Tape Casting Formula Development

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Formulation Steps

- Determine desired loading.
- Adjust formula for correct viscosity.
- Ensure ceramic is dispersed properly.
- Measure tape properties and compare to needs.
- Make a number of tape trials within above parameters looking at effects of additives.
- Optimize tape characteristics per needs.
- Trouble shoot tape defects if they exist.

Loading

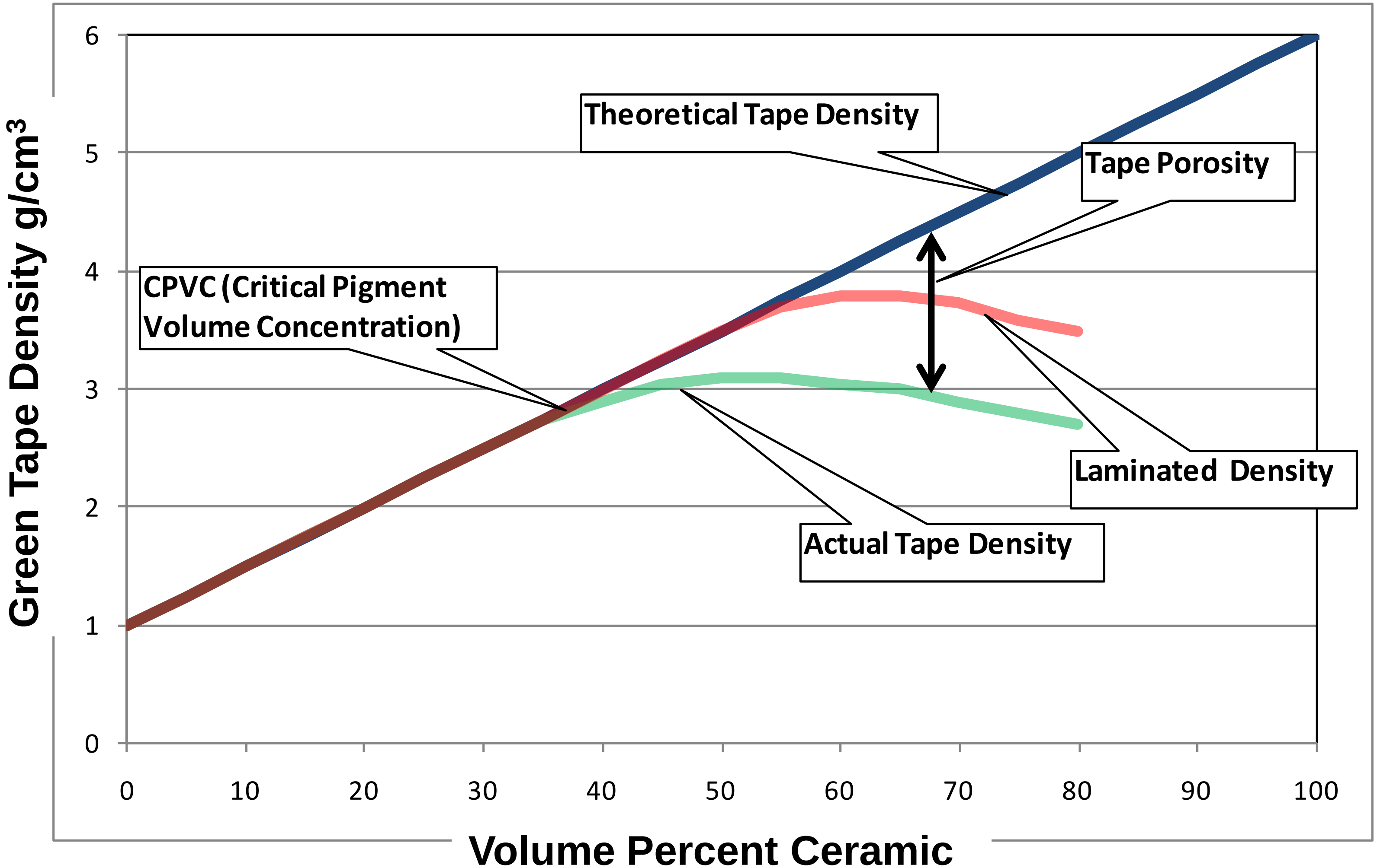
- Most critical part is to target appropriate green tape porosity aim.
  - If tape density is zero it will entrap air bubbles between layers during stacking.
  - Typical stacking process porosity goal would be about 10-20 %.
  - This is determined by comparing actual measured density to theoretical density (see loading curve).
  - Need to know the density of the ceramic powder.
  - Typically binder density is approximated by 1

Volume Vs Weight Loading

- Typical tendency is to use weight loading but since ceramic densities vary widely volume % calculations are more universal.
- Tape casting is similar to paint technology.
- Pigment loading curve (next slide).
- Porosity starts and film properties change dramatically at loadings above the CPVC (critical pigment volume concentration).
- Above the CPVC there is not enough binder to fill the pores between the ceramic particles.
  - The ceramic particles are coated with binder and stuck together with open pores in between like candy coated popcorn.

Loading Curve (Pigment Loading Curve)

Example of 6 g/cm³ ceramic in binder with density of 1 g/cm³



Volume Loading Calculation Example

Component	Weight grams	Solids of component	Solids weight (after drying)	Approximate density of component after drying (g/cm3)	Calculated volume of each component after drying (cm3)	Weight % ceramic in the tape	Volume % ceramic in the tape
Ceramic	66	100%	66	5.9	11.19	90.04	60.51
Water	15	0%	0	1	0.00	0.00	0.00
WB4101	18	35%	6.3	1	6.30	8.59	34.08
PL002 plasticizer	1	100%	1	1	1.00	1.36	5.41
Total	100		73.3		18.49		
	Weight of dried tape			73.3	grams		
	Volume of dried tape (exclude air)			18.49	cm3		
	Theoretical tape density			Divide tape wt by tape volume (ignoring air)			
				3.96	g/cm3		
	Example measured tape density			3.52	g/cm3		
	Calculated porosity (%)			11.1	%		

For this example we are using density of 1 g/cm3 for the organic solids. The density of the organic solids is usually a little bit more than 1.0 g/cm3 but usually for most purposes we usually just use 1.

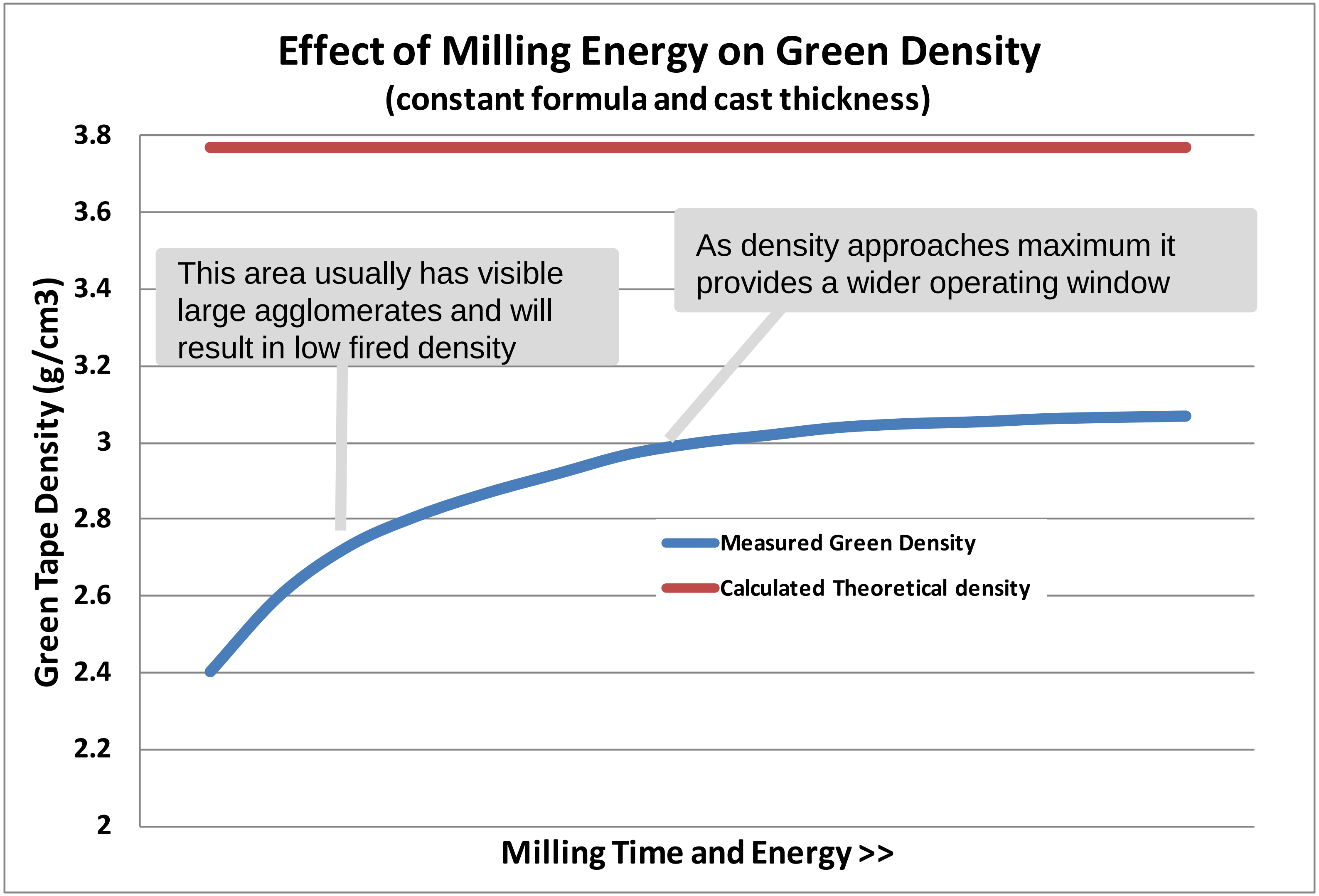
We start out with 100 grams of slip as shown above but after drying it will become 73.3 grams due to the loss of water. If we calculate the volume of each component by dividing its weight by its density and adding these up the total volume of the tape (ignoring any air which may be in the tape) is 18.49 cm3. Therefore if there were no porosity the density of the tape is 73.3g/18.49 cm3 or 3.96 g/cm3. We usually call this the theoretical density. Typically at the higher loading levels of ceramic in tape we are beyond the critical pigment volume loading (a term used in the paint industry and illustrated in the volume loading curve on the next tab). Therefore there is porosity in the tape. By comparing the measured tape density to the theoretical tape density we can calculate a useful estimate for the tape porosity. For most MLCC processes a porosity of about 5-25% is typical. To measure the tape density the weight of the tape is divided by its nonlaminated volume. Typically we cut the tape into pieces of the same dimensions and stack them (by simply laying them on top of one another without lamination) and measure the thickness in several places to get a more accurate measure of the thickness.

Practical Loading Curves

- It is not necessary to run a full range of sample loadings.
- Typical focus is in the 50-70 volume % range and it can be extended if the desired porosity level is not obtained.
- Milling time and dispersion also effect packing density and therefore CPVC.

Green Porosity Goals

- Thicker tapes need less porosity:
  - ~5-10% for 50+ microns
  - ~10-20% for 15 microns
- Tape which has siPET backing still in place during stacking needs even more porosity to avoid bubble entrapment.
  - ~15-30%
- Ceramic with finer particles results in finer interconnected pores which needs to be on high end of porosity range.
- Bottom line: use a practical test and increase porosity if entrapped air occurs.



- For a given tape formula (and tape thickness) the more milling/dispersing energy the higher the green density becomes (assuming an appropriate level of porosity was designed in with the loading).
- In early stages the density goes up faster but reaches a limit of little change with more milling.
- For regular ball milling the larger the ball mill the less time is typically required for good milling.
- To a lesser extent if the same slurry is cast thicker it tends to be a little more dense than thin cast tape.