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The effect of condensing on mechanical properties of feldspathic veneering porcelain

Jansen van Vuuren W-A, Khoo CST, Ng BSK, Waddell JN, Al-Amleh B

Abstract

Objective: To evaluate the effect of ultrasonic condensing on the biaxial flexural strength, translucency and density of a nano-leucite porcelain.

Methods: ISO standard 6872:2008(E) was followed to fabricate 70 discs with Reflex veneering porcelain (Wieland Dental Technik). Specimens were divided into two groups; ultrasonically condensed (n=30) and non-condensed (n=30). Biaxial flexural strengths tests were performed and Weibull modulus calculated for each group. The remaining discs were divided into two groups (n=5) as above. A spectrophotometer (VITA Zahnfabrik) was used to calculate the transparency parameter for each group. The same 10 specimens were used to calculate their density, using Archimedes' principle. Independent-samples t-test was used (SPSS) to compare the results between ultrasonically condensed and non-condensed groups.

Results: No significant difference was recorded between the groups in any of the tests (p>0.05) However, ultrasonic condensing showed a higher Weibull modulus in the fractured discs.

Conclusion: Ultrasonic condensing veneering porcelain powder before firing may not be necessary to improve mechanical properties, porosity reduction, or translucency parameters compared to non-condensed techniques. Nevertheless, caution is advised when interpreting these results, due to the shape factor in making disc forms when compared to porcelain layering on clinical crown forms.

Introduction

Due to its excellent mechanical and aesthetic properties, metal-ceramic dental restorations have been successfully used in dentistry for more than four decades. In 2005 it was estimate that more than 50% of all dental restorations fabricated were metal-ceramics (Denry and Holloway 2010).

Dental veneering porcelains are supplied in a powder form and formulated to mix with either distilled water or a special modelling liquid. This mixture is applied to the prepared substructure and condensed by means of an ultrasonic condenser or manual agitation in order to produce a stable and compact restoration prior to sintering (Hodson 1959, Baker 1960). Ultrasonic condensing is a technique that utilises soundwaves greater than 20 kHz. These soundwaves cannot be heard by the human ear, because of their very high amplitude. It is however, this high amplitude wave that causes ceramic particles to move or vibrate into closer proximity to each other when the sound travels through the un-sintered porcelain (Berg 2015).

There are two main objectives for condensing veneering porcelain: first, to produce lower firing shrinkage and secondly to reduce porosity in the sintered restoration (Anusavice et al. 2014). A dense and highly compacted arrangement of unfired porcelain particles can be produced by vibration, where the porcelain particles are moved closer together, forcing the water and air, previously occupying the spaces between the porcelain particles, to the surface. This is subsequently removed by blotting the surface of the unfired porcelain with absorbent tissue paper. According to Naylor et al. (2009), the presence of porosity in sintered porcelain can have an adverse effect on its strength by acting as crack initiators, produce a lesser density and negatively affect the aesthetics by scattering light similar to the effect of frosted glass, thus decreasing its overall translucency (Palin et al. 2009, Anusavice et al. 2014). However, Cheung et al. (2002) reported that the effect of vibration on the reduction of porosity is limited. The bulk of the porosity reduction occurs in the sintering process to create a dense solid. The partial melting of crystalline phases or sufficient softening of glassy material would promote the contraction of the voids. A study done by Evans et al. (1960) concluded that different condensing techniques had no effect on the density of sintered porcelain, they did however, report a statistical difference in the aesthetics. Thus far, contradicting information is available on the effect of condensing on the mechanical properties of veneering porcelain. Therefore, the purpose of this study was to evaluate and compare the effect of ultrasonic condensing on the biaxial flexural strength, density and translucency on a nano-leucite veneering porcelain as opposed to non-condensed specimens.

Materials and methods

Reflex dentine veneering porcelain (Wieland Dental Technik, Pforzheim, Germany) was used to produce 60 discs, with a diameter of 15 mm and a thickness of 1.2 mm (± 0.2) according to ISO standard 6872:2008(E) (ISO 2008). The specimens were divided into two groups, according to the preparation method. The ultrasonic condensing group (UC) (n=30) were manufactured using an ultrasonic vibrator (Ceramo Sonic 2, Shofu, Tokyo, Japan) at a frequency of 28,000 Hz, with intermittent blotting using clean tissue paper. The non-condensed group (NC) (n=30) were manufactured by loading the specimen former with the porcelain mixture. Excess water was removed by blotting the surface of the porcelain with clean absorbent paper but did not include any form of tapping or vibration during the packing process. All specimens were carefully removed from the specimen former and fired in a porcelain furnace (Dekema AustroMat M, Freilassing, Germany) according to the manufacturer's instructions, with the exception of an extended drying time of nine minutes. This was done due to the geometry of the specimens, which had otherwise caused the specimens to warp and crack. All of the discs were wet ground on both sides using a rotary polishing unit (Tegrapol 21, Struers, Ballerup, Denmark) with 250 and 400 grit abrasive paper. Final wet-grinding was achieved manually with 1000 grit silica carbide abrasive papers. An additional ten specimens were manufactured as described above with Reflex incisal porcelain; these specimens were used for both translucency parameter and density tests. Prior to testing, all specimens were inspected with an LED light for crack lines using a trans-illumination test. All specimens that contained cracks were rejected.

Biaxial flexural strength

ISO standard 6872:2008(E) was followed to determine the biaxial flexural strength (piston on three balls) of the prepared dentine porcelain discs (Cattell et al. 2002, Fleming et al. 2005, ISO 2008).

The porcelain discs were brought to failure in a universal testing machine (Instron, model 3369, Instron Corp.; IL, USA) at a cross-head speed of 1 mm/min. The maximum load at failure was recorded using Instron Bluehill 3 software (Instron Corp.).

The biaxial flexural strength was calculated as (ISO 2008):

Equation 1

$$\sigma = -\,0.2387\,P(X - Y)\,/\,b^2$$

Where:

σ = Maximum centre tensile stress (MPa)
P = Maximum load (N)
b = Specimen thickness at fracture origin (mm)

And

$$X = (1 + \nu)[1+ \ln(r_2/r_3)^2 + [(1 - \nu)/2]((r_2/r_3)^2$$
$$Y = (1 + \nu)[1 + \ln((r_1/r_3)^2] + (1 - \nu)((r_1/r_3)^2$$

Where:

ν = Poisson's ratio (0.25 for porcelain)[12]
r_1 = Radius of support circle (mm)
r_2 = Radius of loaded area (mm)
r_3 = Radius of specimen (mm)

Weibull modulus

Weibull analysis (m) was performed using Microsoft Excel (Microsoft, USA) to determine strength variation among each group. This was used to calculate fracture probabilities of each group as a function of applied stress. This was done using the following formula (Kelly 1995, Della Bona et al. 2003, Yilmaz et al. 2007, Karakoca et al. 2009).

Equation 2

$$P(\sigma) = 1 - \exp[\,-(\sigma/\sigma_o)^{\,m}\,]$$

Where:

P = Probability of failure defined by $P(\sigma) = K/(n+1)$,
K is the rank in strength from least to greatest,
n denotes the total number of specimens per group
σ_o = Scale parameter or characteristic strength (σ63.21%)
m = Dispersion parameter or Weibull modulus related to the slope of the distribution

Microstructural analysis

Porcelain discs with the highest and lowest fracture toughness values were evaluated for presence and size of porosity using a Field Emission Scanning Electron Microscope (JEOL JSM-6700F, Jeol, MA, USA).

Translucency Parameter

Ten Wieland Reflex Incisal veneering porcelain discs were used to determine the Translucency Parameters (TP). A spectrophotometer (VITA Easyshade Compact, VITA Zahnfabrik, Germany) was used to determine the CIE L*a*b* values of each specimen. This was achieved by measuring the values of each specimen against a black and then white background (Omano stage plate, San Jose, USA) with calibration performed before each measurement. Three measurements were taken for each specimen and the average value recorded. The Translucency Parameter formula is (Barizon et al. 2013):

Equation 3

$$TP = [(L_b^* - L_w^*)^2 + (a_b^* - a_w^*)^2 + (b_b^* - b_w^*)^2]^{1/2}$$

Where:

L* = Brightness
a* = Redness/greenness
b* = Yellowness/blueness
b* = Black plate measurement
w* = White plate measurement

Density Test

Density determinations were performed by using Archimedes' principle. This principle states that every solid body immersed in a fluid loses weight by an amount equal to that of the fluid it displaces. The ten specimens used in the translucency test were used in the density test. A precision electronic balance (Voyager Pro Balance, Ohaus, NJ, USA) was used to measure the weight of each disc in air as well as in the distilled water (15°C). The density of a solid is determined with the aid of a liquid whose density Q_0 is known at 15 degrees Celsius. The density Q can be calculated from the weighing as follows (Zhang et al. 2004, Pelaez-Vargas et al. 2011):

Equation 4

$$Pa = \frac{Wd}{Wd - Wss}\;Pw$$

Where:

Pa = Density of the solid
Wd = Weight of the solid in air
Wss Weight of the solid in the auxiliary liquids
Pw = Density of the auxiliary liquid at a given temperature (0.999099g/cm^3)

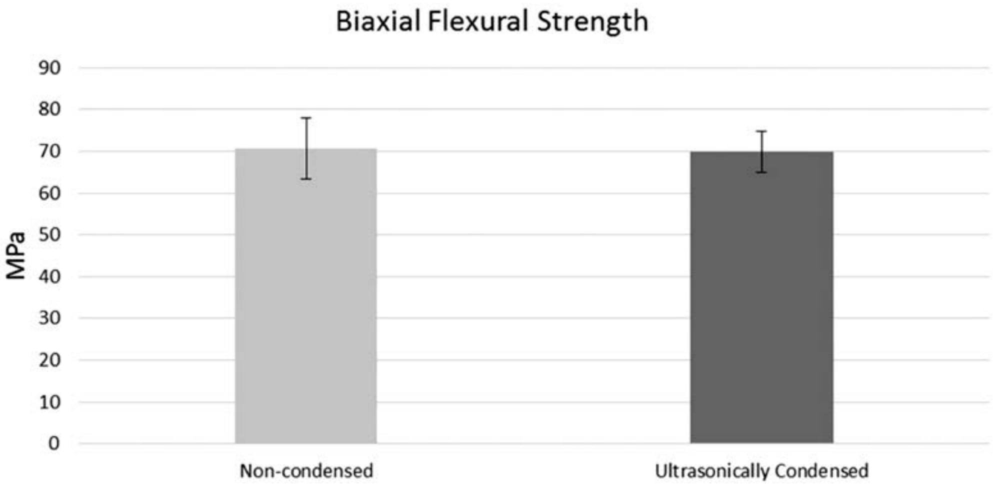

Figure 1: Graph depicting no significant difference in the biaxial flexural strength of non-condensed and ultrasonically condensed Wieland Reflex Dentin ceramic after firing.

Results

An independent-samples t-test (IBM SPPS Statistics, version 23, 2015) was performed to compare the biaxial flexural strength as well as the density and translucency parameter between ultrasonically condensed and non-condensed groups independently. Equal variances (P>0.05) were assumed based on Levene test of variances (P=0.169). There was no significant difference (P>0.05) in biaxial flexural strength for the ultrasonic condensed group (M=69.85, SD=5) and non-condensed group (M=70.59, SD=7.33) as P=0.647. Figure 1 shows the biaxial flexural strength plots with the standard deviations based on these results.

Figure 2 shows the Weibull probability of failure plots for non-condensed and ultrasonically condensed groups respectively. For the non-condensed group, asymmetry is evident, with outliers present on extreme points at either end of the probability plot. For the ultrasonically condensed group, the failure strength plotted on Weibull probability fell in a fairly linear fashion, indicating the assumption of a reasonable Weibull distribution. The Weibull moduli (*m*) values were 11.39 with the normalizing (characteristic) strength at 73.83 MPa for non-condensed

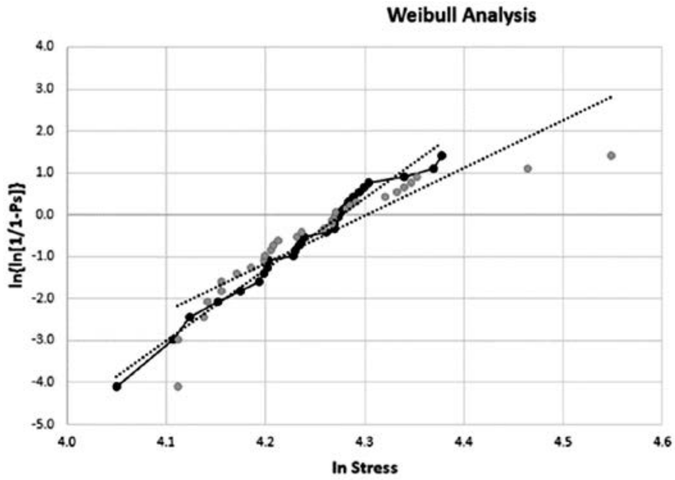

Figure 2. Weibull probability plot for non-condensed and ultrasonically condensed Wieland Reflex Dentin ceramic groups.

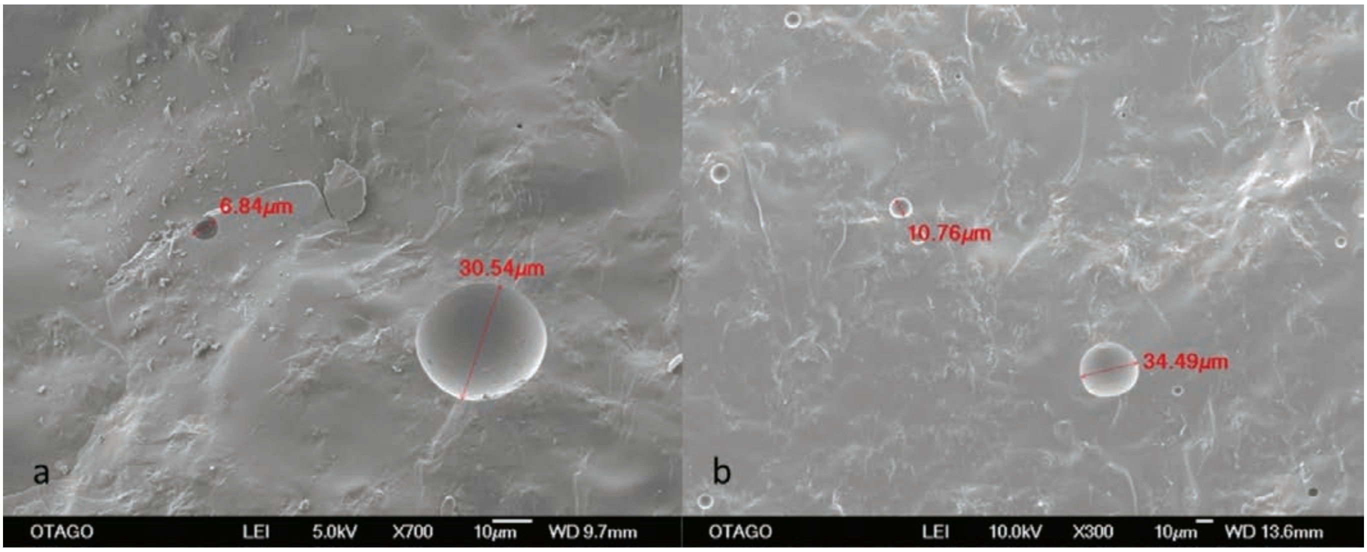

Figure 3. Non-condensed disc (A) and ultrasonically condensed disc (B). This image shows isolated porosities of similar diameter present in both test groups. Note the distinct lack of gull wings.

group and 16.96 with the normalizing strength at 72.04MPa for the ultrasonically condensed group.

No obvious morphological differences were observed in the SEM analysis between fractured discs derived from either groups. Some isolated porosities were observed in both the ultrasonically condensed and non-condensed groups; however the size of porosities found were of similar diameter and did not exceed 35 microns (Fig. 3). Additionally, no gull wings were observed in close proximity to the porosities, indicating that they did not play a role during fracture

The results of Translucency Parameter are listed in Table 1. Equal variances (P>0.05) were assumed based on Levene test for equal variances (P=0.793). No significant difference (P>0.05) was observed between ultrasonic condensed (M=16.39, SD=0.88) and non-condensed (M=16.27, SD=0.68) groups as P=0.816.

The results for the density tests are indicated in Table 2. Equal variances (P>0.05) were assumed based on Levene test (P=0.428). No significant differences (P>0.05) were observed between ultrasonic condensed (M=2.43, SD=0.00829) and non-condensed (M=2.42, SD=0.00396) groups as P=0.087.

Discussion

The purpose of this study was to evaluate and compare the effect of ultrasonic condensing on the biaxial flexural strength, translucency and density of a nano-leucite porcelain.

Statistical analysis concluded that there was no significant difference in biaxial flexural strength between the non-condensed and ultrasonically condensed groups. Weibull analysis is a common method for characterizing the reliability and failure of brittle materials under different flexural configurations (Pelaez-Vargas et al. 2011). The higher Weibull modulus obtained for the ultrasonically condensed group indicated a lower variability of strength, consequently higher reliability of the structures produced by this technique. The higher strength values for ultrasonically condensed porcelain indicates a reliability factor in manufacturing, although the average ultimate flexural strength for the non-condensed group was slightly higher, though not significantly. Its characteristic strength, which would describe the strength of all specimens in that group, indicates that this manufacturing technique is less reliable. Therefore, higher stress levels were necessary to fracture 63.2% of the specimens produced using the ultrasonically condensing technique

It has been reported that the increased reliability of biaxial flexural data can be attributed to the decreased apparent porosity and increased apparent solid density of porcelain specimens (Barizon et al. 2013). Although the authors could find no specific evidence of that in the current study, it was determined that with the stability of the density in both methods, the biaxial flexural strength remained constant as well. Based on a study done by Evans et al. (1990), the method of condensing had no real effect on porosity of sintered ceramic. Gonzaga et al. (2008) went one step further, to show that the increased amount of porosity observed using pressable ceramic did not lead to a decrease in flexural strength.

Table 1. Independent samples test and Levene test for Translucency Parameter indicating no statistical difference between the condensed and non- condensed groups.

	Levene Test for Equality of Variances		t-test for Equality of Means						
								95% Confidence Interval of the Difference	
	F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Equal variances assumed	.074	.793	.241	8	.816	.1195	.4970	-1.0265	1.2656
Equal variances not assumed			.241	7.51	.816	.1195	.4970	-1.0394	1.2786

Table 2. Independent samples test and Levene test for variances for density indicating no statistical difference between the condensed and non- condensed groups.

	Levene Test for Equality of Variances		t-test for Equality of Means						
								95% Confidence Interval of the Difference	
	F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Equal variances assumed	.697	.428	1.947	8	.087	.0080	.0041	-.0014	.0174
Equal variances not assumed			1.947	5.73	.102	.0080	.0041	-.0021	.0181

These results were echoed in the present study. This may be due to the sintering process that ceramics go through to form a solid mass. Due to the viscosity of ceramic in the glass transition phase, the internal voids are rounded off, preventing them from becoming stress concentrators that could lead to catastrophic failure. There are instances, however, where these voids can play a secondary role in the failure of structures. This typically occurs where voids are clustered together and the intersecting boundaries form high stress concentration zones or in cases where the voids are close to the surface or exposed through grinding hence failure is initiated by the same mechanism as mentioned above (Evans 1982). Generally however, it is important to produce porcelains with relatively low apparent porosity to reduce the amount of shrinkage on firing and consequently improve the marginal fit of porcelain in practice (Fleming et al. 2000). Therefore it is concluded that the amount of porosity observed in the specimens had no effect on the flexural strength as reflected in the flexural strength data generated (Gonzaga et al. 2008).

Hodson (1959) asserted that vibrating particles of one uniform size would leave porosity greater than two different size particles or even three. Therefore, the percentage of porosity may vary between porcelain brands according to the distribution of particle sizes. The results obtained in this study may only represent Reflex porcelain, and different results may be obtained with different porcelains or ceramic composition (Evans et al. 1990, Pelaez-Vargas et al. 2011).

According to the Glossary of Prosthodontic Terms (2005) translucency is described as “having the appearance between complete opacity and complete transparency; partially opaque”. Porcelain translucency is regarded as one of the most important factors in controlling the aesthetic outcome of ceramic restorations. This can be affected by many factors, including thickness, microstructure and number of firing cycles (Heffernan et al. 2002, Wang et al. 2013,). Literature suggests that thickness has an indirect effect on the attenuation of light through dental porcelains; the greater the material’s thickness, the lower the attenuation (Zhang et al. 2004). For this reason, the thickness of each specimen in this study was kept constant, measured three times and the mean compared amongst groups. According to Zhang et al. (2004), porcelain type and powder/liquid ratio have a significant interactive effect on the amount of porosity present in sintered porcelain, but no significant effect on the translucency. The present study eliminated the water/powder ratio issue by using a wet tray. Therefore, the results of this study showed no significant differences in porosity or translucency parameters caused by ultrasonic vibration, thus it was not possible to establish any correlation between these factors.

Porcelain condensing via ultrasonic vibration is a popular method used during the veneering process, but it is not a standardized procedure. Apart from the higher Weibull modulus recorded in the ultrasonically condensed group, no other advantage could be seen from this practice. With condensing, we are essentially limiting but not eliminating the structural irregularities possibly obtained in fired porcelain. By not condensing the porcelain, there is an increased element of uncertainty regarding the biaxial flexural strength.

Conclusion

Ultrasonically condensing veneering porcelain before firing may not be necessary to improve the mechanical properties or reduce the amount of apparent porosity. The present study could find no correlations between ultrasonic condensing and improved translucency parameters when compared to specimens that were not condensed. Nevertheless, caution is advised when interpreting these results, due to the shape factor in making disc forms when compared to porcelain layering on clinical crown forms.

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Author details

Wendy-Ann Jansen van Vuuren, NatDipDentTech, BTechDent, MDentTech[a]
Colette ST. Khoo, BDS[b]
Brian SK. Ng, BDS[c]
John N. Waddell, HDE, PGDipCDTech, MDipTech, PhD[d]
Basil Al-Amleh, BDS, DClinDent[e]

[a] Lecturer, Department of Oral Rehabilitation, Sir John Walsh Research Institute, Otago University
[b] Graduate Student, Department of Oral Rehabilitation, Sir John Walsh Research Institute, Otago University
[c] Graduate Student, Department of Oral Rehabilitation, Sir John Walsh Research Institute, Otago University
[d] Associate Professor, Head of Discipline: Biomaterials, Department of Oral Rehabilitation, Sir John Walsh Research Institute, Otago University
[e] Honorary Senior Lecturer, Department of Oral Rehabilitation, Sir John Walsh Research Institute, Otago University

Corresponding author:
Mrs Wendy-Ann Jansen van Vuuren, Department of Oral Rehabilitation, Faculty of Dentistry, PO Box 56, Dunedin 9054, New Zealand. Email: wendy.jvv@otago.ac.nz

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