ADVANCED CERAMICS
MANUFACTURING

FastCoreTechnology

Prepared 4-28-2020

Physical Properties and Performance Evaluation

FastCore technology allows the production of hollow parts utilizing a soluble core. Legacy technologies including plaster, molten salt, and bladders have limitations. These limitations have left the industry with a need for a material that minimizes tooling investment, reduces tooling costs, increases production rates, and does not affect the final part due to chemical interactions.

FastCore technology is used by ACM to make net shape mandrels for customers. These mandrels are delivered pre-formed and sealed with PTFE tape. They arrive at your facility as a ready to use shop supply. FastCore technology is suitable for rapid prototyping and production quantities. FastCore is suitable for autoclave processing at temperatures up to 400°F/180°C.

ACM's on-site manufacturing system allows forming of net shape mandrels or machinable blocks. Blocks can be rapidly machined by one of our on-site CNC routers and bonded to achieve large, complex geometries.

FastCore mandrels are porous and are pre-sealed before composite processing to prevent resin infiltration.

Contents: **Page**

Physical Properties

Table 1. Physical properties of FastCore

Property	FastCore	Units
Specific Heat	1.1	J / g – °C
Dry density	0.40-0.53	g/cm^3

Thermal Properties

Being porous in nature and ceramic based allows FastCore materials to be stable under high temperature and autoclave pressures typical for the composite industry.

- ***Coefficient of Thermal Expansion (CTE)***

Table 2. CTE data for FastCore. (Graph on next page)

Material	**Measurement Direction**	**CTE** [ppm / °C] *	**Polynomial Equation n=2**
FastCore	length	**5.61**	$y = 0.0051 x^2 + 3.8496x + 6.8118$
AquaCore	length	**4.95**	$y = 0.0048 x^2 + 4.007x + 9.0214$
AquaCore retest	length	**4.85**	$y = 0.0047 x^2 + 4.0398x + 5.8596$

1) The reported average CTE is calculated as a linear regression slope of the cooling phase over thefull temperature range.
2) The +/- calculated measurement uncertainty for each measurement is 0.05.
3) Test conducted by PMIC in a custom quartz dilatometer in air according to ASTM E228-06

*Measurements were recorded every 5 seconds as the temperature was cycledbetween °C nd 180°C at a maximum rate of 0.25°C/min. The temperature was held for 45 minutes at the extremes to minimize thermal gradients.

- ***Thermal Conductivity (TC)***

Test method ASTM E-1225

FastCore has low thermal conductivity that protects its binder system from extreme temperature conditions for short periods of time. Standard operating conditions less than 180°C have little to no effect on the binder's solubility.

Table 3. Thermal Conductivity data for FastCore .

Description	**Nominal Temperature**	**0**	**90**	**180**
FastCore	Tested Temperature	0	91	180
	Conductivity *(W/m-°K)*	0.19	0.23	0.28
	Uncertainty %	*12.3*	*12.3*	*11*
AquaCore	Tested Temperature	0	91	180
	Conductivity *(W/m-°K)*	0.23	0.28	0.32
	Uncertainty %	*11.1*	*11.4*	*11*

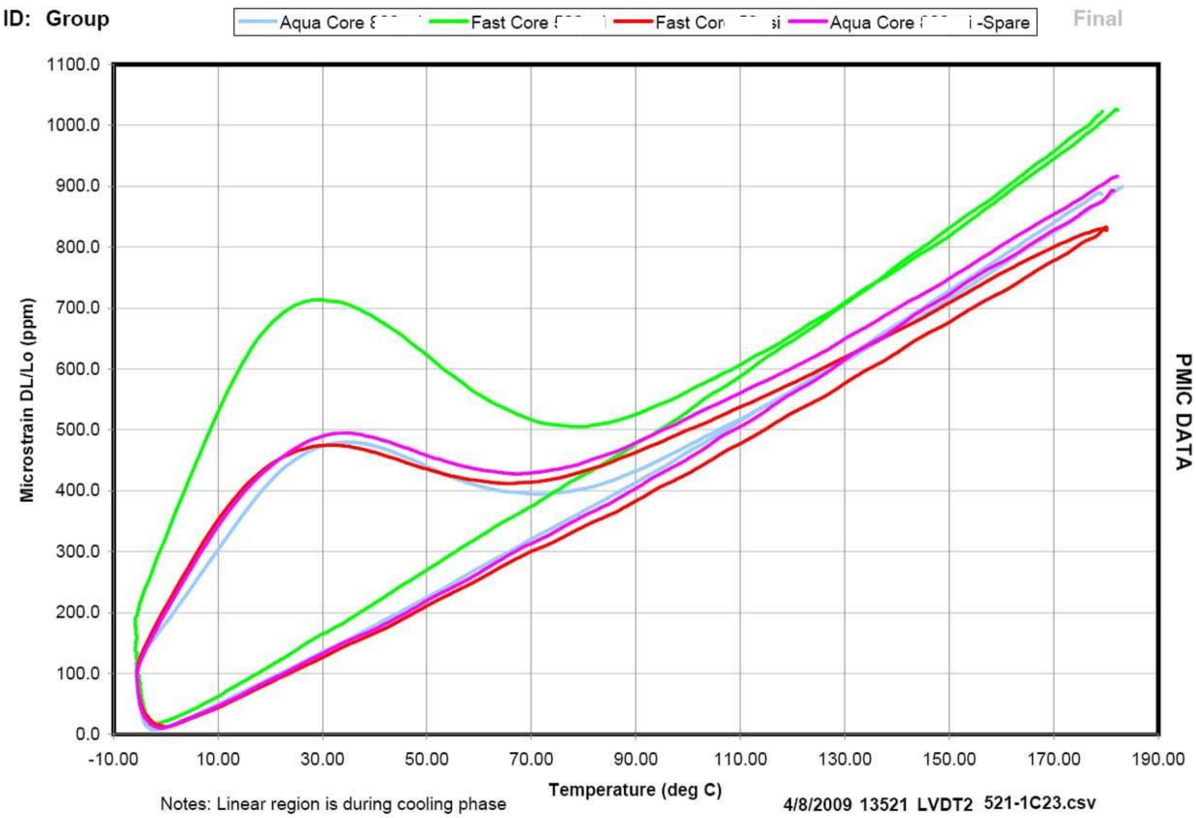

Figure 1. Expansion during thermal cycling.

Figure 1 shows the repeatable CTE response for the FastCore material as well as the previous AquaCore material line. Samples were preheated at 180°C for 45 min before cycling and then cooled showing a very linear shrinkage trend. The samples were held at 0°C for 45 min then heated. The hold at 0°C introduces moisture into the material which is first released below 100°C before continuing linear growth at the final utilization temperatures. Proper handling of the FastCore mandrel material will ensure no moisture introduction and a linear CTE response. CTE design consideration should utilize the linear shrinkage curve for CTE compensation.

- ***Thermal Gravimetric Analysis (TGA)***

TGA reveals the FastCore material to be thermally stable to over 350°C. However, water solubility is decreased above the glass transition temperature of 182°C.

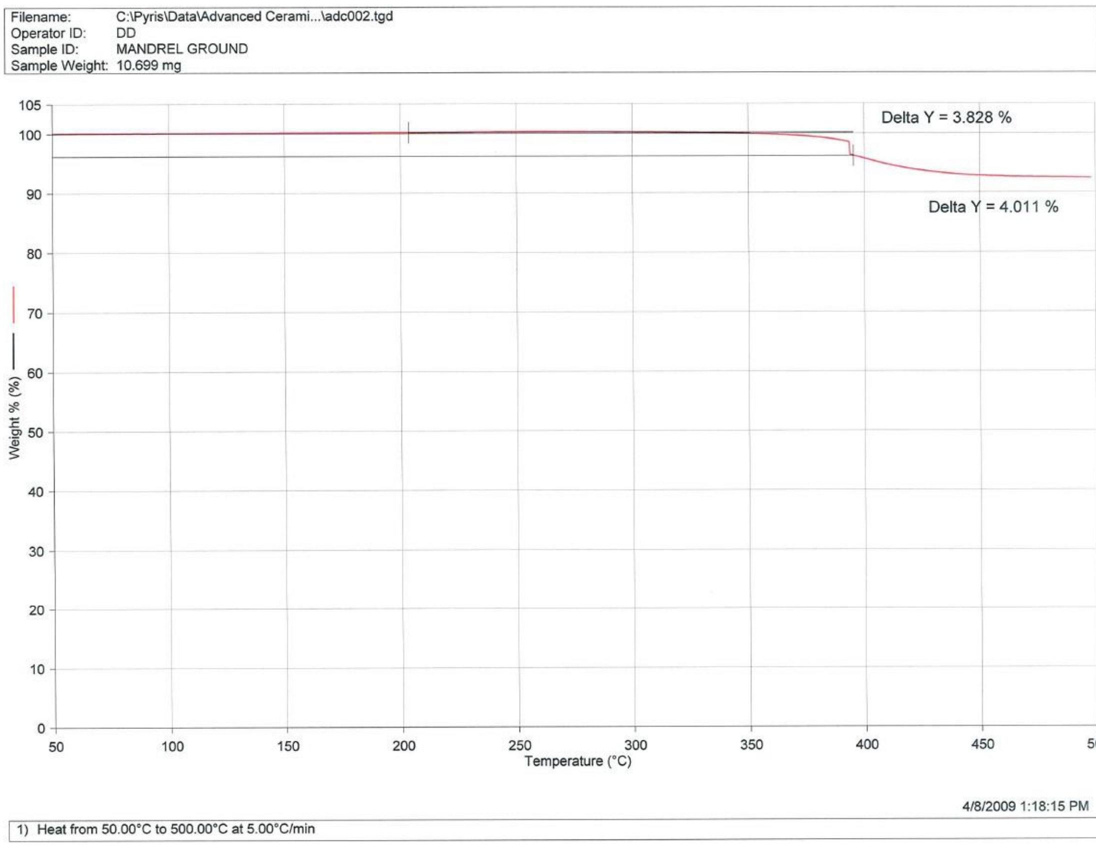

Figure 2. TGA for FastCore.

- ***Differential Scanning Calorimetry (DSC)***

Table 4. DSC data for FastCore.

Sample ID	First Heat	Second Heat
FastCore	54 °C (endothermic peak)	T_g 182°C (glass transition)
AquaCore	44 °C (endothermic peak)	T_g 182°C (glass transition)

Note: samples were cooled and retested with no detection of first heat.

DSC shows a small amount of heat is utilized to release a trace amount of water upon initial heating. Re-heating shows all water is gone.

Mechanical properties

- ***Strength and Modulus***

Although not as strong as eutectic salt or plaster, FastCore is more than capable of withstanding the relatively low pressures of an autoclave (<120psi) on the composite mandrel. The material will exhibit different strength properties as a function of its forming method or composition. ACM can adjust the standard FastCore formulation for a range of possible conditions if the standard products are deficient in a particular property.

Table 5. Mechanical properties of FastCore .

Test*	**Condition**	**Formed** [psi]
Compressive Strength		
	23°C	**225**
	150°C	**150**
***Flexural Strength**	*23°C*	**145**
	150°C	TBD
***Flexural Modulus**	*23°C*	40,400

* Measurements carried out utilizing mechanical testing devices both in house and with external laboratories (4-point).

Spectroscopy

- **Fourier Transform Infrared Spectroscopy (FTIR)**

FTIR was used to verify the lack of silicone presence within the FastCore material or sealer.

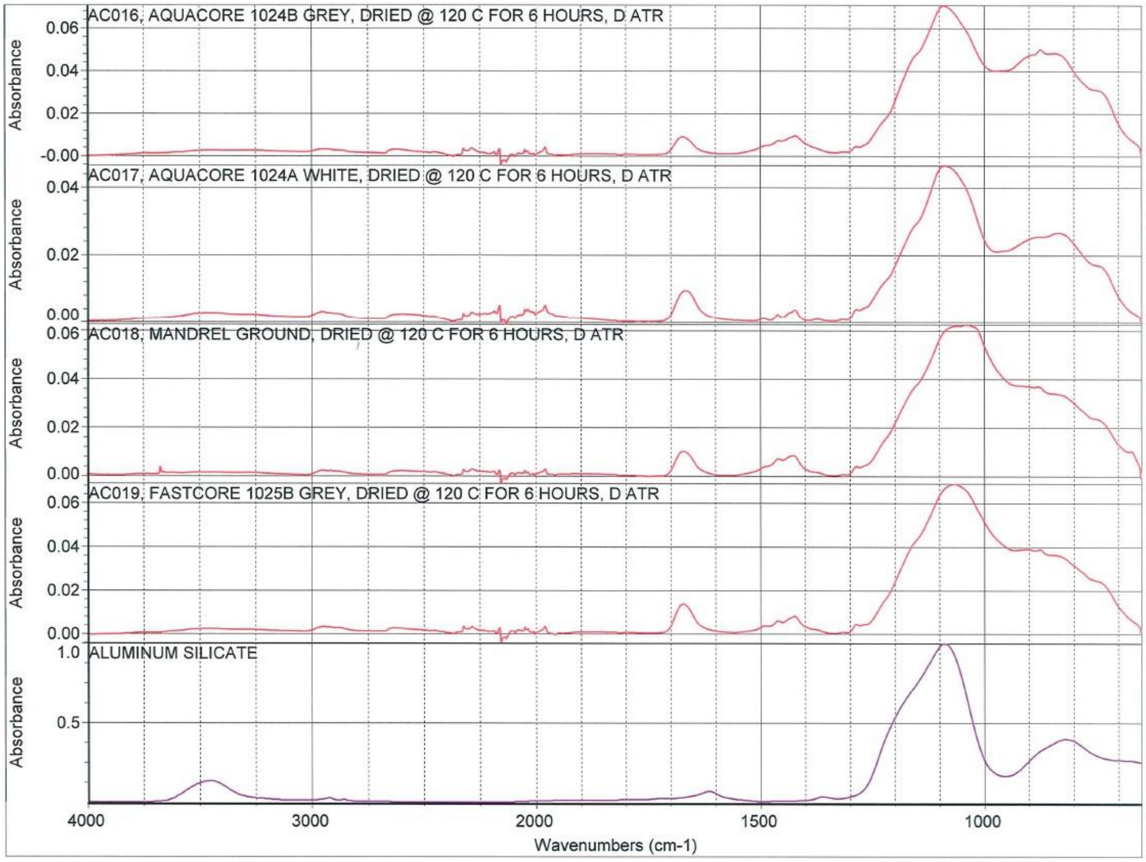

Figure 3. FTIR analysis of water soluble mandrel materials.

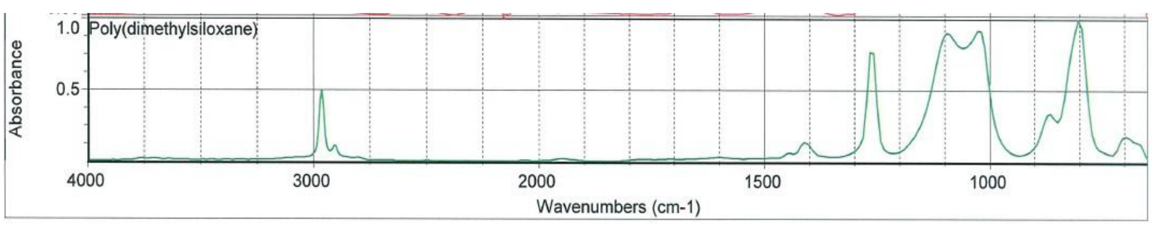

Figure 4. FTIR spectra of silicone reference.

Tests done at an independent laboratory verified silicone was absent/undetectable (no peaks at 3000 and 1400 cm^{-1}). Silicone is not expected to be present in any composite due to the FastCore material.

Environmental testing

FastCore materials are environmentally benign. Independent testing verified little to no heavy metal contamination within the material. Other components have been deemed either food or industrially safe. An increased pH is associated with the material effluent washout that may need to be neutralized with baking soda if local water regulations are impacted.

Method References:

- DRYWEIGHT: SW-846 Method 1311 (Percent Solids Determination, section 7.1.1).
- ICP: EPA Method 200.7/6010B (Inductively Coupled Plasma). Sample Prep: Acid digestion.
- PH: EPA Method 150.1 (Electrometric)
- TCLP-ICP: EPA Method 200.7/6010B (Inductively Coupled Plasma). Extraction by SW-846 Method 1311 (TCLP).

Table 6. Independent environmental testing of FastCore .

Test Name	Component Name	Detection limit *Greater than <*	Result	
Dry weight	FastCore dissolved		33% component	
ICP	Silver	0.003	0.003	mg/L
	Cadmium	0.002	0.002	mg/L
	Chromium		**0.014**	mg/L
	Copper		**0.064**	mg/L
	Nickel	0.008	0.008	mg/L
	Lead		**0.013**	mg/L
	Zinc		**0.005**	mg/L
TCLP-ICP	Barium		**0.094**	mg/L
	Cadmium	0.004	0.004	mg/L
	Chromium		**0.011**	mg/L
	Lead	0.025	0.025	mg/L
	Silver	0.005	0.005	mg/L
pH			**10.2**	

In-depth environment studies performed by the DOD using fathead minnows showed little to no environmental impact on aquatic species. Test data is available upon request.