Manufacturability study of CLEARCERAM®-Z (T008) compared to other low CTE materials

Chris Ghio[a,*], Kousuke Nakajima[b] and Jessica DeGroote[c,†]
[a]*Ohara Corporation, 50 Columbia Road, Branchburg Township, Somerville NJ 08876, U.S.A.*
[b]*Ohara Incorporated, 15-30, Oyama 1-Chome, Sagamihara-Shi, Kanagawa 229 Japan*
[c]*Optimax Systems Inc., 6367 Dean Parkway, Ontario NY 14519, U.S.A.*
[*]chrisghio@oharacorp.com and [†]jdegroote@optimaxsi.com

Abstract: CLEARCERAM®-Z, CLEARCERAM®-Z HS and CLEARCERAM®-Z (T008) are ultra-low thermal expansion materials. This paper gives a comparison of their thermal properties as well as their manufacturability using traditional grinding and polishing methods.

OCIS codes: (160.4670) Optical materials, (220.4610) Optical fabrication

1. Introduction to CLEARCERAM®-Z HS and CLEARCERAM®-Z (T008)

CLEARCERAM®-Z was originally developed as an ultra-low thermal expansion material. The thermal expansion of this material, while very low, does not actually represent a true zero expansion material. This also holds true for alternative materials in the marketplace such as fused silica and other low expansion materials. The CLEARCERAM®-Z HS and CLEARCERAM®-Z (T008) were developed in an attempt to reduce the thermal expansion and approach a true zero expansion material. A comparison of some key characteristics is shown below in Table 1.

		CLEARCERAM-Z	CLEARCERAM-Z HS	CLEARCERAM-Z (T008)
Coefficient Of Thermal Expansion (CTE)x10^{-7}/deg C (over 0-50 deg C)		0.0+/-1.0	0.0+/-0.2	0.0*
Abrasion (A)		62	64	62
Material Transmission (XMS)	500 nm	> 83%	> 80%	> 83%
	980 nm	> 90%	> 90%	> 90%
	1550 nm	> 91%	> 90%	> 90%
N_d		1.546	1.547	1.545
Advantage		Transparent	Tighter CTE spec	Transparent & Tighter CTE spec

Table 1: Key characteristics for the Ohara CLEARCERAM®-Z materials. *Value as measured within the accuracy of current measurement tool.

These CTE variations are evident when the materials are compared by plotting the change in length over original length of material as a function of temperature change as seen in Figure 1 below.

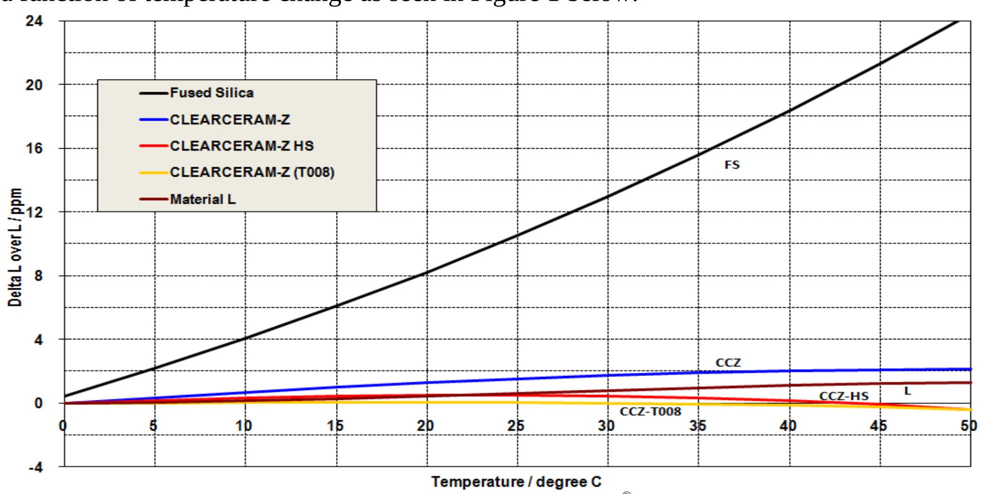

Figure 1: Thermal expansion curves for CLEARCERAM®-Z versions and fused silica

2. Grinding theory and experimental design

Preston[1] was a pioneer in determining a relationship for removal rates for grinding and polishing glass. He determined that removal rates increased linearly with both velocity and normal pressure. His work was extended by Buijs et. al[2, 3] who incorporated the mechanical properties of glass into calculating the grinding removal rates of glass. A modified version of their removal rate equation (terms relating to mean abrasive size of the load bearing particles have been removed) is shown as Equation 1, where MRR is the material removal rate, E is the Young's modulus, K_c is the fracture toughness and H_v is the Vickers microhardness, p is the normal pressure and v is velocity. Buijs et al. also defined a relationship between the resulting peak-to-valley (PV) surface roughness and the glass mechanical properties (see Equation 2).

$$MRR \propto \frac{E^{5/4}}{K_c \cdot H_v^2}\, pv \tag{1}$$

$$PV \propto \frac{E^{1/2}}{H_v} \tag{2}$$

The purpose of this work was to determine and compare how the novel Ohara CLEARCERAM®-Z (T008) material and the CLEARCERAM®-Z HS compares to the traditional CLEARCERAM®-Z material and similar low coefficient of thermal expansion (CTE) materials with respect to manufacturability. The results generated would also be compared to equations 1 and 2 shown above. The materials were all supplied in the form of 150mm diameter disks. The materials consisted of CLEARCERAM®-Z (T008), CLEARCERAM®-Z, CLEARCERAM®-Z HS, Material L and fused silica. Material L is a low CTE material not manufactured by Ohara, included in the study as a comparison. Table 2 lists the material mechanical and chemical properties.

	E [GPa]	Hk [GPa]	RW(p) [%]	RA(p) [%]	Ralkali(p) [%]
CLEARCERAM-Z	91	5.9	0.02	0.02	0.17
CLEARCERAM-Z HS	92	5.8	0.02	0.04	0.19
CLEARCERAM-Z (T008)	91	5.8	0.02	0.03	0.17
Fused Silica	73	6.0	0.00	0.00	0.61
Material L	91	6.2	0.02	0.02	0.16

Table 2 – Material Mechanical and Chemical Properties. Measurement conditions:
Young's Modulus, E: Ultrasonic method, MODEL 25DL from Panametrics Co., Ltd.
Knoop microhardness, Hk: Knoop microhardness test (Load 0.98N for 15 seconds)
Water resistance, RW(p): Powder method, grain size 425-600µm, immersed in DI water for 60 minutes
Acid resistance, RA(p): Powder method, grain size 435-600µm, immersed in 0.01N Nitric Acid solution for 60 minutes
Alkali resistance, Ralkali(p): Powder method, grain size 425-600µm, immersed in 0.1N NaOH solution for 60 minutes

The experiment was designed to ensure that each material was exposed to the same conditions (pressure, velocity, abrasives, etc.) for the same amount of <u>time</u>. The four manufacturing steps performed on the five low expansion materials were as follows: 30-minutes ground with 20µm Al_2O_3 in 5-minute increments, 30-minutes ground with 9µm Al_2O_3 in 5-minute increments, 195 minutes gray out with polyurethane polishing pad and a cerium oxide slurry with a slightly alkaline pH, and finish for two hours on a continuous pitch polisher (CP). The actual amount of material removed varied for each of the materials, but the amount of material removed in the 9µm grind and pad polish step was still higher than two times the areal PV surface roughness measured with a white light interferometer of the previous step. Lambropoulos et al.[4] determined that two times the areal PV surface roughness of a ground surface measured with a white light interferometer is the upper limit of the amount of sub-surface damage (SSD) present after grinding for most brittle materials.

3. Results

As indicated earlier, the processing time for each of the materials was constant in this experiment. Using the removal rate information collected for each process step and the amount of SSD present after each grinding step, the estimated average manufacturing time was calculated for each material. The calculations assume that each step in the process would completely remove the SSD induced from the previous step, therefore removing two times the resulting average PV surface roughness from the previous step. The calculated average manufacturing times shown in Figure 2 do not include any CP polishing time or any handling time (i.e. set-up, blocking, measuring, cleaning, etc.). [The CP polishing time was not included because the scope of this experiment did not include obtaining a surface with a specific surface figure*] The average manufacturing times are not to be considered a rule, but only as a tool for comparison between the five low CTE materials studied in this experiment.

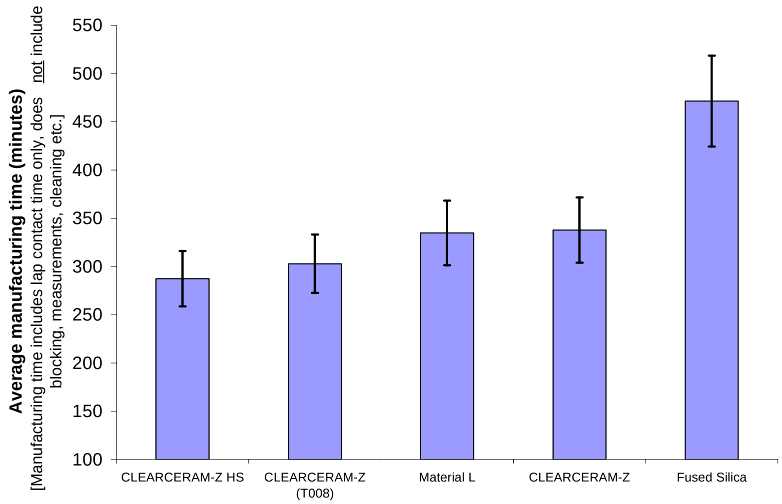

Figure 2: Calculated average manufacturing time for the five low CTE materials. Manufacturing time only includes lap contact during grinding and gray out. It does NOT include final CP polishing, blocking, measuring, cleaning, etc. The error bars indicate a +/-10% error in calculation

In addition, Table 3 lists all of the final surface roughness values measured after two hours of polishing on a CP. These values were all measured with a Zygo NewView 200 white light interferometer[5]. The results in Table 3 show that all five materials had similar surface roughness values after two hours of CP polishing.

	Surface Roughness Values [nm]			
	PV	st dev	RMS	st dev
CLEARCERAM-Z	4.2	0.9	0.38	0.03
CLEARCERAM-Z HS	4.3	0.4	0.51	0.03
CLEARCERAM-Z (T008)	4.3	0.9	0.47	0.07
Material L	4.5	0.2	0.51	0.02
Fused Silica	4.4	1.0	0.38	0.01

Table 3 – Average surface roughness data for the five low CTE materials after two hours on the CP with CeO_2.

4. Summary

Results demonstrate that the Ohara CLEARCERAM®-Z (T008) material represents a true zero-expansion material. Results also indicate that CLEARCERAM®-Z (T008) and CLEARCERAM®-Z HS have improved grinding and polishing rates compared to other low CTE materials within error, which was expected based on their mechanical properties and the relationships outlined in Equations 1 and 2. The CLEARCERAM®-Z HS has the most efficient manufacturing time which is 39% faster than the least efficient material examined in this study. All of the low CTE materials have similar surface roughness values after two hours of polishing.

5. References

[1] Preston, F.W., *The theory and design of plate glass polishing machines.* Journal of the Society of Glass Technology, 1927. **11**: p. 214 - 256.
[2] Buijs, M. and K. Korpel-van Houten, *A Model for Lapping of Glass.* Journal of Materials Science, 1993. **28**(11): p. 3014-3020.
[3] Buijs, M. and K. Korpel-van Houten, *Three-Body Abrasion of Brittle Materials as Studied by Lapping.* Wear, 1993. **166**(2): p. 237-245.
[4] Lambropoulos, J.C., et al. *Non-contact estimate of grinding-induced subsurface damage*. in *Optical Manufacturing and Testing III*. 1999. Denver, CO: SPIE.
[5] *Zygo NewView 200, 20x Mirau objective, 10μm scan length, three phase averages, unfiltered, remove spikes: on*.

* All five materials had surface qualities of better than λ/10 PV after only two hours on the CP