test (STATISTICA) was applied when appropriate (95% confidence level).

Results

Mean values, standard deviations, one-way ANOVA and the Newman-Keuls *post-hoc* comparisons for the first and final loading cycles and deformation are presented in Table II. Figure 2 shows the change in force, which was required to deflect the specimen.

Force required to deflect the specimens during the first loading cycle and final cycle were statistically different ($p < 0.05$) between one polyamide based polymer (Valplast: 8.70 MPa, 6.69 MPa) and PMMA based polymers (Acrytone: 13.86 MPa, 12.20 MPa and Acron: 25.98 MPa, 22.97 MPa). The other

Table II. Mean and standard deviation (SD) of first and final cycling load (MPa) and deformation (mm).

Denture base material	Cycling load (MP[a])		Deformation (mm)
	First cycling	Final cycling	
Valplast	8.70 (1.03)	6.69 (0.74)	0.17 (0.03)
LucitoneFRS	13.96 (0.74)[c]	13.39 (0.84)[c,d]	0.03 (0.02)[b]
EstheShot	18.04 (0.83)[b]	17.58 (0.82)[b]	0.03 (0.02)[b]
EstheShotBright	13.98 (0.83)[c]	13.75 (0.91)[c]	0.01 (0.01)[b]
ReigningN	19.44 (0.85)[a]	19.01 (0.68)[a]	0.02 (0.02)[b]
Acrytone	13.86 (0.73)[c]	12.20 (0.60)[d]	0.08 (0.02)[a]
Acron	25.98 (1.30)	22.97 (1.35)	0.07 (0.02)[a]

The same letter denotes groups that were not significantly different from each other in cycling load group or deformation group ($p > 0.05$).

polyamide based polymer (LucitoneFRS: 13.96 MPa, 13.39 MPa), polyester based polymers (EsthShot: 18.04 MPa, 17.58 MPa and EstheShotBright: 13.98 MPa, 13.75 MPa) and polycarbonate based polymer (ReigningN: 19.44 MPa, 19.01 MPa) did not show significant differences ($p > 0.05$). None of the materials fractured during the loading test.

One polyamide based polymer (Valplast: 0.17 mm) demonstrated the largest deformation among the materials ($p < 0.05$). The deformation of PMMA based polymers (Acrytone: 0.08 mm and Acron: 0.07 mm) were significantly higher than that of the other polyamide based polymer (LucitoneFRS: 0.03 mm), polyester based polymers (EstheShot: 0.03 mm and EstheShotBright: 0.01 mm) and polycarbonate based polymer (ReigningN: 0.02 mm) ($p < 0.05$).

Discussion

The null hypothesis of this study was rejected. The first cycling load of injection-molded thermoplastic

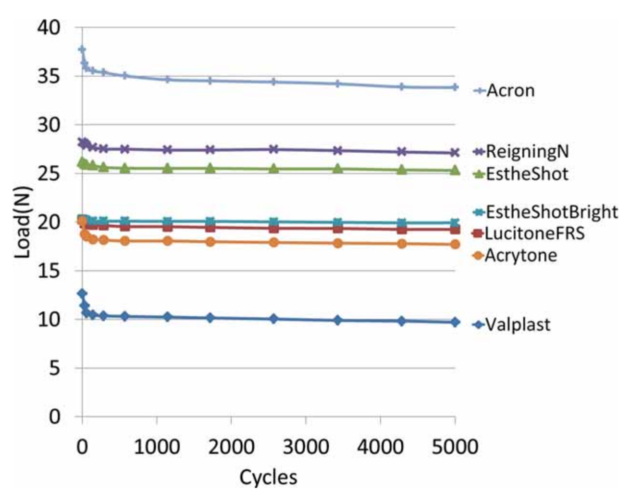

Figure 2. Load plotted against the number of loading cycles during the cyclic bending test with a deflection magnitude of 1 mm.

denture base resins were different from the final cycling load.

It is preferable for the injection-molded thermoplastic resins of RPDs without metal clasps to maintain long-term flexibility without substantially changing in the mouth. This is because the retentive arm of RPDs without metal clasps is obtained by extending part of the denture base. If the retentive arm of RPDs without metal clasps show changing flexibility and plastic deformation, some undesired phenomenon, e.g. loss of RPD's retention, may occur. Therefore, evaluating cycling load and plastic deformation of injection-molded thermoplastic denture base resins under cyclic deflection are beneficial from a clinical perspective.

In this study, test specimens were stored in water for 1 month until testing in order to saturate specimens with water. It is known that water exerts significant effects on the mechanical and dimensional properties of the polymer [20]. Water molecules may also interfere with entanglement of polymer chains and thereby change the physical characteristics of the polymer. In a previous study, water sorption over a 1 month period significantly decreased the elastic modulus of one polyamide based polymer (Valplast) and PMMA based polymers, whereas the other polyamide based polymer (LucitoneFRS), polyester based polymers and polycarbonate based polymer did not show significant differences [15].

Test specimens were loaded for 5000 loading cycles, which corresponds to ~ 3 years of denture use, assuming the patient inserts and removes the RPD twice a day [16]. Specimens were loaded at 1.0 mm for deflection and force in order to measure bending resistance. In previous studies [11,13,15] flexural strength at the proportional limit of the thermoplastic resins of RPDs without metal clasps was estimated to exist around 2 mm for deflection, in accordance to ISO 1567 [18] and ISO 1567:1999/Amd 1:2003 standards [19]. The flexural strengths at the proportional limits of denture base resins has been demonstrated in previous studies: (a) polyamide based polymer (Valplast) was 13.7 MPa, (b) polyamide based polymer (LucitoneFRS) was 22.3MPa, (c) polyester based polymer (EsthShot) was 30.4 MPa, (d) polyester based polymer (EstheShotBright) was 24.2 MPa, (e) polycarbonate based polymer (ReigningN) was 31.94 MPa, (f) PMMA based polymer (Acrytone) was 17.63 MPa, and (g) PMMA based polymer (Acron) was 38.2 MPa [11,13,15]. The first and final cycling loads with a deflection magnitude of 1 mm were lower than the flexural strengths at the proportional limit. This study utilized bending magnitude, which is lower than the proportional limit, but is assumed to simulate better clinical conditions.

The frequency of loading the specimen can cause internal heat formation, which has been shown to influence results [21,22]. In this study, the frequency was low (0.5 Hz), and the test specimens were immersed in water at 23 ± 1ºC during testing. Thus, it is unlikely that heat generated inside the test specimen could have considerably influenced the results [23]. The load-cycle curves of the deflection magnitude of 1.0 mm were drawn for all test materials (Figure 2). These are clearly demonstrated in the fatigue profiles, where the cycling load required to cause 1.0 mm deflection of materials, especially for one polyamide based polymer (Valplast) and PMMA based polymers, decreased within the first 100 cycles. The load-deflection curves of the first cycling load and the final cycling load are presented in Figure 3. The final cycling curves of one polyamide based polymer (Valplast) and PMMA based polymers were moved downward towards the first cycling curves with each loading cycle. Force required to deflect the specimens during the first loading cycle and final cycle were statistically different for one polyamide based polymer (Valplast) and PMMA based polymers. The other polyamide based polymer (LucitoneFRS), polyester based polymers and polycarbonate based polymer did not show significant differences. None of the materials fractured during the loading test. The first and final cycling loads of one polyamide based polymer (Valplast) and PMMA based polymers showed significant differences, because these denture based polymers exhibited plastic deformation. Several studies have reported that craze and crack occurred during the fatigue test [24,25]. Plastic deformations and fractures develop progressively over many stress cycles after the initiation of a crack from a critical flaw and, subsequently, by propagation of the crack until a sudden, unexpected fracture occurs. Plastic resins exhibit considerable plastic deformation before failure. Stresses can produce premature plastic deformation and fracture of a dental prosthesis because microscopic flaws grow slowly over many cycles of stress. In this study, the formation of the craze and crack in the specimens under constant tensile load was studied with an optical microscope using transmitted light (Leica DMLB, magnification ×100–400; Leica Microsystems Wetzlar GmbH, Wetzlar, Germany). However, the craze and crack in the specimens were not observed.

Plastic resin has the property of viscoelasticity [26]. Viscoelasticity occurs when the material has characteristics of an elastic solid and viscous fluid. Elasticity of plastic resin is ordinarily thought of as an instantaneous response to an applied stress and does not appear to be a time-dependent property. The viscosity of plastic resin is the ease with which liquid-like flow may occur and is easy to deform. Ideally, the only required property of Injection-molded thermoplastic denture base resins for RPDs without metal clasps is elasticity, but not viscosity. Viscoelasticity can be considered based on the structural formula of polymer backbones. One polyamide based polymer

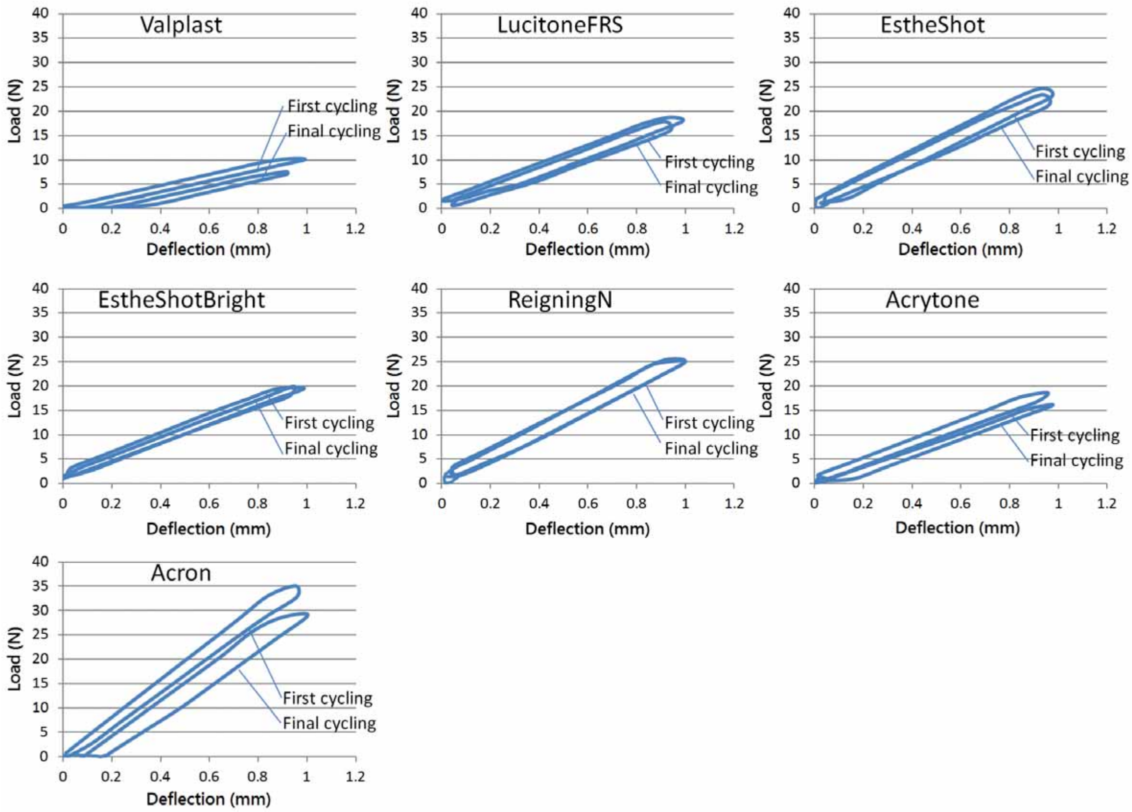

Figure 3. Load-deflection curves of first cycling and final cycling.

(Valplast) and PMMA based polymers did not have rigid chemical structures, e.g. benzene ring, in their polymer backbone. It is known that polymers that have ring-like structures in their chemical formula show good mechanical and chemical resistance. Hence, one polyamide based polymer (Valplast) and PMMA based polymers are made of a material that is more susceptible to plastic deformation and the other polyamide based polymer (LucitoneFRS), polyester based polymers and polycarbonate based polymer are not made of a material susceptible to plastic deformation.

This study indicated that cycling deflection affected the morphological stability of the injection-molded thermoplastic denture base resins. As mentioned earlier, the deformation of the injection-molded thermoplastic resin for RPDs without metal clasps affects retention of the RPD; hence, deformation after cycling deflection is clinically imperative. The findings of this study suggest that the morphological stability of the thermoplastic resin in an RPD without metal clasps at the retention area will change as the patient uses the denture over time. Therefore, RPDs without metal clasps fabricated from injection-molded thermoplastic denture base resins require a level of maintenance far exceeding that of conventional removable partial dentures. When using RPDs without metal clasps, the contact of the polymer part of the denture to the surface of the retaining teeth can potentially cause denture-induced caries. Polymers are known to absorb more proteins and microbes on their surface than metals and ceramics [27–30]. Therefore, special care needs to be taken to ensure good oral hygiene with patients that use such RPDs. Also, research and development toward antimicrobial polymers and composites may reduce the problem of microbe adhesion in the future [31–33]. Ideally, it is preferable for an RPD denture base without metal clasps to have a high flexural strength at the proportional limit, relatively low elastic modulus and high durability to deformation under cycling deflection. The present study demonstrated that the effect of cycling deflection on the injection-molded thermoplastic denture base resins differs from resin to resin. The properties of injection-molded thermoplastic denture base resins need to be considered in order to choose the most suitable polymer for RPDs without metal clasps.

Conclusions

Under the present experimental conditions, the following conclusions can be drawn:

(1) One polyamide based polymer exhibited the greatest deformation and the other polyamide based polymer, polyester based polymers and polycarbonate based polymer had the lowest

deformation among the denture base materials to cycling deflection.

(2) Cycling deflection significantly decreased the load required to deflect for one polyamide based polymer and PMMA based polymers, whereas the other polyamide based polymer, polyester based polymers and polycarbonate based polymer did not show significant differences.

Acknowledgments

This study is part of the BioCity Turku Biomaterials Research Program (www.biomaterials.utu.fi)

Declaration of interest: The authors report no conflicts of interest. The authors alone are responsible for the content and writing of the paper.

References

[1] Goiato MC, Panzarini SR, Tomiko C, Luvizuto ER. Temporary flexible immediately removable partial denture: A case report. Dent Today 2008;27:114,116.
[2] Kaplan P. Flexible removable partial dentures: Design and clasp concepts. Dent Today 2008;27:120,122–3.
[3] Ito M, Wee AG, Miyamoto T, Kawai Y. The combination of a nylon and traditional partial removable dental prosthesis for improved esthetics: A clinical report. J Prosthet Dent 2013; 109:5–8.
[4] Katsumata Y, Hojo S, Hamano N, Watanabe T, Yamaguchi H, Okada S. Bonding strength of autopolymerizing resin to nylon denture base polymer. Dent Mater J 2009; 28:409–18.
[5] MacGregor AR, Graham J, Stafford GD, Huggett R. Recent experiences with denture polymers. J Dent 1984;12:146–57.
[6] Vallittu PK. Comparison of the in vitro fatigue resistance of an acrylic resin removable partial denture reinforced with continuous glass fibers or metal wires. J Prosthodont 1996;5:115–21.
[7] Vallittu PK, Lassila VP, Lappalainen R. Evaluation of damage to removable dentures in two cities in Finland. Acta Odontol Scand 1993;51:363–9.
[8] Vallittu PK, Miettinen T. Duration of induction melting of cobalt-chromium alloy and its effect on resistance to deflection fatigue of cast denture clasps. J Prosthet Dent 1996;75: 332–6.
[9] Vallittu PK, Luotio K. Effects of cobalt-chromium alloy surface casting on resistance to deflection fatigue and surface hardness of titanium. Int J Prosthodont 1996;9:527–32.
[10] Takabayashi Y. Characteristics of denture thermoplastic resins for non-metal clasp dentures. Dent Mater J 2010;29: 353–61.
[11] Hamanaka I, Takahashi Y, Shimizu H. Mechanical properties of injection-molded thermoplastic denture base resins. Acta Odontol Scand 2011;69:75–9.
[12] Takahashi Y, Hamanaka I, Shimizu H. Effect of thermal shock on mechanical properties of injection-molded thermoplastic denture base resins. Acta Odontol Scand 2012;70:297–302.
[13] Hamanaka I, Takahashi Y, Shimizu H. Properties of injection-molded thermoplastic polyester denture base resins. Acta Odontol Scand 2014;72:139–44.
[14] Hamanaka I, Shimizu H, Takahashi Y. Shear bond strength of an autopolymerizing repair resin to injection-molded thermoplastic denture base resins. Acta Odontol Scand 2013;71: 1250–4.
[15] Hamanaka I, Iwamoto M, Lassila VP, Vallittu PK, Shimizu H, Takahashi Y. Influence of water sorption on mechanical properties of injection-molded thermoplastic denture base resins. Acta Odontol Scand 2014;72:859–65.
[16] Osada H, Shimpo H, Hayakawa T, Ohkubo C. Influence of thickness and undercut of thermoplastic resin clasps on retentive force. Dent Mater J 2013;32:381–9.
[17] Anusavice KJ. Phillips' science of dental materials. 12th Edition. St. Louis: Saunders; 2013. pp 48–68.
[18] International Standard. ISO 1567 for Dentistry–Denture base polymers. Geneva, Switzerland: International Organization for Standardization; 1999.
[19] International Standard. ISO 1567 AMENDMENT 1 for Dentistry–Denture base polymers AMENDMENT 1. Geneva, Switzerland: International Organization for Standardization; 2003.
[20] Anusavice KJ. Phillips' science of dental materials. 11th Edition. St. Louis, MO: Sanders; 2003. pp 721–57.
[21] Manley TR, Stonebanks JA. A multi-station machine for the fatigue testing of denture base materials. Biomaterials 1980;1: 125–8.
[22] Rittel D. An investigation of the heat generated during cyclic loading of two glassy polymers. Part I: Experimental. Mech Mater 2000;32:131–47.
[23] Yuen BKC, Taheri F. The effects of loading frequency, tensile overload and compressive underload on the fatigue crack propagation behaviour of polymethyl methacrylate. Polym Test 2004;23:491–500.
[24] Oysaed H, Ruyter IE. Creep studies of multiphase acrylic systems. J Biomed Mater Res 1989;23:719–33.
[25] Oysaed H, Ruyter IE. Formation and growth of crazes in multiphase acrylic systems. J Mater Sci 1987;22:3373–8.
[26] Darvell BW. Materials science for dentistry. 9th Edition. Cambridge, UK: Woodhead Publishing Limited; 2009. pp 82–107.
[27] Waltimo T, Tanner J, Vallittu P, Haapasalo M. Adherence of Candida albicans to the surface of polymethylmethacrylate-E glass fiber composite used in dentures. Int J Prosthodont 1999;12:83–6.
[28] Tanner J, Vallittu PK, Söderling E. Adherence of Streptococcus mutans to an E-glass fiber-reinforced composite and conventional restorative materials used in prosthetic dentistry. J Biomed Mater Res 2000;49:250–6.
[29] Tanner J, Vallittu PK, Söderling E. Effect of water storage of E-glass fiber-reinforced composite on adhesion of Streptococcus mutans. Biomaterials 2001;22:1613–8.
[30] Tanner J, Carlén A, Söderling E, Vallittu PK. Adsorption of parotid saliva proteins and adhesion of Streptococcus mutans ATCC 21752 to dental fiber-reinforced composites. J Biomed Mater Res B Appl Biomater 2003;66:391–8.
[31] Lahdenperä MS, Puska MA, Alander PM, Waltimo T, Vallittu PK. Release of chlorhexidine digluconate and flexural properties of glass fibre reinforced provisional fixed partial denture polymer. J Mater Sci Mater Med 2004;15:1349–53.
[32] He J, Söderling E, Vallittu PK, Lassila LV. Investigation of double bond conversion, mechanical properties, and antibacterial activity of dental resins with different alkyl chain length quaternary ammonium methacrylate monomers (QAM). J Biomater Sci Polym Ed 2013;24:565–73.
[33] He J, Söderling E, Vallittu PK, Lassila LV. Preparation and evaluation of dental resin with antibacterial and radio-opaque functions. Int J Mol Sci 2013;14:5445–60.