CEREC SpeedFire furnace versus InFire HTC Speed furnace: comparison of flexural and fatigue strength of Katana STML zirconia with different sintering programs

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ABSTRACT

Objective: This study investigated the effect of different sintering furnaces, the inFire HTC Speed and the CEREC SpeedFire, on the flexural strength, fatigue strength, translucency, opalescence, and Weibull modulus of Katana STML zirconia bars.

Material and Methods: Katana STML zirconia dental material specimens (bars) were cut according to ISO 6872 standards using a 3-dimensional beam milling file provided by Dentsply Sirona. The blocks measured 1.3mm x 4mm x 18mm post-sintering. Specimens were randomly assigned to groupings (strength-testing group and furnace) and sintered. After sintering, specimens were polished in accordance with ISO 6872. Specimens were then tested for their initial three-point bending flexural strength and following fatigue strength in the Instron universal testing machine, and a Weibull modulus was calculated from the results. Spectrophotometry was used to measure the translucency and opalescence of the post-sintered specimens.

Results: Upon initial flexural strength testing, the Katana STML specimens sintered in the CEREC SpeedFire furnace had a statistically greater ($P>0.0046$) strength than the specimens sintered in the inFire HTC Speed furnace. The fatigue testing was performed at 2 Hz and 6000 cycles per specimen to test for failure. The ultimate fatigue strength of CEREC SpeedFire specimens was found to be greater than that of inFire HTC Speed specimens, but not in a statistically significant way. The SpeedFire furnace also produced zirconia bars with a greater Weibull modulus and significantly greater translucency and opalescence.

Conclusions: The CEREC SpeedFire furnace, with its propriety and much more rapid sintering cycle, showed equivalent to greater strength and optical properties when compared to the traditional manufacturer’s recommended sintering cycle in the inFire HTC furnace. The CEREC SpeedFire furnace can sinter a crown in less than half an hour compared to the inFire HTC oven requiring multiple hours. Therefore, the new SpeedFire oven opens same-day dentistry applications to yttria-stabilized zirconia such as Katana STML.

INTRODUCTION

Patients can now expect to receive a crown or milled restoration on the same day that the dentist prepares their crown. With the widespread use of chairside digital scanning and in-clinic milling, the multi-appointment crown procedure has become antiquated. Dentists who have Dentsply Sirona digital scanning, milling, and oven units are able to produce same-day ceramics for their patients. Dental ceramics themselves can be broken up into different categories: predominantly glass, particle-filled glass, and polycrystalline ceramics[1]. The ceramics principally used in same-day dentistry are the glassy materials such as the feldspathic or synthetic aluminosilicate glass (VITABLOCS Mark II, IPS Empress CAD) and particle-filled glasses/glass-ceramics such as lithium disilicate (IPS e.max CAD)[1]. However, the polycrystalline ceramics such as polycrystalline alumina (Vita AL-Cubes) and polycrystalline zirconia (IPS e.max ZirCAD, Dentsply Sirona inCoris ZI, and Katana STML) require a multi-hour sintering process that prevents them from being used in same-day dentistry applications.

Specifically, the benefits of polycrystalline zirconia are biocompatibility, strength and toughness making zirconia crowns a top choice for many dentists[2]. These ceramics contain no glass; glass creates an irregular network and decreases strength. Polycrystalline ceramics have their atoms arranged in a defined array which makes them harder to initiate a crack.[1] Specifically, polycrystalline zirconia used in dental applications can have their atoms arranged in 3 different phases depending on temperature range changes and doping materials. The three zirconia crystallographic phases are the monoclinic (M) phase, the tetragonal phase (T), and the cubic phase (C). The monoclinic phase is stable at room temperature up to 1170ºC with lower mechanical properties than the tetragonal phase which is stable between 1170 ºC and 2370 ºC. There a volumetric decrease as the material transitions from monoclinic to tetragonal phases.[2] CAD/CAM dental zirconia is milled in the monoclinic phase and sintered in a furnace to bring it to the tetragonal phase. The material, however, has been alloyed with lower valence oxides, such as MgO, La_2O_3, Cao and Y_2O_3 which prevents the lattice structure from returning to the monoclinic phase at room temperature when the milled restoration leaves the furnace. Polycrystalline dental zirconia gets additional strength through a process known as transformation toughening. To summarize the process, as a crack propagates in the tetragonal phase, the lattice structure transforms to monoclinic phase with the ensuing volumetric increase, thus expanding the material in the opposite direction of the stress field.[2]

Yttrium stabilized zirconia (YSZ) makes up the broadest portion of available dental zirconia on the market. The first generation of this material, as described above, has enhanced material characteristics, but it is also high opacity, yielding it unusable as a restorative monoblock. This generation of zirconia could be used as a framework with veneered porcelain which still has potential for the porcelain to chip and fracture. In order to achieve greater esthetics and use yttrium-stabilized zirconia without veneering, manufacturers needed to increase translucency. This was achieved through decreasing grain size which increased translucency but maintained the material characteristic of transformation toughening. The next generation of YSZ is defined as having yttrium oxide stabilizer > 3mol%. Whereas previous generations were defined as being tetragonal, the increase in stabilizer also yielded a cubic phase of up to 53%, compromising the mechanical properties by limiting the transformation toughening material characteristic. A recent study by Pereira found that third generation Katana YSZ materials had lower mechanical properties than second generation. However, the third generation 4mol% (Katana STML) had greater fatigue strength than the 5mol% zirconia (Katana UTML).[3]

Third generation YSZ dental materials are now on the market and available for CAD/CAM applications. Dentists today have the option of producing a YSZ crown with higher optical/esthetic properties, albeit lower mechanical properties. As discussed, the sintering process is highly critical for YSZ restorations, and the multi-hour sintering cycles previously limited zirconia restorations to being laboratory fabricated. However, with the 2016 release of the CEREC SpeedFire furnace[4], zirconia restorations can now be produced clinic-side due to its sintering cycle being less than 30 minutes, opening zirconia to same-day dentistry applications.

A previous study by Ersoy, et al, tetragonal YSZ using rapid sintering cycles in the inFire HTC speed furnace and found increased flexural strength with the faster cycles[5]. The aim of this study is to determine if the CEREC SpeedFire furnace can produce third generation YSZ restorations with equivalent optical and mechanic properties compared to the inFire HTC. The tested null hypothesis is that the CEREC SpeedFire and inFire HTC would produce equivalent optical (translucency and opalescence) and mechanical (flexural and fatigue strength) properties in third generation YSZ Katana STML.

METHODS AND MATERIALS

Zirconia bars were fabricated through 5-axis milling of Kuraray Katana STML A1 pucks. Dimensions were set to parameters that yielded post-sintering bars of 4 mm in width, 1.3 mm in depth, and 18 mm in length[6]. This was accomplished through a stereolithography file (.stl) provided by Dentsply Sirona to the Air Force Prosthodontic Dental Laboratory. Bar specimens were polished and randomized to one of four groupings:

	inFire HTC Speed	CEREC SpeedFire
Flexural Strength	A (18 bars)	B (18 bars)
Fatigue Strength	C (20 bars)	D (20 bars)

Table 1. Specimen groupings

The same .stl file then was used in the Sirona Omnicam to generate a sintering workload for the CEREC SpeedFire based upon a proprietary sintering program. The CEREC SpeedFire furnace specimens were sintered individually based upon the generated workload, resulting in a half hour sintering cycle. The inFire HTC Speed furnace specimens were sintered in groups of no greater than 8 bars per cycle using the manufacturer's sintering specifications. The inFire HTC Speed furnace was programed to increase temperature at a rate of 10°C per minute and ramp to 1550°C, hold for 2 hours, and ramp down at a rate of -10°C[7]. The resulting sintering cycle of inFire HTC for Katana STML was 7.28 hours.

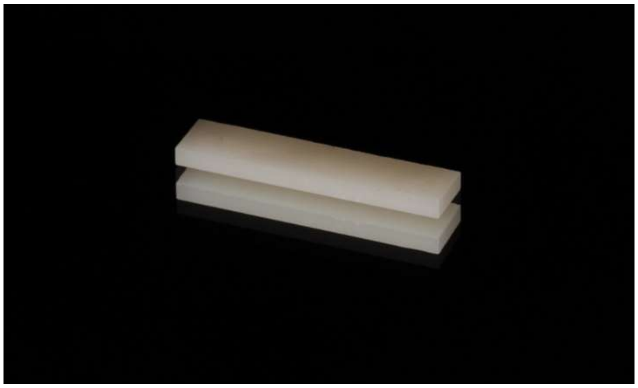


Figure 1. Katana STML specimen

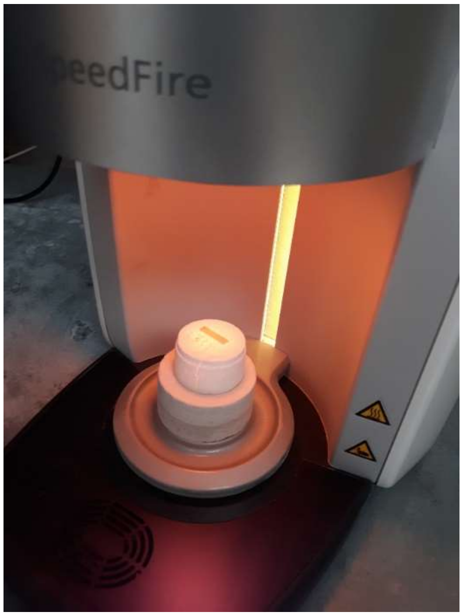


Figure 2. CEREC SpeedFire Furnace

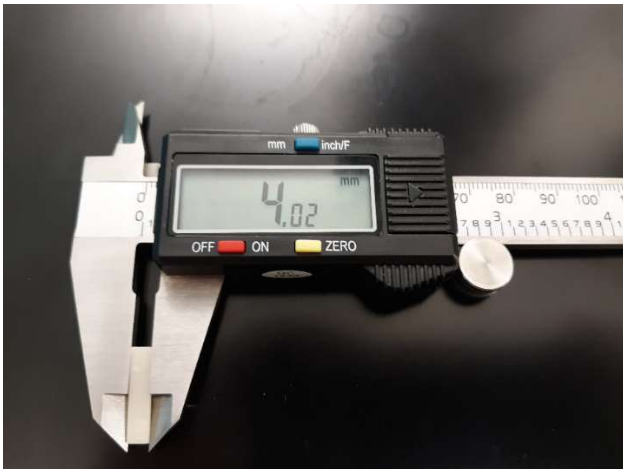


Figure 3. Measurement of STML bars

Testing of the zirconia ceramic specimens was done according to International Standard ISO 6872, Dentistry – Ceramic Materials, 2015[6]. The flexural strength of the inFire HTC Speed and CEREC SpeedFire bars was tested via a 3-point bending test. The bars were first measured with digital calipers to the nearest 0.01mm. Bars were placed centrally across a 15mm span on the Instron testing machine (Model 5543, Instron, Canton, MA) with the 4mm wide face perpendicular to the long axis of the load applied at a crosshead speed of 1.0 mm/min. The flexural strength was calculated using the formula[6]:

$$FS = \frac{3Fl}{2bd^2}$$

where *F* is the loading force at the fracture point; *l* is the length of the support span (15 mm); *b* is the width; and, *d* is the depth. F was recorded using Instron Blue Hill software.

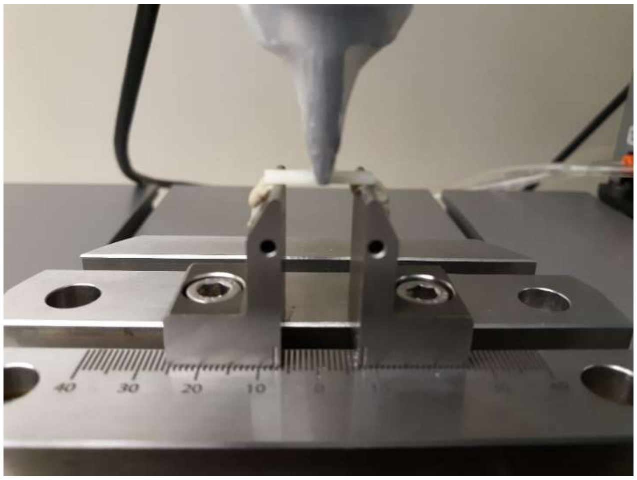


Figure 4. 15mm span for 3-point bending test

A staircase approach was used to calculate fatigue strength (endurance limit) of the Katana STML zirconia bars. Test interval increases and decreases were chosen to be 10% of the flexural strength. Duration was set at 6000 cycles and 2 hertz. If the specimen broke before 6000 cycles were reached, it was recorded as a failure. If the specimen remained unfractured, it was recorded as a success. Test failures and successes were sorted and numbered from lowest to highest force at which failure or success occurred. The fatigue strength (endurance limit) was calculated from the following formula[8,9]:

$$S_e' = \sigma_0 + d\left(\frac{A_n}{\sum n_i} \pm \frac{1}{2}\right), \quad A_n = \sum i n_i$$

where the positive sign is used if more tests resulted in success, and a negative sign is used when more failures occurred during testing. σ_0 is the lowest stress level in the grouping, and the number of events (failures or successes) is assigned to n_i for each stress level σ_i.

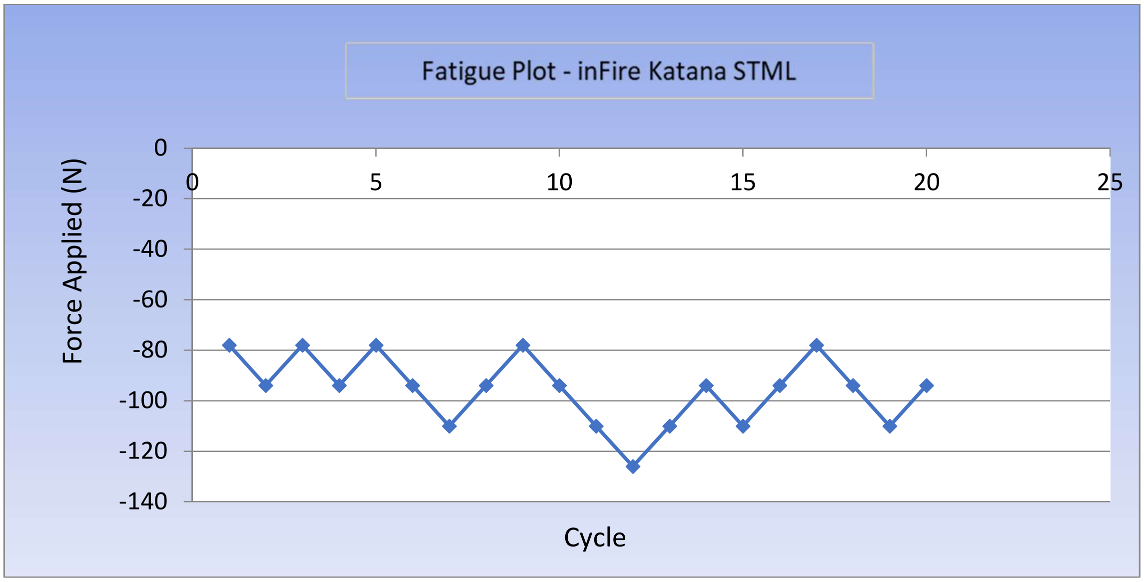


Figure 5. Fatigue plot for inFire HTC sintered Katana STML bars

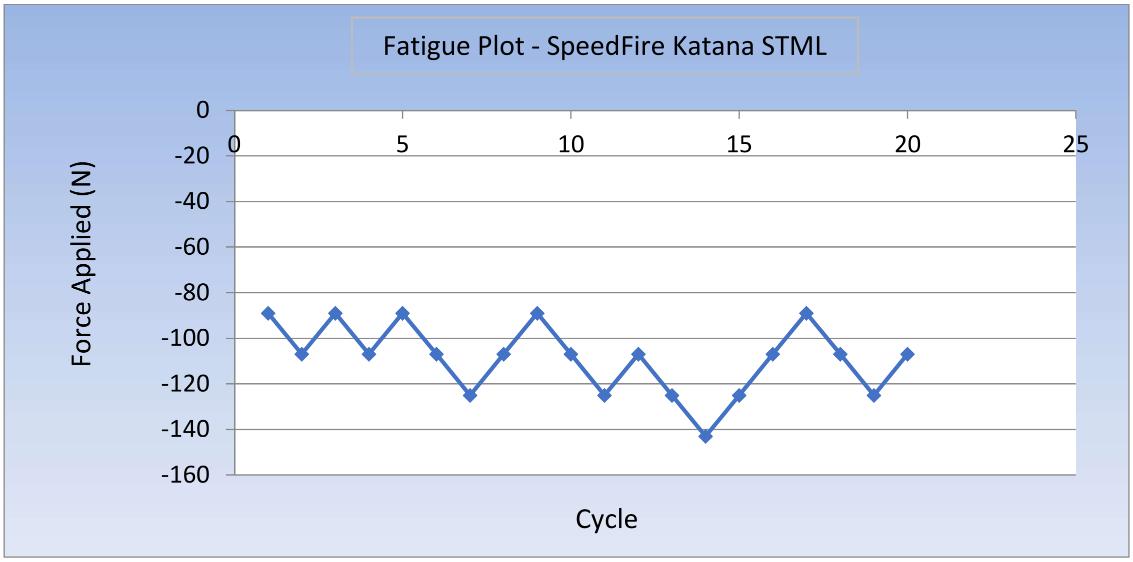


Figure 6. Fatigue plot for SpeedFire sintered Katana STML bars

Figure 7. VITA Easyshade Compact

A dental spectrophotometer (VITA Easyshade Compact) was used to determine the translucency and opalescence of the bars. Ten bars of inFire specimens and ten bars of SpeedFire specimens were measured on both a black and a white background. The CIE L*a*b* color space values were measured three times for each sample on each background. The translucency parameter (TP) and opalescence parameter (OP) were calculated[10]:

$$TP = ((L_B - L_W)^2 + (a_B - a_W)^2 + (b_B - b_W)^2)^{1/2}$$
$$OP = ((a_B - a_W)^2 + (b_B - b_W)^2)^{1/2}$$

where B and W denote the black and white backgrounds, respectively. L* is a measure of the lightness, a* represents the amount of red and green present, and b* represents the amount of yellow and blue.

The Weibull modulus was calculated for a fixed volume from the following formula:

$$ln\left[ln\frac{1}{1-P}\right] = m * ln\sigma + k$$

Where the Weibull modulus, m, was calculated from plotting ln[ln(1/(1-Pi))] against $\ln\sigma_i$ and determining the slope.[11]

RESULTS

Properties of Katana STML	Furnace inFire HTC Speed mean (std dev)	 CEREC SpeedFire mean (std dev)	p-value
Flexural Strength (MPa)	482.44 (83.3)	567.31* (76.2)	.005
Fatigue Strength (N)	95.6 (41.2)	109.45 (44.0)	0.47
Translucency Parameter	14.7 (1.1)	15.7* (0.8)	0.01
Opalescence Parameter	6.1 (0.8)	7.1* (0.7)	0.03
Weibull Modulus	6.70	8.52	

Table 2: Mean and standard deviation of the strength properties, optical parameters, and grain size of the zirconia using high-speed and conventional sintering times. * denotes rows which are significantly different ($p < 0.05$).

The mean and standard deviation of the flexural and fatigue strengths and the optical properties were calculated as discussed in the methods section. JMP software t-Tests were performed to determine statistical difference in the results between each group of bars sintered in different furnaces.

The CEREC SpeedFire furnace produced Katana STML bars with greater flexural strength, fatigue strength, and Weibull modulus. The flexural strength being statistically significantly greater for the SpeedFire than the inFire HTC. The SpeedFire also produced bars with statistically significantly greater translucency and opalescence.

DISCUSSION

Based upon the results of this study, the null hypothesis that the SpeedFire furnace would produce equivalent flexural strength as the inFire HTC was rejected. The great flexural strength of zirconia-based ceramics enables them to be used in high stress-bearing areas of the mouth[12]. The results of flexural strength testing in this study are consistent with those found in the Ersoy et al study, in which the highest flexural strengths were seen in pre-heated ovens in which the zirconia bars were sintered for the shortest amount of time compared to ramping-and-holding sintering cycles[5].

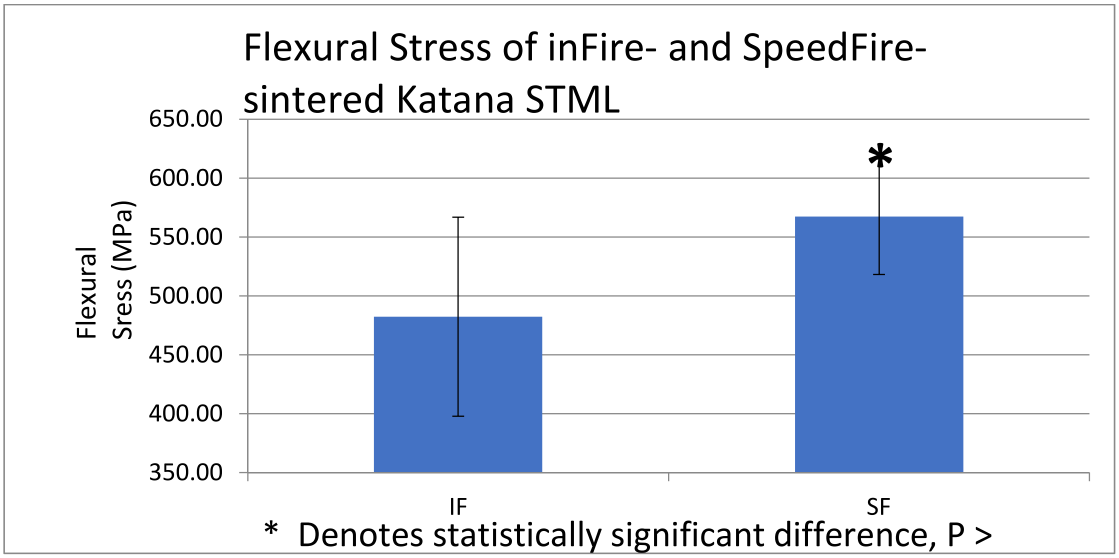


Figure 8. Plotted Flexural Strength of Katana STML

The null hypothesis that the SpeedFire furnace would produce equivalent fatigue strength as the inFire HTC was accepted. The concept of cyclic loading to produce fatigue is important in the mouth as it presents a realistic failure mode; zirconia restorations must endure years of repeat loading intraorally[13].

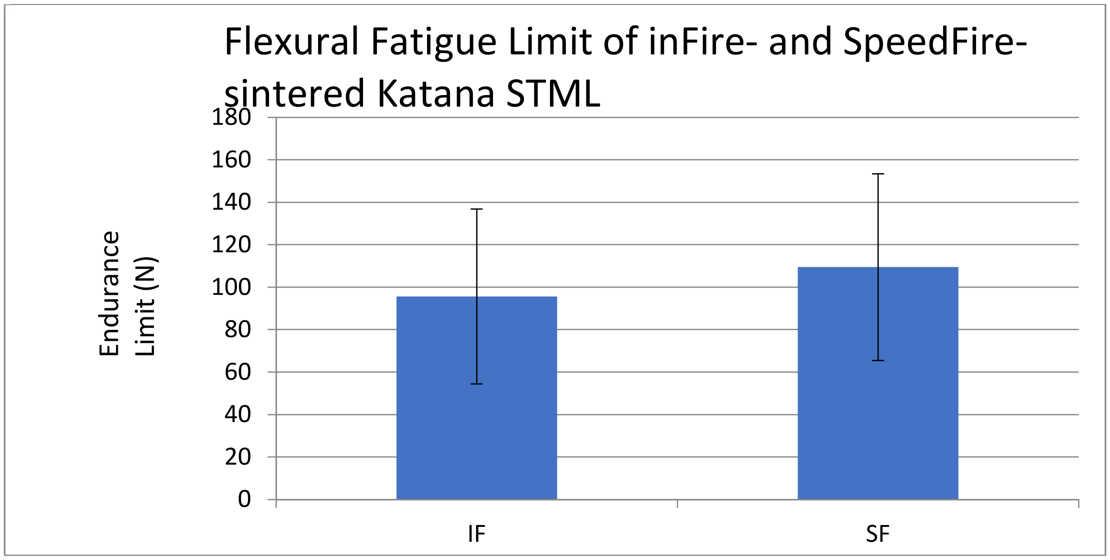
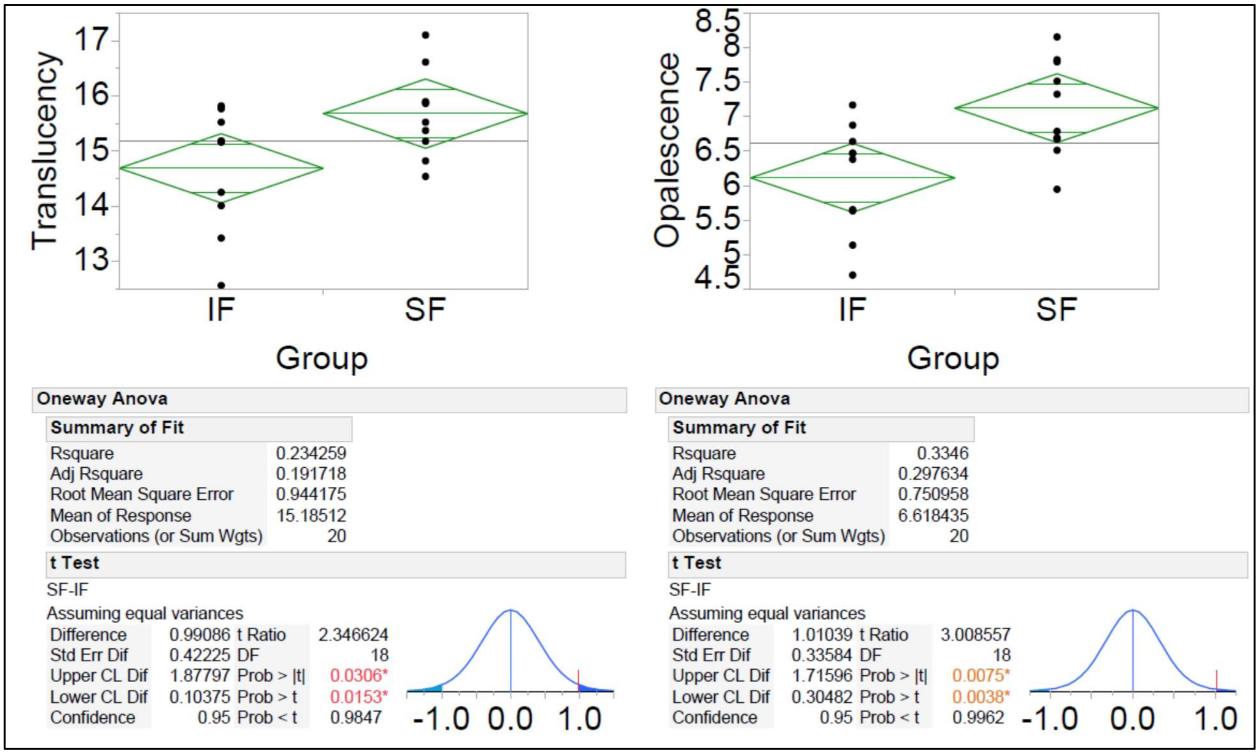


Figure 9. Plotted Fatigue Strength of Katana STML

The null hypothesis that the SpeedFire furnace would produce equivalent translucency and opalescence as the inFire HTC was rejected due to the fact that the SpeedFire produced more translucent and opalescent bars. Higher parameters indicate more translucency and more opalescence. In a study by Kim et al, more translucent dental zirconia restorations were obtained from shorter sintering times using microwave sintering of 20 minutes versus conventional sintering of 2, 10, and 40 hours. Translucency of dental zirconia is based on sintering temperature, additives, and the heating method. The translucency of a material is dependent on how the light scatters off of it. For zirconia, a grainsize of <100 nm is necessary to obtain proper translucency for tetragonal YSZ. YSZ is mostly opaque due to the grain boundaries and small defects present due to tetragonal-to-monoclinic transformations.[14] The addition of cubic phase zirconia enhances the translucency but decreases mechanical properties. If the sintering process can be altered, i.e. through SpeedFire sintering, greater mechanical properties can be expected with higher translucency, third-generation YSZs such as Katana STML.



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Oneway Anova
 Summary of Fit
 Rsquare                      0.234259
 Adj Rsquare                  0.191718
 Root Mean Square Error       0.944175
 Mean of Response             15.18512
 Observations (or Sum Wgts)         20
 t Test
SF-IF
Assuming equal variances
 Difference    0.99086 t Ratio   2.346624
 Std Err Dif   0.42225 DF              18
 Upper CL Dif  1.87797 Prob > |t|  0.0306*
 Lower CL Dif  0.10375 Prob > t    0.0153*
 Confidence       0.95 Prob < t    0.9847
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Oneway Anova
 Summary of Fit
 Rsquare                        0.3346
 Adj Rsquare                  0.297634
 Root Mean Square Error       0.750958
 Mean of Response             6.618435
 Observations (or Sum Wgts)         20
 t Test
SF-IF
Assuming equal variances
 Difference    1.01039 t Ratio   3.008557
 Std Err Dif   0.33584 DF              18
 Upper CL Dif  1.71596 Prob > |t|  0.0075*
 Lower CL Dif  0.30482 Prob > t    0.0038*
 Confidence       0.95 Prob < t    0.9962
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Figure 10. Statistical analyses of Katana STML translucency and opalescence

Within the limits of this study, the SpeedFire sintered Katana STML had a larger Weibull modulus. Katana STML, along with the dental ceramics, are considered a brittle material. For these types of materials, there is inherently a weakest-link at which the largest flaw in the fibers is present and at which the fracture will occur. If the flaws are assumed to be randomly distributed throughout the volume of the specimen, then calculating the Weibull modulus of a group of specimens of consistent volume at their point of flexural strength will allow a comparison of consistency between materials. The higher the Weibull modulus, the smaller the variation from sample to sample.[11]

Future studies should examine multiple CAD/CAM materials. The SpeedFire furnace not only sinters zirconia-based ceramics, it can also be used for crystallization. A multi-material study with larger sample sizes would be beneficial to determine overall effectiveness of the furnace with its propriety heating programming. However, the SpeedFire furnace appears to be an appropriate choice for dentists wanting to create YSZ same-day restorations with equivalent strength and optical properties.

CONCLUSION

In summary, the Katana STML specimens produced for this study had greater flexural strength, fatigue strength, translucency, opalescence, and Weibull modulus when sintered in the CEREC SpeedFire furnace than the traditional counterpart, the inFire HTC Speed furnace. In addition to the superior properties, the CEREC SpeedFire is also significantly smaller and has the ability to be used in a dental clinic instead of a dental laboratory with same-day applications due to its rapid sintering cycle.

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