SPEED SINTERING: how fast can zirconia be sintered or how fast should zirconia be sintered?

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Dental zirconia is a remarkable restorative material that has enabled dental laboratories to attain a level of productivity higher than ever before. The single part of the process that many technicians find troublesome, however, is the sintering operation. Most manufacturers recommend sintering cycles from four to eleven hours. Is there a better way? Is there a faster way? This paper will explore the properties of zirconia that impact its ability to densify quickly as well as the equipment necessary to ensure the final restoration is dense, strong and exhibits the proper shade.

Why do we sinter zirconia?

Zirconia is second only to diamond in hardness when it is fully dense. This is the reason zirconia discs are made to be only about fifty percent dense. The material in this state can be milled without difficulty. This highlights one of zirconia's most interesting properties, isotropic sintering. Most materials, alloys or ceramics, will shrink most where the mass is the highest i.e. where the pontics are, resulting in a three unit bridge distorting into a 'U' shape. Zirconia will shrink uniformly in all three dimensions regardless of the objects center of mass.

What happens during sintering?

The two processes that occur during sintering is densification, going from 50 to 100 percent dense, and shade development. The final color of the restoration is only developed at high temperatures. These processes require energy that is provided by the heat from the furnace. Attaining a high density is important for the strength and translucency of the material. The proper shade is seen after the absorption of sufficient heat. So how much heat is needed? The answer is, "it depends."

Most people know that it takes longer to cook a stuffed turkey than an empty one. The reason is simple, there is more mass in the stuffed turkey. It works the same with sintering zirconia: the more units in the furnace, the longer it takes to sinter. Also, the larger the sintering furnace, the longer the sintering time since the insides of the furnace also need to be heated.

The other important factor is: What is being sintered?

Zirconia has poor thermal conductivity, that is, it doesn't even out the heat within the material's structure. This causes bridges to be sensitive to thermal shock, especially on cooling. Anytime a thick section of zirconia is adjacent to a thin section there is a potential for fracture. Examples are: a heavy pontic next to a thin abutment and a thin milling support connected to a thick bridge. The risk of fracture means that bridgework should <u>not</u> be rapidly sintered and definitely <u>not</u> fast cooled.

What are the conditions for speed sintering?

The analysis above leaves us with the following conditions for rapid sintering:

1. Single units only (because bridges may fracture).
2. A few units in the furnace (to reduce the amount of mass needed to be heated).
3. A small furnace.

The furnace turns out to be a very important part of the speed sintering process. The traditional zirconia sintering furnace uses molybdenum di-silicide heating elements because these elements can produce a large amount of heat per square centimeter and have a high maximum temperature. A typical porcelain oven uses silicon carbide heating elements that have a lower working temperature and about half the power output of molybdenum di-silicide. Recently, a few manufacturers have introduced small furnaces heated by silicon carbide to process a few (three to six) zirconia sintering units very quickly. (Some zirconia manufacturers show a short sintering cycle but require the units to be removed from the furnace at 800°C, so they do not count the actual time to cool down.) These small silicon carbide furnaces sometimes allow the zirconia to attain sufficient translucency but do not provide enough heat for shade development.

Shade development in zirconia requires heat (energy) in order for the coloring element atom to diffuse to and then replace a zirconia atom on the crystal lattice. Never mind the details, the point is that additional energy is needed for shade development above that needed for attaining some level of translucency. While some people are satisfied starting with an A3 shade in order to wind up with A2, Argen's goal is to have the zirconia properly sintered and exhibit both the proper strength and shade.

The published literature[1,2,3] shows mixed results for speed sintering of zirconia successfully. An analysis of the literature shows a significant dependence on both materials and furnace.

One manufacturer, KDF, has introduced a small furnace (KDF Speed) that uses molybdenum di-silicide heating elements. We have tested this furnace and present our findings below.

1. Jerman E (et al), Effect of high-speed sintering on the flexural strength of hydrothermal and thermo-mechanically aged zirconia materials. Dent Mater. 2020 Sep;36(9):1144-1150. doi: 10.1016/j.dental.2020.05.013. Epub 2020 Jun 30.
2. Ahmed WM (et al) The influence of altering sintering protocols on the optical and mechanical properties of zirconia: A review. J Esthet Restor Dent. 2019 Sep;31(5):423-430. doi: 10.1111/jerd.12492. Epub 2019 May 29.
3. Lawso, N.C and Maharishi, A Strength and Translucency of zirconia after high-speed sintering. J. EstheticRestor Dent. 2020 Mar:32 (2):219-225. doi:10.111/jerd.12524

KDF Zircom Speed Evaluation

For this evaluation we used samples of ArgenZ HT+ Pre-shaded Zirconia for strength and transmission testing. Samples (discs) were milled from the same lot number of ArgenZ zirconia and were split with one group sintered KDF Zircon furnace using a standard sintering cycle as the control while the other group was sintered in the KDF *Speed* furnace using a Speed Sintering Cycle. Single central and molar units were also fabricated and sintered in the two cycles.

STANDARD SINTERING CYCLE

Step	Temperature	Time (min)
1	Heat to 900°C	90
2	Heat to 1510°C	85
3	Hold at 1510°C	120
4	Cool to 1000°C	75
5	Cool to 200°C	80
	Total time	450 min.

SPEED SINTERING CYCLE

Step	Temperature	Time (min)
1	Heat to 900°C	15
2	Heat to 1525°C	20
3	Hold at 1525°C	45
4	Cool to 1400°C	2
5	Cool to 1200°C	3
6	Cool to 800°C	10
7	Cool to 350°C	10
	Total time	105 min.

The sintered samples were then polished and tested on either an Instron universal system for biaxial flexure testing or a PerkinElmer UV/VIS for transmission/wavelength testing.

Results

The initial biaxial flexure strength results surprised us so the test was repeated. Both sample sets processed in the speed sintering cycle exhibited strength results similar to the standard sintering cycle. There was no statistical difference between the three strength values.

BIAXIAL FLEXURAL STRENGTH

First Round Speed Sintering	Second Round Speed Sintering	Standard Sintering Cycle
1219 MPa	1237 MPa	1250 MPa

TRANSLUCENCY AND COLOR RESULTS

	Translucency (600nm)	L	a	b	Cab	Hue
Speed Cycle	36.2	62.6	1.1	23	23	87
Standard Cycle	36.9	63.4	0.76	22	22	88

There was very little difference in translucency. A small shift in Hue was observed. These differences were difficult to see in the fired and glazed units shown below.

ArgenZ HT+ shade A2 speed sintered unit is on the left and the standard sintered unit is on the right.

ArgenZ HT+ML shade A1 speed sintered unit is on the left and the standard sintered unit is on the right.

ArgenZ HT+ML shade A3 speed sintered unit is on the left and the standard sintered unit is on the right.

These results demonstrated that the KDF Speed sintering furnace was capable of firing single zirconia units in only 105 minutes without loss of strength or shade.

Summary

Time is a priority factor in the dental laboratory workflow. In an effort to speed up workflow, it is important to ensure use of tested processes that will result in the best possible output. For best results, choose a sintering furnace that is specifically intended for speed sintering. ■