Peer-reviewed paper; submitted May 2020; accepted June 2020

Mechanical properties of denture base resin materials: CAD/CAM versus traditional heat-cure

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Abstract

Statement of Problem Rapid development in computer assisted design and computer assisted manufacturing (CAD/CAM) technologies are driving material development. This has led to the evolution of pre-polymerized poly-methyl-methacrylate (PMMA) denture base CAD/CAM milling blocks, which are used to manufacture complete dentures digitally. Researchers have investigated the mechanical properties of these materials, and to date, no data are available on the effect of simulated aging on the mechanical properties of these materials.

Purpose The aim of this study was to investigate and compare the mechanical properties of two commercially available CAD/CAM denture base materials and two traditional heat-cured denture base materials, before and after thermal cycling.

Material and Methods ISO 20795-1:2013 standard testing methods were used to determine the flexural strength, elastic modulus and fracture toughness of two CAD/CAM denture base materials and two heat-cured denture base materials before and after thermal cycling. For flexural strength testing and determination of elastic modulus, both with and without thermal cycling, 30 specimens were prepared for each material group. For fracture toughness testing, both with and without thermal cycling, 15 specimens were prepared for each material group. The flexural strength data were used to calculate the Weibull modulus and characteristic strength for all test groups. One-way ANOVA and Student's t-test were used ($P< 0.05$) to determine statistical significance between material type, within group comparisons as well as comparing cycled versus non-cycled groups.

Results Flexural strength measurements for most test groups were statistically similar before and after thermal cycling, apart from the Ivocap product, which produced significantly lower results after thermal cycling. Elastic modulus measurements for most test groups were statistically different after thermal cycling, apart from the Ivocap product, which produced statistically similar results before and after thermal cycling. Fracture toughness measurements for most test groups were statistically similar before and after thermal cycling, apart from the Vertex product, which produced significantly higher results after thermal cycling. Weibull statistics indicated better reliability for most test groups after thermal cycling. The Ivocap product produced a 30% drop in reliability after thermal cycling, although this is still 3x higher than the Vertex material.

Conclusions All materials tested have sufficient flexural strength to resist fracture under normal wearing conditions, both before and after thermal cycling. Denture base materials that rely on a strict manufacturing protocol, such as mass produced pre-polymerized blocks or pre-dispensed and automated processing regimes, are more reliable and would eliminate operator error.

Introduction

Since the introduction of PMMA (poly-methyl-methacrylate) acrylic resin material in 1936, it has been extensively used in dentistry for the fabrication of dentures and other types of prostheses (Sun et al. 2009; Kanazawa et al. 2011; Alhareb et al. 2017; Gad et al. 2017). Modern denture base materials are aesthetically pleasing, bio-compatible and easy to manipulate, process and repair. The low density of these materials makes the dentures relatively lightweight and easy to wear. However, processing errors can adversely affect the fracture toughness, strength and chemical stability of these materials (Bonso and Pearson 2012). The correct application and polymerization process of acrylic resin is very important for the full development of the materials' physical and biological properties (Bhola 2010; Kanazawa et al. 2011). These materials should allow for adequate strength and resilience for day-to-day use under various service conditions, as well as remain thermally and chemically stable to ensure structural stability and integrity (Goiato et al. 2015). Conventional processing methods cannot totally control the polymerization rates and amount of porosities, which can adversely influence the mechanical properties of the material (Pacquet et al. 2019). We are currently in an era of digital revolution where development in the form of CAD/CAM (Computer Aided Design and Computer Aided Manufacturing) and related technologies are changing clinical workflows, treatment planning, as well as driving material development (Hian da Silva et al. 2017; Janeva et al. 2018). The development of digital denture workflows has been happening at a slower pace in comparison with fixed prosthetic solutions, however, these are now readily available in the dental market (Bidra et al. 2013; Bilgin et al. 2015). The literature reports that these CAD/CAM fabricated denture techniques and materials are associated with a number of advantages such as; a reduced number of patient visits (Janeva et al. 2018); less potential for dentures to house microorganisms, therefore minimising infections; reduced cost for the

patient; reproducibility due to stored digital data; improved quality control (Bidra et al. 2013) and superior strength and fit of the dentures due to the use of pre-polymerised PMMA resin milling blocks (Goodacre et al. 2012; Steinmassl et al. 2018a; Pacquet et al. 2019). The PMMA milling blocks are manufactured by injection moulding and polymerized under high temperatures and pressures thereby preventing shrinkage of the final prosthesis (Infante et al. 2014; Srinivasan et al. 2017; Steinmassl et al. 2018a) and producing a highly densified material with the assumption of fewer micro-porosities (Steinmassl et al. 2018b). However, there are limited studies that have investigated and compared the mechanical properties of CAD/CAM denture base materials to those of conventional heat-cured materials (Janeva et al. 2018; Sonmez et al. 2018; Steinmassl et al. 2018b; Pacquet et al. 2019), and none have investigated the impact of simulated aging which is known to reduce the flexural strength. The aim of this study was to investigate and compare the mechanical properties of two commercially available CAD/CAM denture base materials with two traditional heat-cured denture base materials, before and after artificial aging by means of thermal cycling.

Materials and Methods

This study investigated and compared the flexural strength, elastic modulus and fracture toughness of four commercially available denture base materials before and after thermal cycling. Weibull analysis was completed with the flexural strength results to determine the Weibull modulus (m). During the specimen preparation phase, all specimens were prepared following manufacturer's instructions. The materials and associated processing methods are listed in Table 1. All laboratory tests were done in accordance with the stipulations as outlined in ISO 20795-1:2013 (ISO 2013). Table 2 shows a summary of the experimental groups.

Flexural strength and elastic modulus testing

Base plate wax (Kerr, USA) was used to fabricate wax blocks (65 mm x 45 mm x 12 mm). The blocks were flasked using traditional denture processing techniques to manufacture several Vertex Rapid Simplified heat-cured (VRS_HC) denture base blocks. Although this material can be rapidly cured using a 20 minute curing cycle at 100°C, the authors followed a slower curing method at 80 °C for 6 hours. The Ivobase (Ivocap) injection heat cure (IVB_HC) denture base blocks were manufactured using the proprietary Ivobase Injector system. The acrylic blocks were sectioned lengthwise into plates of 65mm x 12mm x 4mm, using a band saw (Dyco Machine Tools, NZ) and utilizing air cooling to mitigate heat generation. The Polident CAD (PD_CAD) and Ivobase CAD (IVB_CAD) materials were supplied in round milling discs (diameter 105mm, thickness 30mm) and subsequently cut to dimensions (65mm x 12mm x 4mm), also by band saw. The two groups of cut specimens were wet-ground to final dimensions of 64mm x 10mm x 3.3mm (+/-0.02mm) using 1200 grit silicon carbide abrasive paper (Struers, Denmark) in a polishing unit (Struers Tegrapol 11, Denmark). A total of 60 specimens were prepared for each material type and specimens were randomly assigned into two equal groups; non-cycled (n=30) and thermal cycled (n=30), as shown in Table 2. The 30 specimens forming the non-cycled group were stored in a temperature-controlled water bath (Thermo Scientific, USA) at 37°C for 50 hours prior to the flexural strength testing as per ISO20795-1:2013 requirements. The 30 specimens

Table 1. Test group abbreviations for the material's trade name, manufacturer and processing techniques used in the study.

Abbreviation	Trade name	Manufacturer	Processing
PD_CAD	Polident	Polident d.o.o, Volcja, Slovenia	CAD/CAM milling
IVB_CAD	IvoBase	Ivoclar Vivadent Ltd, Schaan, Liechtenstein	CAD/CAM milling
IVB_HC	Ivocap Ivobase	Ivoclar Vivadent Ltd, Schaan, Liechtenstein	Heat-cure injection
VRS_HC	Vertex Rapid simplified	Vertex-Dental B.V. Zeist, The Netherlands	Heat-cure pack and press

Table 2. Number of specimens for each sample group per test method.

Material	Flexural strength testing		Fracture toughness testing	
	Thermal Cycled between 5° and 55°C (x 20 000 cycles) (water stored at 37°C as per 20795-1:2013)	Non-Cycled (water stored at 37°C as per 20795-1:2013)	Thermal Cycled between 5° and 55°C (x 20 000 cycles) (water stored at 37°C as per 20795-1:2013)	Non-Cycled (water stored at 37°C as per 20795-1:2013)
PD_CAD	n=30	n=30	n=15	n=15
IVB_CAD	n=30	n=30	n=15	n=15
IVB_HC	n=30	n=30	n=15	n=15
VRS_HC	n=30	n=30	n=15	n=15

forming the thermal-cycled group were cycled between thermostatically controlled water baths (Proto-tech, USA) at 5ºC and 55ºC with a dwell time of 15 seconds in each temperature for 20 000 cycles representing two years of intra-oral use (Polychronakis et al. 2017). The transfer time between the baths was 3 seconds. These specimens were then also stored in the same manner as the non-cycled specimens. Three-point bend flexural strength tests were performed on all specimens using a universal testing machine (Instron 3369, Instron, USA) with a constant displacement rate of 5(+/-1)mm/min. Results were recorded using Instron Bluehill 3 software (Instron Corp. Canton, USA).

The ultimate flexural strength (σ) was calculated in MPa, using the following formula.

[1]

$$\sigma = \frac{3Fl}{2bh^2}$$

Where:
F = maximum load, in Newtons
l = support span in mm
b = width of specimen in mm
h = height of specimen in mm

Weibull Analysis
The variability of the flexural strength values was analyzed using the Weibull distribution calculation:

[2]

$$Pf = 1 - \exp - \frac{\sigma}{\sigma_0} m$$

Where
Pf = the fracture probability,
σ = the flexural strength,
σ_0 = the characteristic strength or scaling parameter where the stress has the fracture probability of 63.2%.
m = the Weibull modulus or shape parameter of the distribution of strength data as a function of failure probability, seen as the slope of linear fittings to the strength data when plotted in a lnln (1/ (1-Pf)) versus ln (σ) graph. (Quinn and Quinn 2010; Peampring and Sanohkan 2014).

The elastic modulus was calculated using the following formula

[3]

$$E = \frac{F_l l^3}{4bh^3 d}$$

Where:
F_l = the load, in Newtons, at a point in the straight line portion (with the maximum slope) of the load/deflection curve
d = is the deflection, in millimetres, at load F_l
l = support span in mm
b = width of specimen in mm
h = height of specimen in mm

Fracture toughness and elastic modulus testing

Denture base acrylic blocks (65 mm x 45 mm x 12 mm) were manufactured in the same way as for the flexural strength test. These blocks were then further sectioned by band saw under compressed air cooling conditions, then wet-ground to final dimensions of 39 mm x 8 mm x 4 mm (+/-0.02mm) using 1200 grit silicon carbide abrasive paper. Thirty specimens were prepared for each of the material types and randomly assigned into two equal groups; thermal-cycled (n=15) and non-cycled (n=15), as shown in Table 2. Each specimen was fixed lengthwise in a holding device where the centerline was marked across the broad side of each specimen. A pre-crack was cut under irrigation using a notching machine with a diamond blade to a depth of (3.0 ± 0.2) mm along the marked centerline. A sharp blade was used to cut a sharp notch on the bottom of each pre-crack. A stereoscopic zoom microscope (SMZ800, Nikon Corporation, Japan) was then used to measure the notch depth on each specimen. The 15 specimens forming the non-cycled group were stored in the temperature controlled water bath at 37°C for 7 days (+/- 2hours), then conditioned at 23ºC for 60 minutes prior to the fracture toughness testing as per ISO20795-1:2013 requirements. The 15 specimens forming the thermal-cycled group were cycled between thermostatically controlled water baths at 5ºC and 55ºC for 20 000 cycles with a dwell time of 15 seconds in each temperature. The transfer time between the baths was 3 seconds. These specimens were then stored in the same manner as the non-thermal-cycled specimens. After thermal cycling and water storage, 3-point bend fracture toughness tests were performed using the universal testing machine (Instron 3369, Instron, USA) and a constant displacement rate of 5(+/-1)mm/min. Results were recorded using Instron Bluehill 3 software. Fracture toughness values were calculated using the following formulas (ISO 2013);

Calculation of maximum stress intensity factor:

Height	h_t = (8.0 ± 0.2) mm
Width	b_t = (4.0 ± 0.2) mm
Pre-crack	a' = (3.0 ± 0.2) mm
Crack length	a (0.1 mm – 0.4 mm longer than a')
Span	l_t = (32±.01) mm

[4]

$$K_{max} = \frac{\int P_{max} l_t}{b_t h_t^{3/2}} \times \sqrt{10^{-3}}\ M\ Pam^{1/2}$$

Where:
$\int$ is a geometrical function dependent on x

[5]

$$\int(x) = 3x^{½}[1.99 - x(1-x)(2.15 - 3.93x + 2.7x^2]/[2(1+2x)(1-x)^{3/2}]$$

And

$$x = a/h_t \quad [6]$$

Statistical analysis

Appropriate summary statistics (means and standard deviations) for forces, counts and percentages for type of failure, were carried out for the initial analysis of the flexural strength, elastic modulus and fracture toughness results. Standard model diagnostics (normality and equal variance) were evaluated visually using histograms and scatter plots. One-way ANOVA models were used to evaluate the overall effects with the interaction between the groups. Post-hoc testing was applied where the interaction or main effect was statistically significant, with the significance level set at 95%. Initially, a within group comparison was done on the four groups that compared non-cycled and cycled group relationships and then the non-cycled groups were directly compared to the corresponding cycled groups. All analyses were done using Microsoft Excel.

Results

Flexural strength of a material represents the highest stress within a material before it yields.

The mechanical properties for all groups are reported in Table 3 and Figure 1. PD_CAD exhibited the highest flexural strength results for the non-cycled specimens, and IVB_CAD the lowest with statistically significant differences between them. Within group comparisons showed statistically significant differences for all groups compared, apart from IVB_HC and VRS_HC which were statistically similar. For the cycled group, PD_CAD exhibited the highest flexural strength results and IVB_CAD the lowest, with statistically significant differences between them. Within group comparisons showed statistically significant differences for all groups compared, apart from PD_CAD and IVB_HC. Although PD_CAD recorded the highest mean flexural strength, it was found to be statistically similar when compared to VRS_HC. Comparing the non-cycled group to the cycled group for each material, the only material that showed a statistical significant difference in the flexural strength measurements after thermal cycling was IVB_HC.

Elastic modulus

Elastic modulus indicates the rigidity/stiffness of a material. The results are shown in Figure 2 and Table 3. For the non-cycled group, PD_CAD exhibited the highest elastic modulus and IVB_CAD the lowest, with statistical differences observed between the measured groups. Within group comparison of the different non-cycled groups indicated no statistically significant differences between IVB_CAD, IVB_HC and VRS_HC. Within group comparison of the different cycled groups indicated no statistically significant differences between VRS_HC and PD_CAD. When comparing the non-cycled group to the cycled group for each material, the only material that showed no statistical difference in elastic modulus measurements without thermal cycling and after thermal cycling, was IVB-HC.

Fracture toughness

The fracture toughness of a material expresses the materials' resistance to brittle fracture. The results are presented in Table 3 and Figure 3. IVB_CAD exhibited the highest flexural strength results for the non-cycled specimens, and IVB_HC the lowest with statistically significant differences between them. Within group comparison of the different non-cycled groups also indicated statistically significant differences for all comparisons, except for IVB_HC compared to VRS_HC, which were statistically similar. The fracture toughness values for the cycled group indicated IVB_CAD exhibited the highest fracture toughness results for the non-cycled groups, and IVB_HC the lowest with statistically significant differences between them. Within group comparison of the different cycled groups, significant statistical differences were recorded for all compared groups. Although IVB_CAD recorded the highest fracture toughness means, this group was statistically similar when compared to PD_CAD.

Comparing the non-cycled group to the cycled group for each material, the only material that showed a statistical significant difference in fracture toughness measurements after thermal cycling was VRS_HC.

Table 3. Results for mechanical properties and Weibull analysis for all tested specimens for both the non-cycled (shaded in grey) and cycled groups (non-shaded).

	PD_CAD	IVB_CAD	IVB_HC	VRS_HC
Flex Strength in MPa(S.DEV)	125.73 (43.23) #	91.42 (4.91) #	100.28 (4.09)*	100.89 (19.36)* #
	112.96 (6.08)* #	87.44 (4.06) #	94.19 (5.98)	105.33 (23.09)* #
Elastic Modulus in MPa (S.DEV)	2067.20(296.78)	1802.78(286.73)*	1927.53(196.79)* #	1874.85(122.38)*
	1933.59(71.06)	1613.56 (123.72)	1889.61(118.64)* #	2125.19(341.90)*
Fracture toughness in Kmax MPa m1/2 (S.DEV)	1.87 (.16) #	2.19 (.27) #	1.55 (.1)* #	1.57 (.13)*
	1.98 (.03)* #	2.08 (.21)* #	1.56 (.17) #	1.71 (.21)
Weibull (m)	17.29	22.34	29.28	5.05
	22.28	25.65	20.39	5.57
Characteristic strength in MPa	114.37	93.64	102.17	106.82
	115.69	89.30	96.46	114.35

*Indicates no statistical significant difference between the values in the same row.

# Indicates no statistical significant difference between the same material before and after thermal cycling.

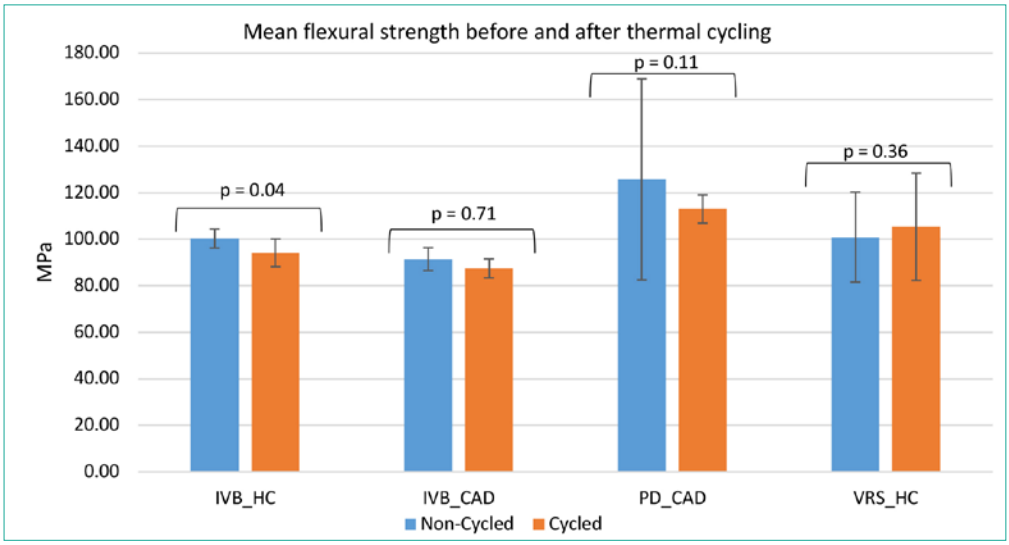

Figure 1. Mean flexural strength (MPa) of non-cycled and cycled groups with standard deviations. The 95% confidence intervals (p values) are indicated above each material group.

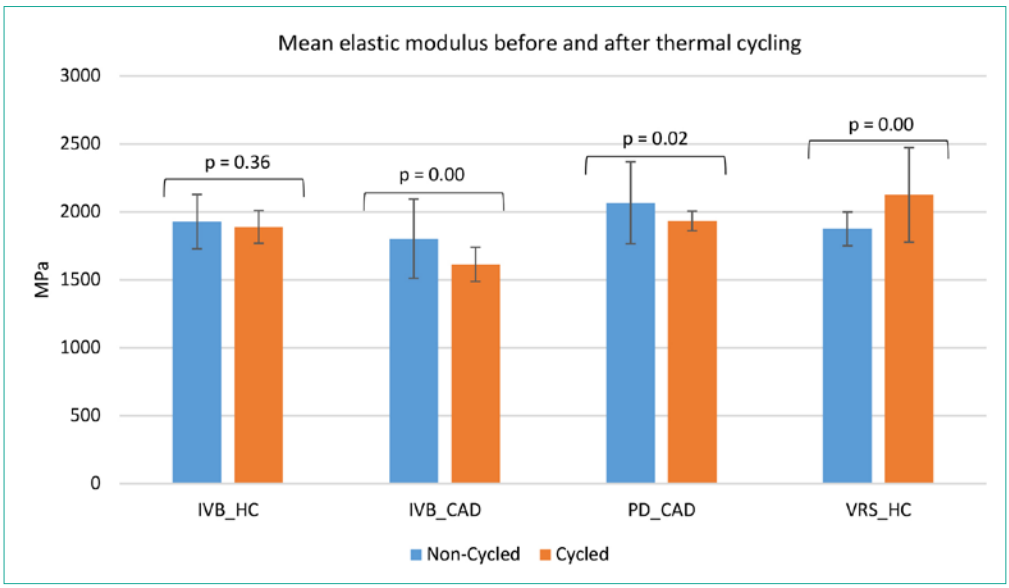

Figure 2. Mean elastic modulus (MPa) for testing groups before and after thermal cycling with standard deviations. The 95% confidence intervals (p values) are indicated above each material group.

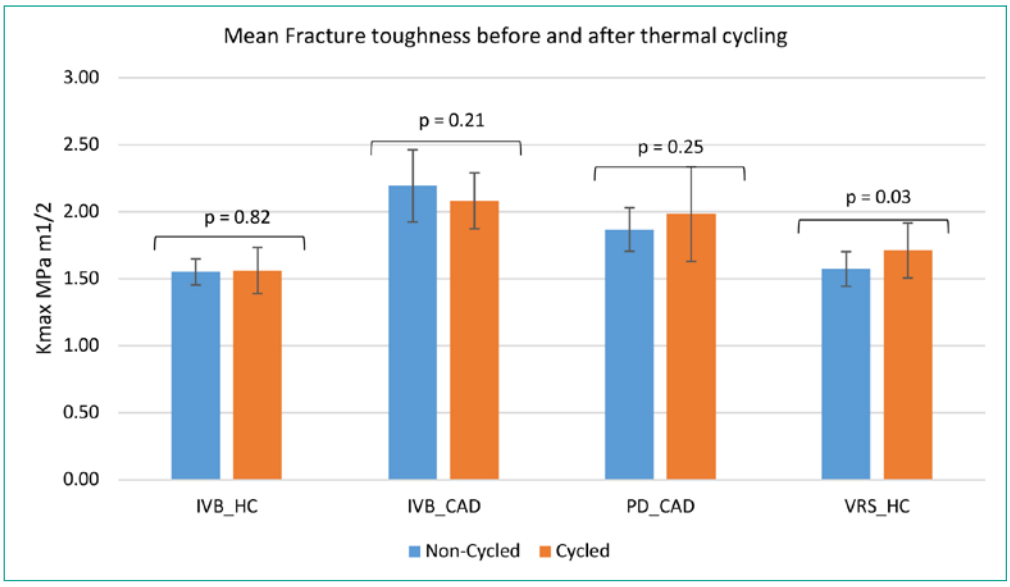

Figure 3. Mean fracture toughness (Kmax MPa $m^{1/2}$) of non-cycled and cycled groups with standard deviations. The 95% confidence intervals (p values) are indicated above each material group.

Weibull analysis

In the context of this research, Weibull analysis (*m*) was used to determine the reliability characteristics of the tested materials. The Weibull statistics were derived from the flexural strength values provided in Table 3 and Figures 4 and 5. The non-thermal-cycled test group, VRS_HC (m=5.05) showed a lower level of reliability when Weibull analysis was performed, in contrast to the remaining materials, which were all above a Weibull modulus of 17 (Table 3, Figures 4 and 5). After thermal cycling the VRS_HC group Weibull modulus showed a 10% reliability improvement, whereas the PD_CAD showed a 29% increase in reliability and IVB-CAD showed a 15% increase. IVB_HC was the only material to show a decrease in reliability (30%) after thermal cycling.

The characteristic strength for these materials (Table 3) were calculated as part of the Weibull analysis, and is indicative of the strength below which a specified portion (63.32%) of the valid test specimens would fail. Therefore, the higher the characteristic strength, the lower the risk of failure. In this case, IVB_CAD and IVB_HC showed higher characteristic strength without thermal cycling treatment, whereas PD_CAD and VRS_HC, showed improved characteristic strength after the thermal cycling treatment.

Discussion

Removable acrylic dentures are prone to crack or fracture in function. Apart from accidental breakage and poor denture design (Ucar et al. 2012b), these issues can also be attributed to the poor mechanical and physical properties of the denture base resin, and have contributed to the development of new manufacturing techniques and materials (Steinmassl et al. 2018b).
The aim of this study was to investigate and compare the mechanical properties of two commercially available CAD/CAM denture base materials with two traditional heat-cured denture base materials, before and after artificial aging by means of thermal cycling. The 20 000 cycles that the specimens were subjected to represented the thermal changing cycles that occur in the mouth for approximately two years (Polychronakis et al. 2017). This "aging" protocol does not simulate real intra-oral conditions but is used to evaluate the behaviour of these materials when subjected to thermal stress and exposure to fluids and normal temperature ranges of 5ºC–55ºC (Peampring and Sanohkan 2014; Ayaz et al. 2015).

The flexural strength value of a material can be defined as the stress in a material just before it yields (Finoti et al. 2012). This material property is of great importance for denture bases as it provides information about

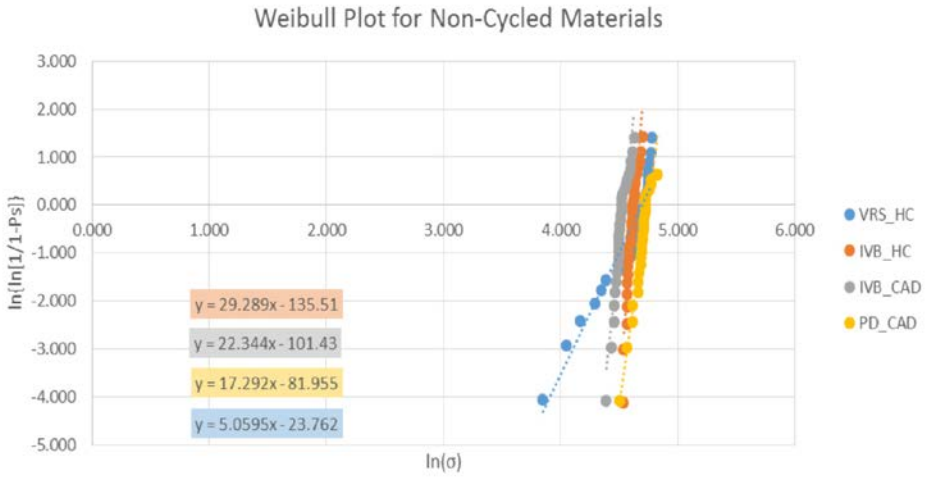

Figure 4. Weibull plot, indicating the Weibull modulus distribution for each of the four denture base materials tested directly after processing and without thermal cycling.

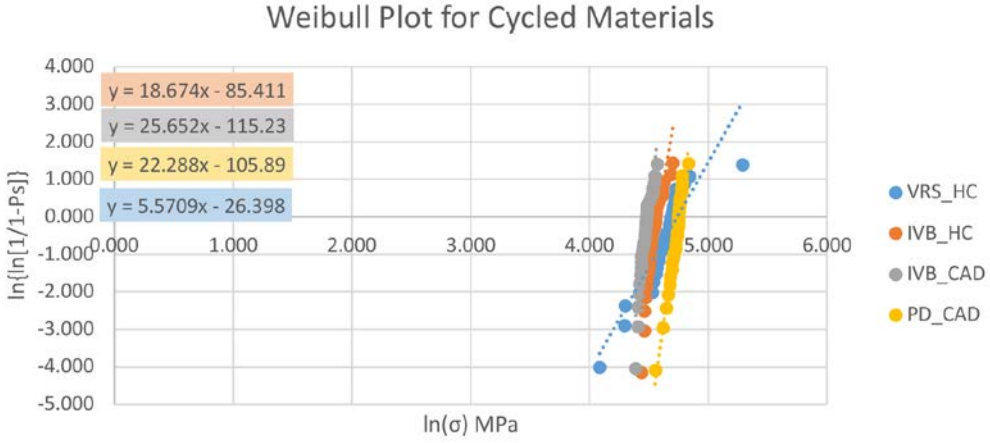

Figure 5. Weibull plot, indicating the Weibull modulus distribution for each of the four denture base materials tested after thermal cycling

the amount of stress a prosthesis could be subjected to before it cracks or breaks (Jaikumar et al. 2015). Dentures typically fracture along the midline, as a result of flexure. Therefore, the denture base should have sufficient flexural strength to resist fracture (Ajaj-Alkordy and Alsaadi 2014; Jaikumar et al. 2015). According to ISO 20795–1, no denture material should have a flexural strength lower than 60MPa for Class 2, and no less than 65MPa for Class 1, 3, 4 and 5 denture base materials (ISO 2013). Many researchers have reported that long term exposure to water, as well as thermal fluctuation can decrease the flexural strength of denture base materials. (Yunus et al. 2005; Ucar et al. 2012a; Ucar et al. 2012b; Ayaz et al. 2015; Polychronakis et al. 2017). This drop in flexural strength was found to be true in the current study for only one of the materials tested (IVB_HC), with a statistically significant reduction of ~ 6MPa. This might be attributed to plasticizers and other soluble components leaching out over an extended period of time causing free monomer to be replaced by fluids. This absorption of fluids causes the acrylates to plasticize, thus reducing the flexural strength. Polychronakis (2017) suggested that the high temperature of the thermal cycling process potentially causes water molecules to diffuse rapidly between the polymer chains because of an extension of the distance between them causing the chains to slip over each other more easily under load and weakness in the material (Finoti et al. 2012; Polychronakis et al. 2017). Machado et al (2012) and Takahashi (2012) suggested that the thermal fluctuation between 5ºC–55ºC can cause continuous expansions and contractions within the molecular structures of denture materials and lead to static fatigue of the material.

Although flexibility of a material would influence the way energy is absorbed and distributed through the structure of the prosthesis when it is impacted, it would also influence the rigidity and cross-arch force distribution during mastication. A denture base material with a high elastic modulus can withstand permanent deformation during masticatory functions. However, too high an elastic modulus can be a disadvantage from a clinical point of view (Ucar et al. 2012b). Although in-vitro tests can be considered to be a limitation to this study they can be predictive of clinical performance. According to the ISO 20795–1 standard, elastic modulus of the processed material shall be no less than 2000 MPa for class 1, 3, 4 and 5 denture base materials and no less than 1500MPa for Class 2 materials (ISO 2013). Within the limits of the study, the results showed that of the Class I materials tested only PD_CAD (non-cycled) and VRS (cycled) met these limits. IVB_HC (type 2) acrylic also falls within the parameters of the required elastic modulus for denture base acrylics, both before and after thermal cycling. However, unlike all other tested materials, this material's Weibull analysis indicated a 30% drop in reliability after the thermal cycling process. Even with this drop, it still retains an acceptable Weibull slope when compared to VRS_HC. The Weibull distribution is indicative of how consistently the materials would perform and is often related to the flaw distribution within a material. As the present results indicate, one would expect the Weibull distribution for the CAD/CAM materials to be rather high, as these are mass produced under high pressure, which in theory would produce a more homogenous block of material (Baba 2016; Aguirre et al. 2019; Pacquet et al. 2019). However, the findings of this study show a significant improvement in Weibull distribution for all but one (IVB_HC) of the materials after thermal cycling. The reason for this could possibly be explained by studies that have suggested that the presence of small plasticizing molecules, such as water, may in fact aid the molecular movement that disperses energy, thus increasing reliability over time (Causton 1975; Lloyd 1982; Bonso and Pearson 2012). Because CAD/CAM denture base materials are pre-polymerized, highly condensed and less porous than conventional denture acrylic resin (McLaughlin and Ramos Jr 2015), the authors would suggest that the stability in flexural strength and fracture toughness in combination with the high Weibull statistics is related to the manufacturing process, which would allow for homogenous penetration and distribution of fluids over time. As IVB_HC is also reliant on a very controlled manufacturing protocol, the stability in this material's elastic modulus and fracture toughness could also be attributed to the manufacturing protocol, however the fracture toughness results for this material is well below the recommended 1.9MPa $m^{1/2}$.

The ability of a restorative material to resist crack propagation is of crucial importance especially in stress bearing areas, or "notched" areas such as the fraenum and incisal notches in maxillary dentures (Silva et al. 2013). Both of the CAD/CAM denture acrylic materials performed very well in the fracture toughness tests and showed no statistically significant differences after thermal cycling. This can potentially be attributed to their highly cross-linked structure which provides a sufficient number of bridges between linear macro-molecules to form a three-dimensional network which decreases water sorption and prevent the plasticizing effect normally caused in this fashion (Silva et al. 2013; Alp et al. 2019).

Normally, during thermal cycling, the hot water may accelerate the uptake of water which would result in the plasticization of the polymer components and decrease the mechanical properties in some materials. Conversely, in the case of VRS_HC, the hot water may also have enhanced the release of degradation products and free monomer molecules which potentially promoted further free-radical polymerization reactions and increased the degree of conversion, resulting in an increase in this material's fracture toughness results (Urban et al. 2009; Silva et al. 2013).

Conclusion

Within the limits of the study all materials tested have sufficient flexural strength, both before and after thermal cycling, to resist fracture under normal wearing conditions. IVB_CAD, IVB_HC and PD_CAD showed the least general variability (2%, 6% and 1% respectively) between the cycled and non-cycled measurements for all test performed. The CAD/CAM materials seem to be the most reliable and stable of the tested materials.

This leads the authors to conclude that denture base materials that rely on a strict manufacturing protocol, such as mass produced pre-polymerized blocks or pre-dispensed and automated processing regimes, are more reliable and would eliminate operator error to a large degree.

This research highlights the importance of material choice and fabrication technique considerations when producing complete dentures. Although complete denture CAD/CAM materials and techniques are in their infancy, the technological advancement to date shows that this technology provides potential for improvement in denture predictability and treatment outcomes.

Acknowledgments

Supported by the New Zealand Institute for Dental Technicians' Research Grant

The authors thank Ivoclar Vivadent NZ for their support in supplying materials for testing. They were not consulted about the research findings and the authors have no financial interests.

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