PURDUE UNIVERSITY

PURDUE MATERIALS ENGINEERING

Optimizing Dispersion of Boron Carbide and Sintering Aids for Colloidal Processing and Pressureless Sintering

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January 29th, 2020

ICACC

The American Ceramic Society www.ceramics.org

APL JOHNS HOPKINS APPLIED PHYSICS LABORATORY

Boron carbide boasts high hardness and low density, but has processing limitations

Density = 2.52 g/cm^3

Hardness = 30-38 GPa

Armor, sandblasting nozzles, abrasives

Strong covalent bonds

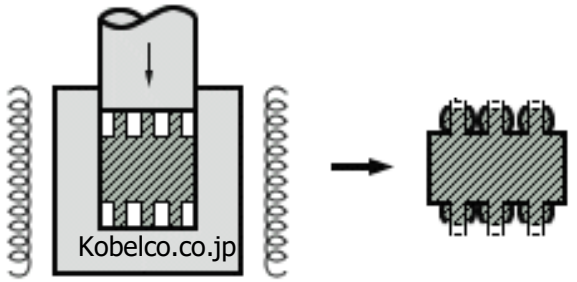
=

High hardness

High melting point

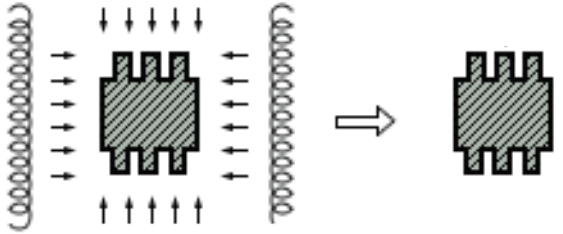
Poor sintering ability

Hot pressing



Dense, but simple shapes

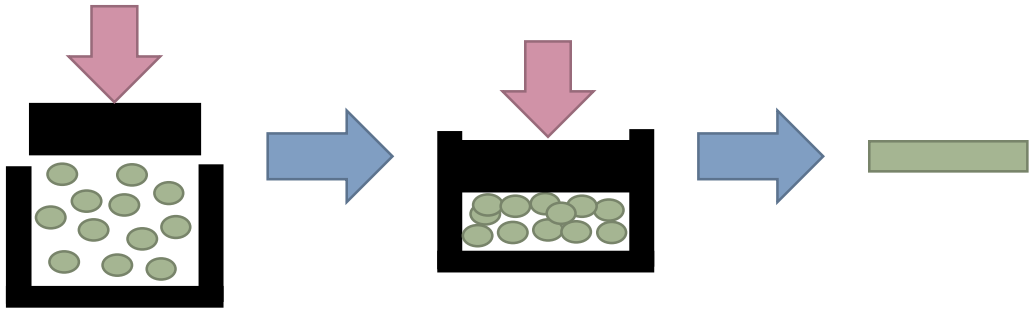
Hot isostatic pressing



Dense & complex shaped, but costly

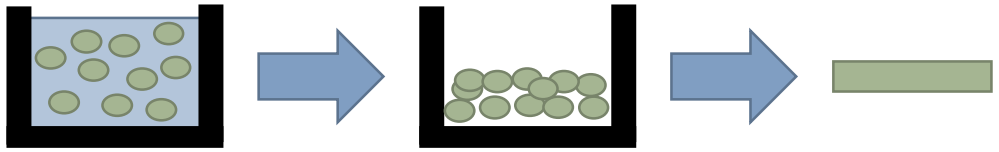
"What is Hot Isostatic Pressing?" Kobelco.co.jp

Aqueous colloidal processing of ceramics offers many advantages



Dry powder processing

vs



Colloidal processing

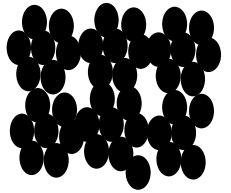
- Slip casting
- Direct ink writing
- Injection molding
- Gel casting

Creation of complex shapes

Dense green bodies

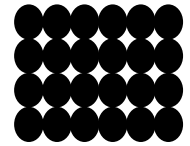
Safe & environmentally friendly

Diaz-Cano



agglomerated

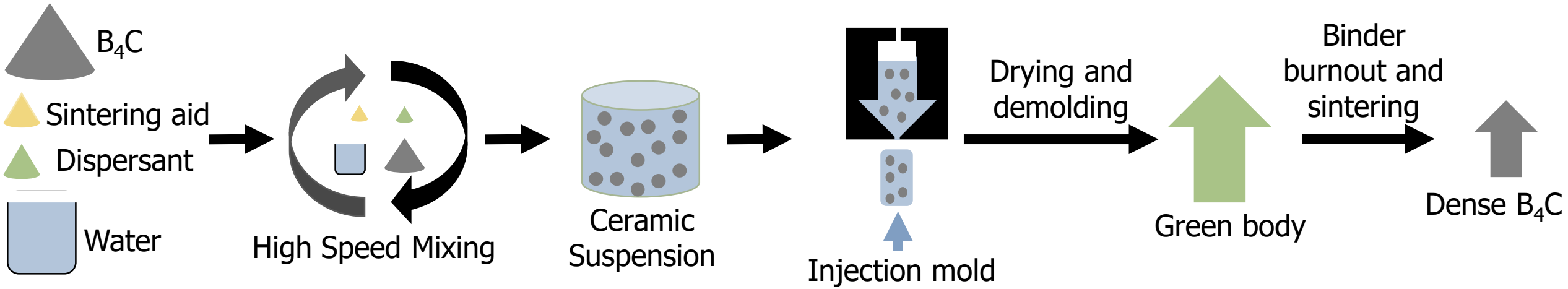
vs

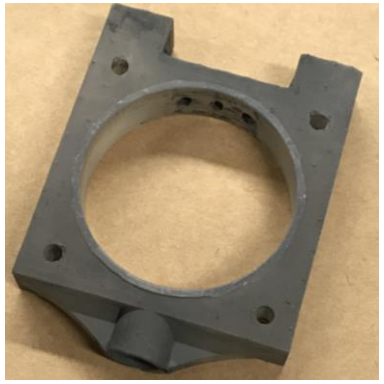


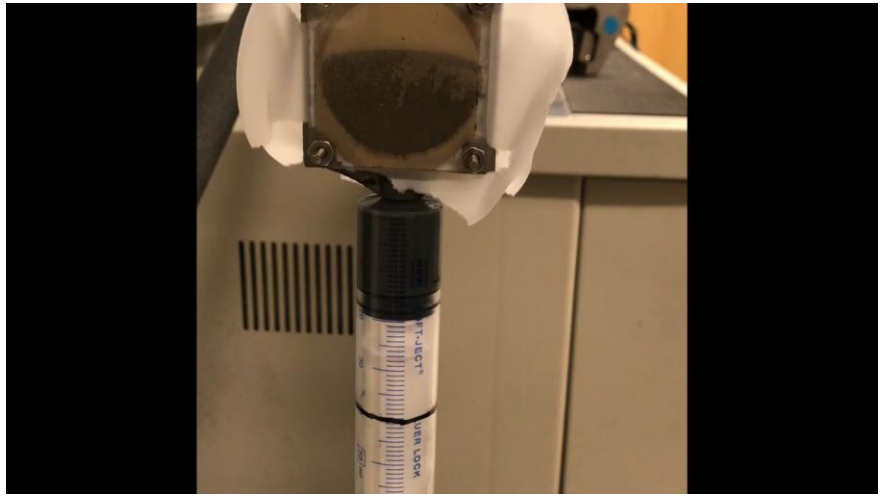
dispersed

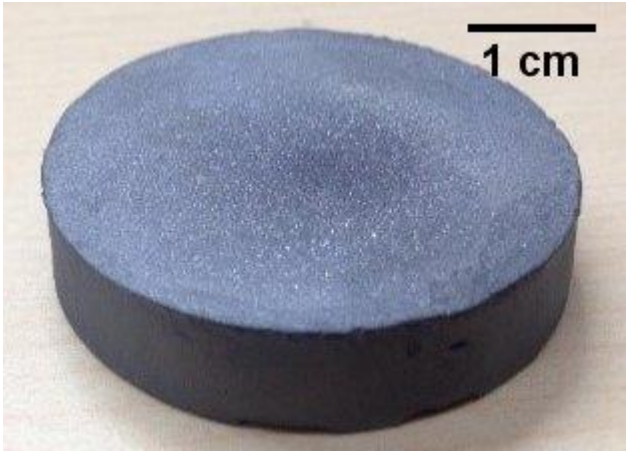
Diaz-Cano, A. (Purdue University, 2017).

We aim to create dense ceramics with room temperature, aqueous injection molding and pressureless sintering







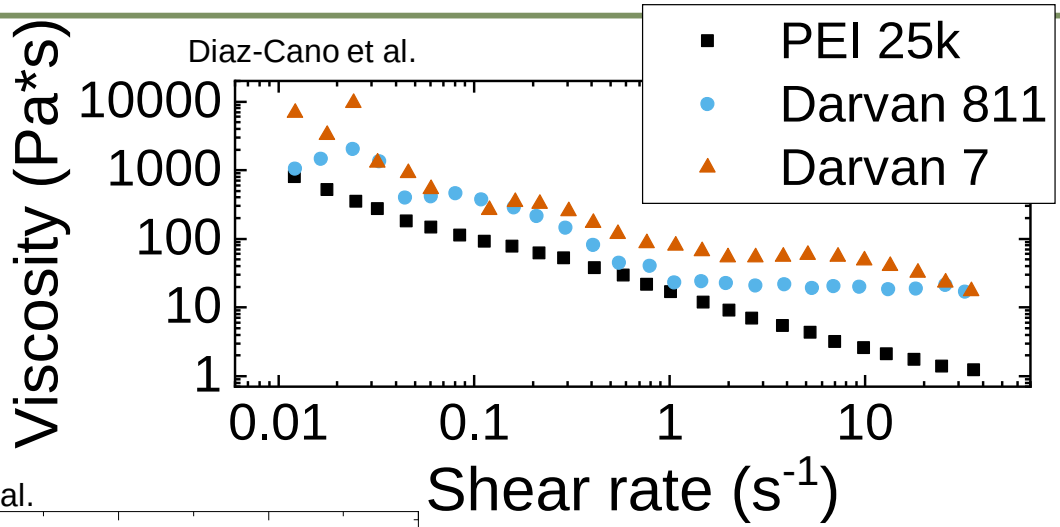


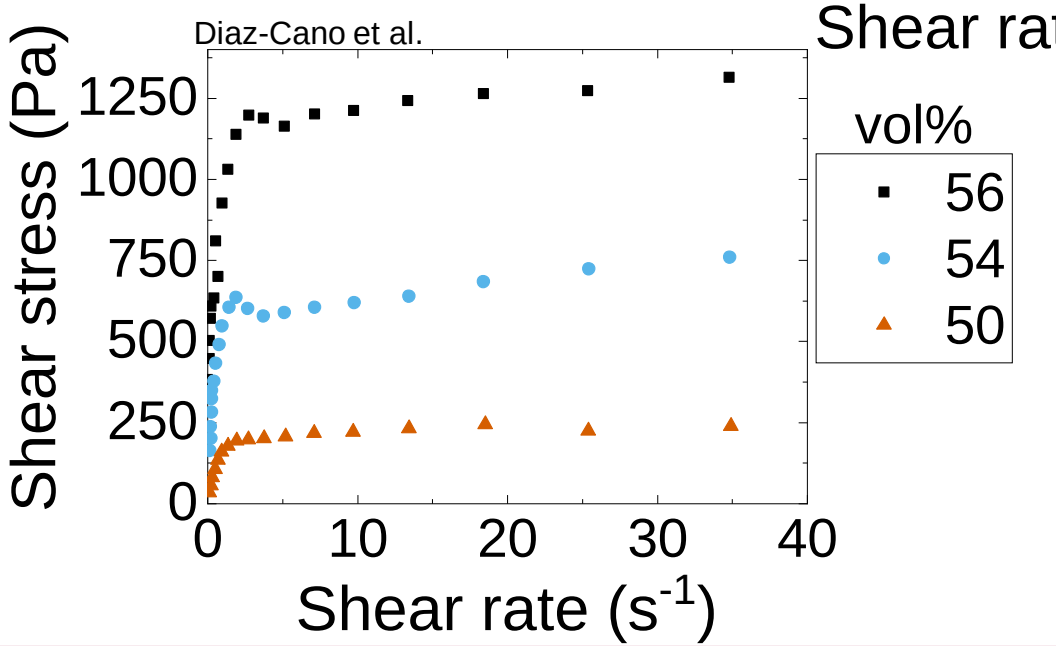
Graphic adapted from Erich Weaver

Colloidal processing suspensions must be stable and have ideal rheological behavior

Aqueous suspensions with tailored rheology

- Yield stress
- Shear thinning
- High particle loading
  - Improve green body density
  - Reduce drying shrinkage
- Viscosity
  - Low as possible to reduce air bubbles



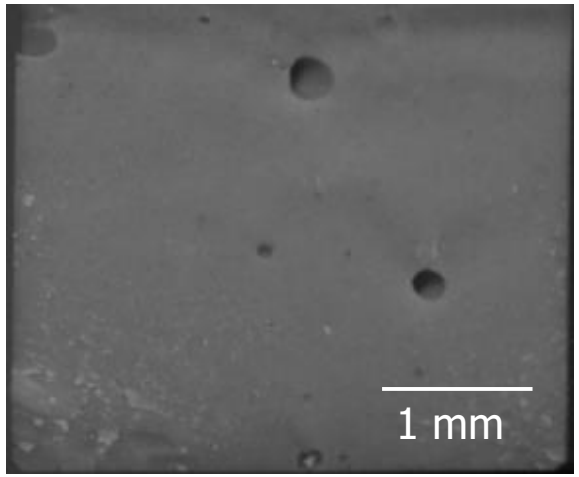


Tune rheological properties to processing method

Diaz-Cano, A et al., *Ceram. Int.*, **43** (2017) 8572–8578

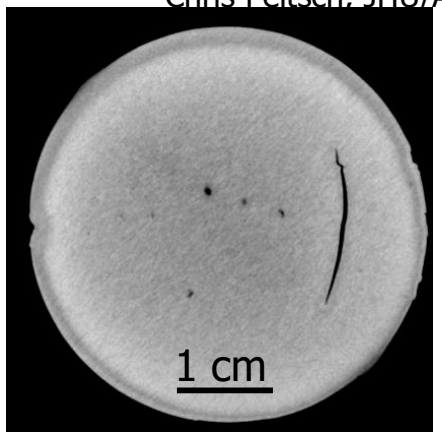
Many challenges are faced when colloidally processing ceramics

Rueschhoff et al.



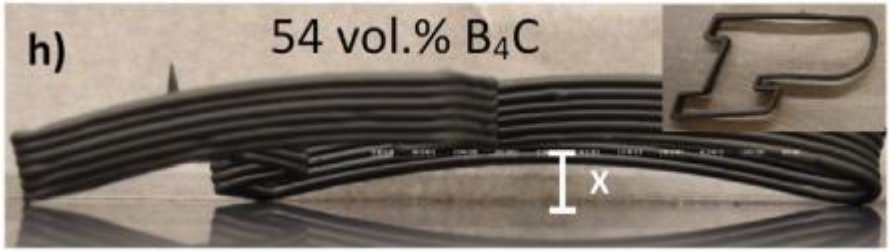
Air bubbles

Chris Peitsch, JHU/APL



Cracking

Costakis et al.



Shape retention

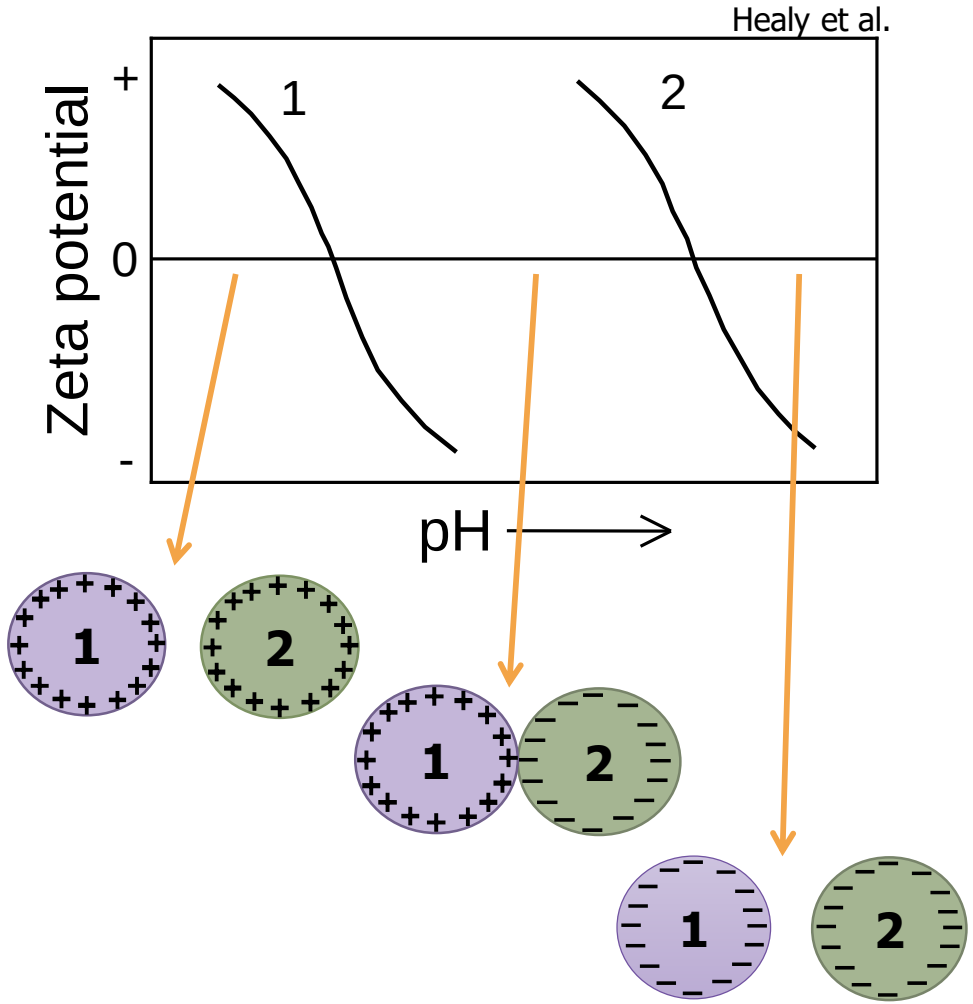
Pressurelessly sintered B_4C may require sintering aids

We need homogenous dispersion of particle types…

but each ceramic has different surface chemistry

Rueschhoff, L. M. et al., *Ceram. Int.* **43**, 10791–10798 (2017).
Costakis, W. J. et al., *J. Eur. Ceram. Soc.* **36**, 3249–3256 (2016).

The creation of multicomponent ceramic suspensions presents additional concerns

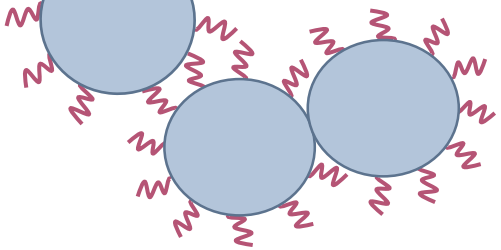


Coagulation 1 1 Heterocoagulation 1 2

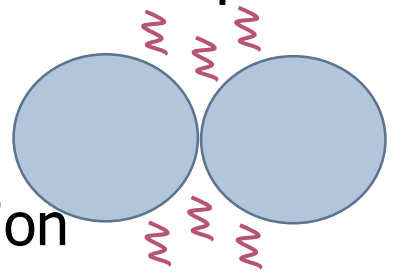
(Some coagulation could be desired!)

Adsorption of dispersants to particles of different surface chemistries may also depend on pH

Bridging



Coagulation

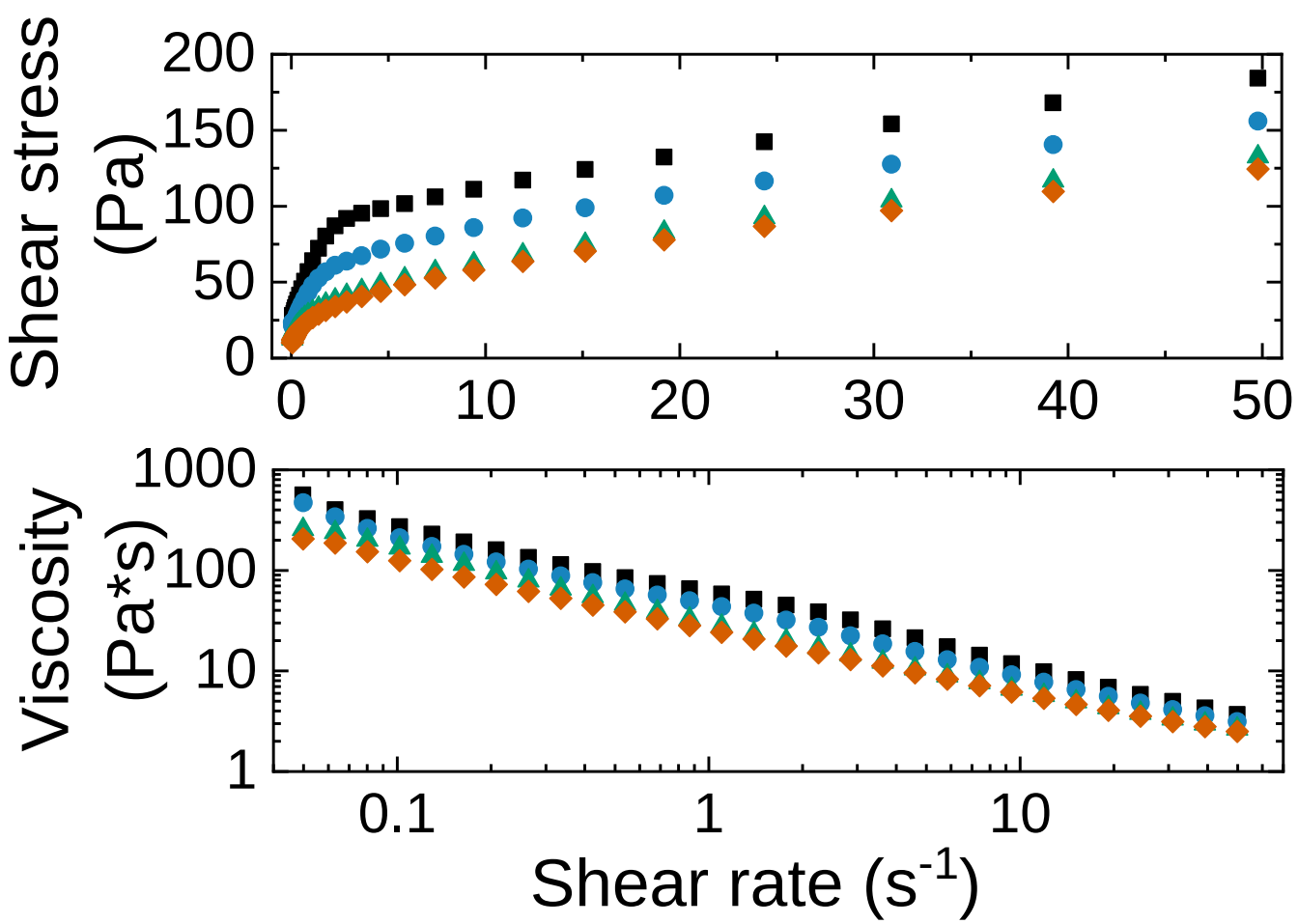


Depletion flocculation

Dispersion of sintering aid particles – Could it affect densification, properties?

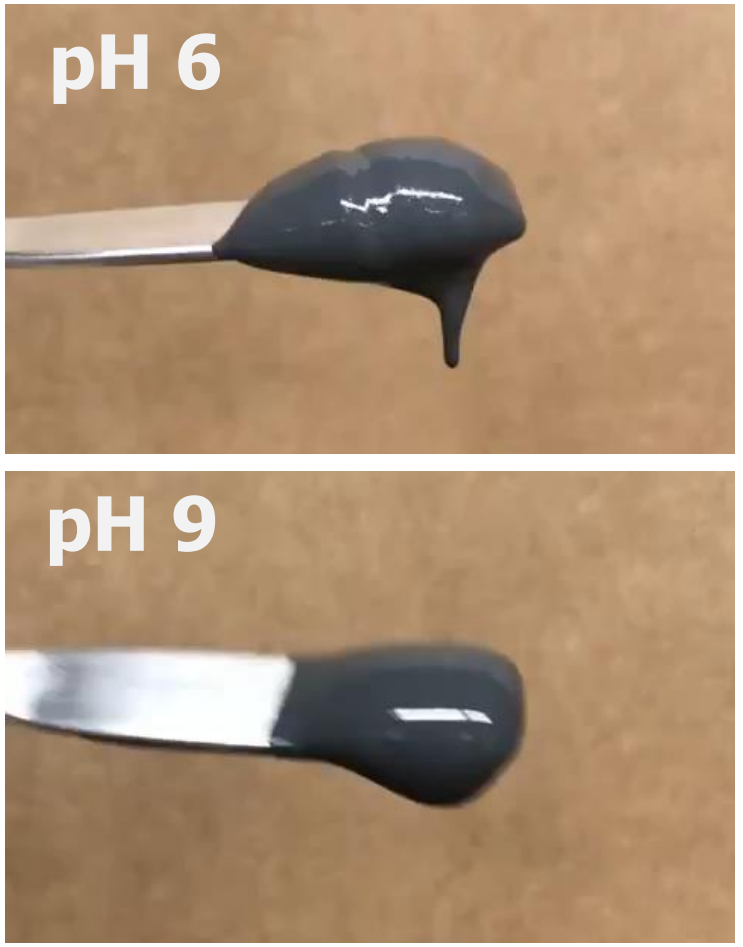
Healy, T. W. et al., *J. Colloid Interface Sci.* **42**, 647–649 (1973).

Altering suspension pH is a simple way to affect the stability of B_4C suspensions



pH
6.1
7.5
8.5
9.3

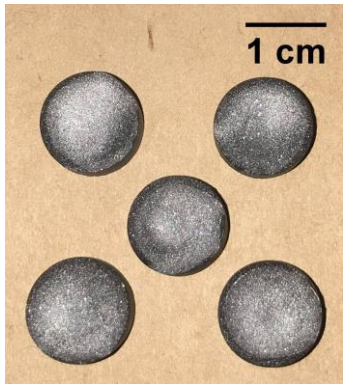
51 vol%
3.6 vol% PEI

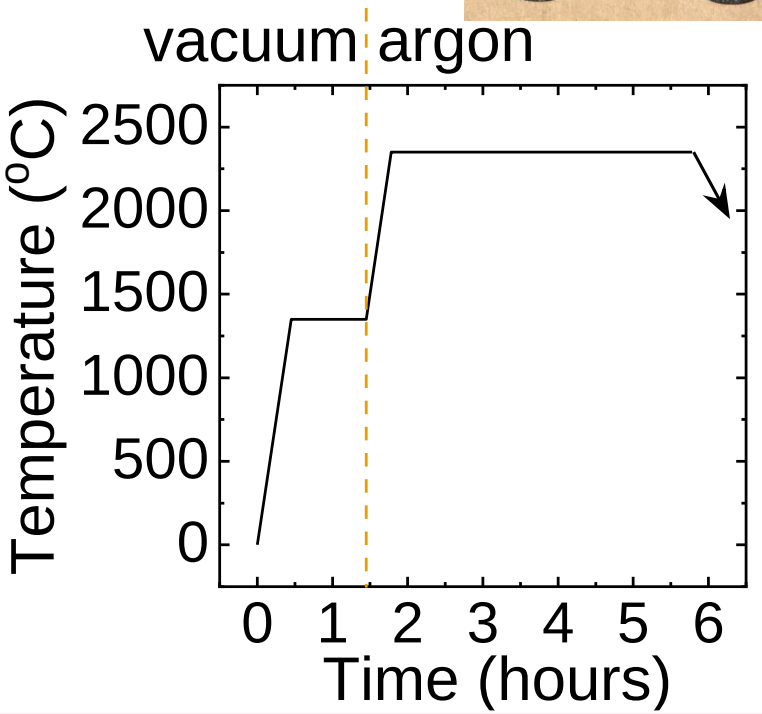


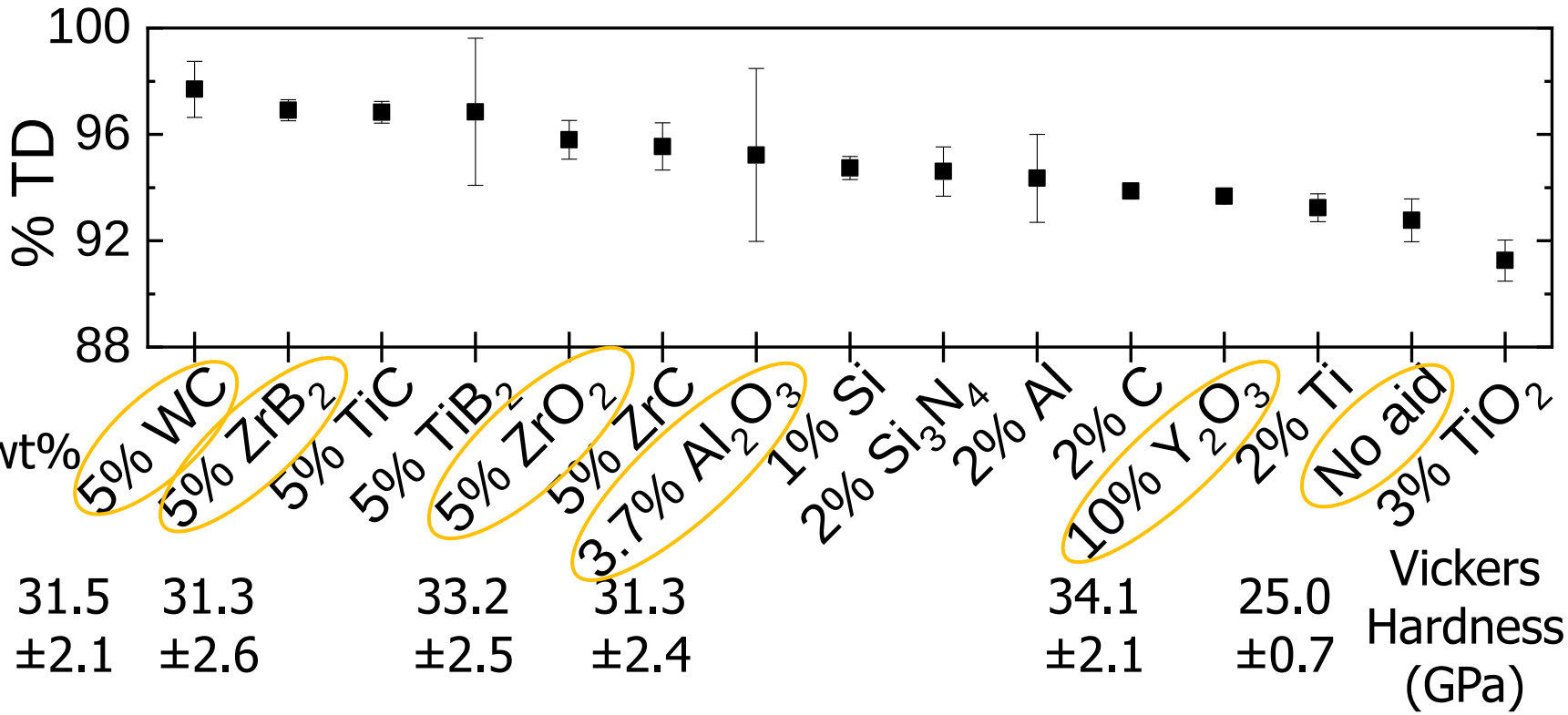
Dispersion of B_4C with PEI dispersant improves with increasing pH

Potential sintering aids were identified for optimization in multicomponent suspensions

51 vol% solids
3.6 vol% PEI
pH ~ 9

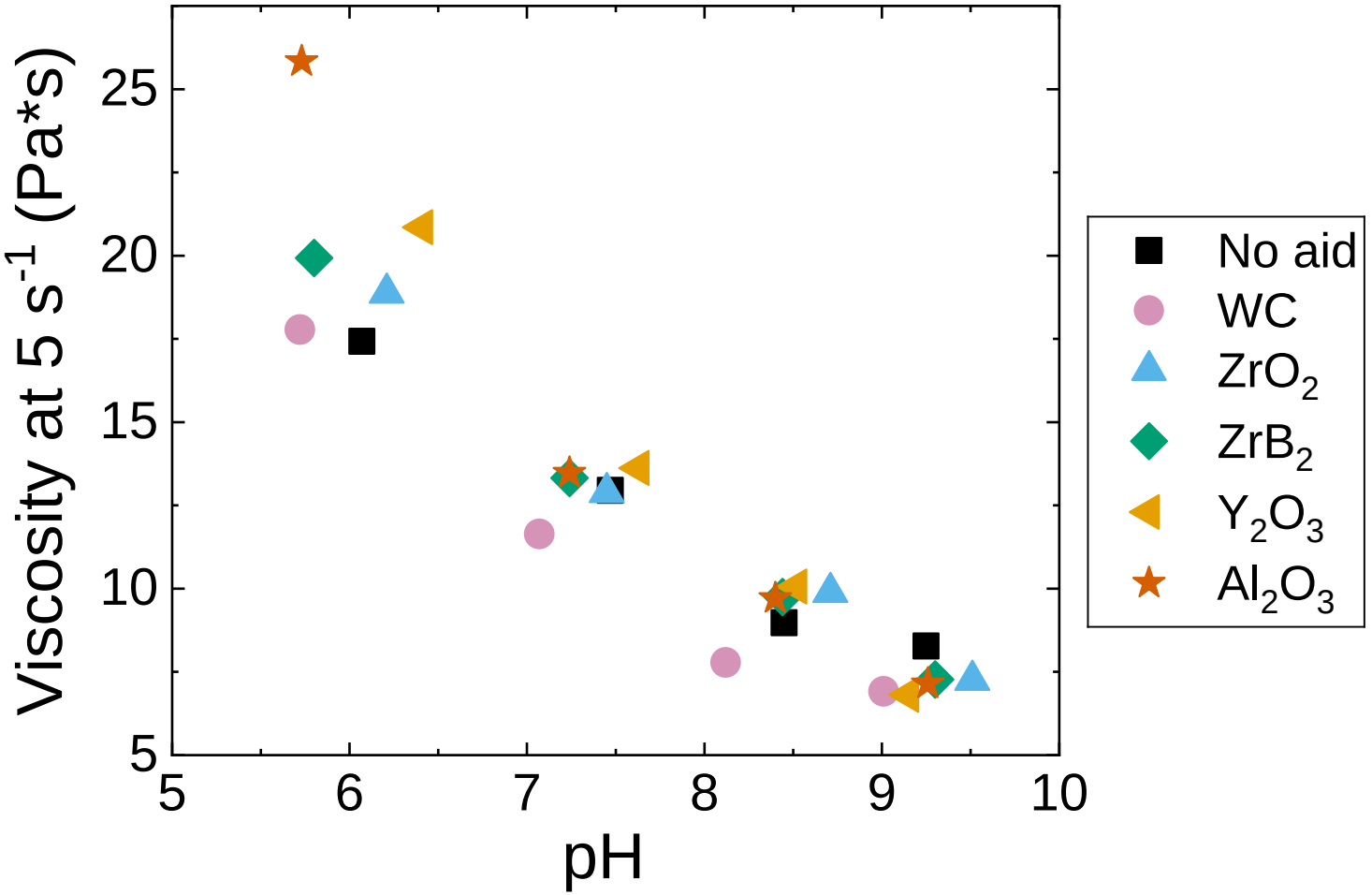






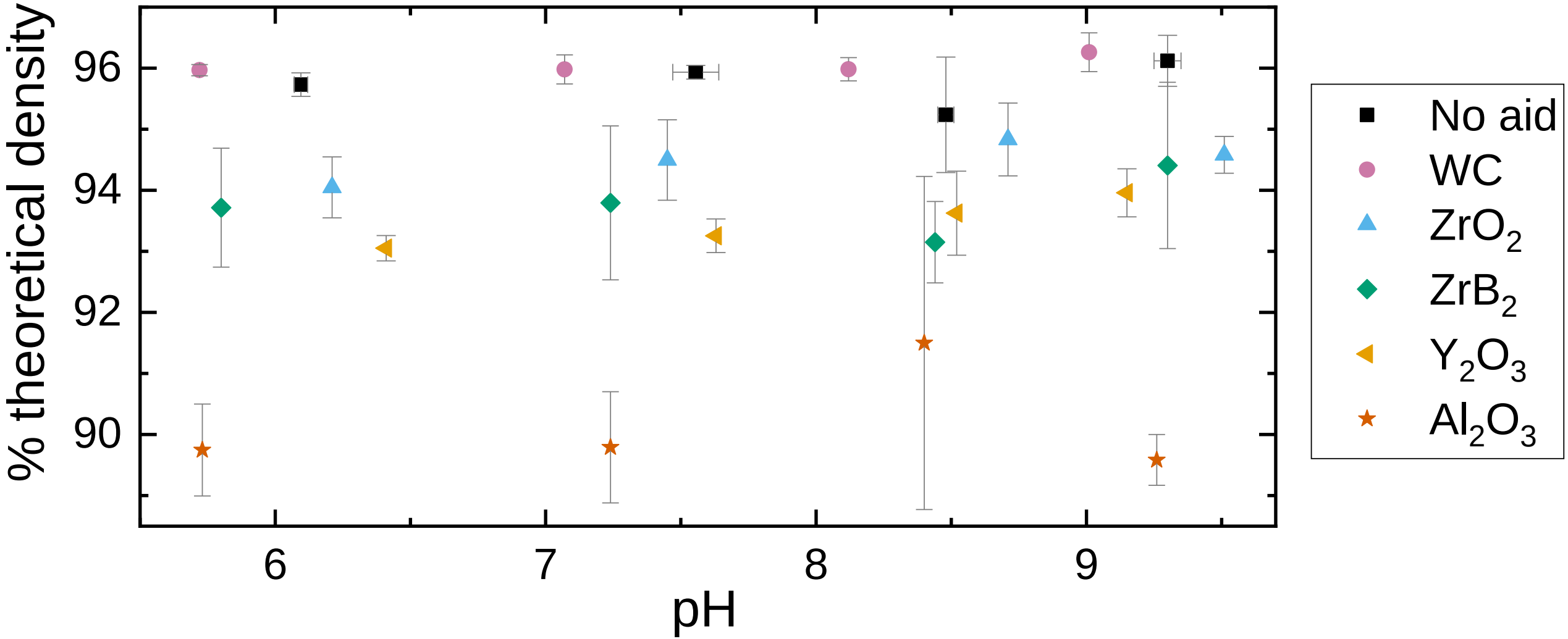
Could pH adjustment affect densification, microstructure or hardness due to changing sintering aid dispersion?

In the amounts tested, the sintering aids did not destabilize the B_4C suspension

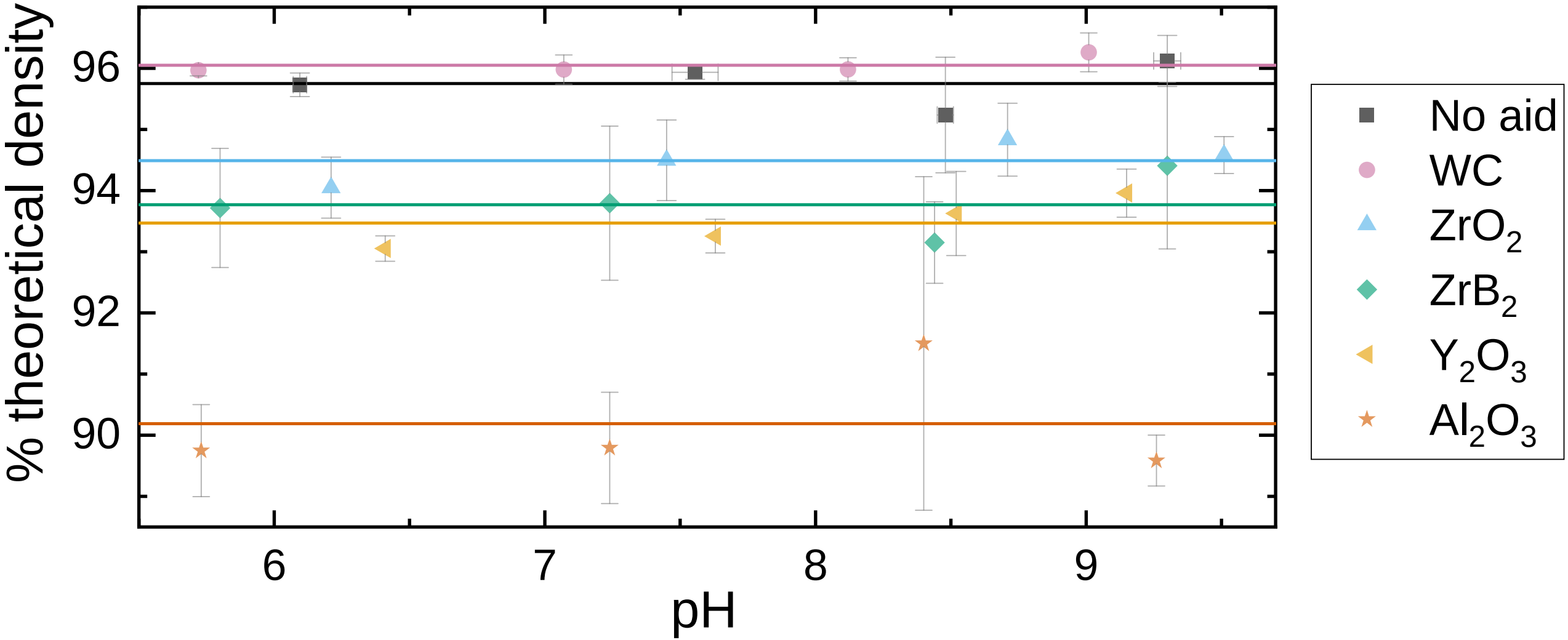


Though the suspension viscosity is not affected, the dispersion of sintering aids themselves cannot be determined

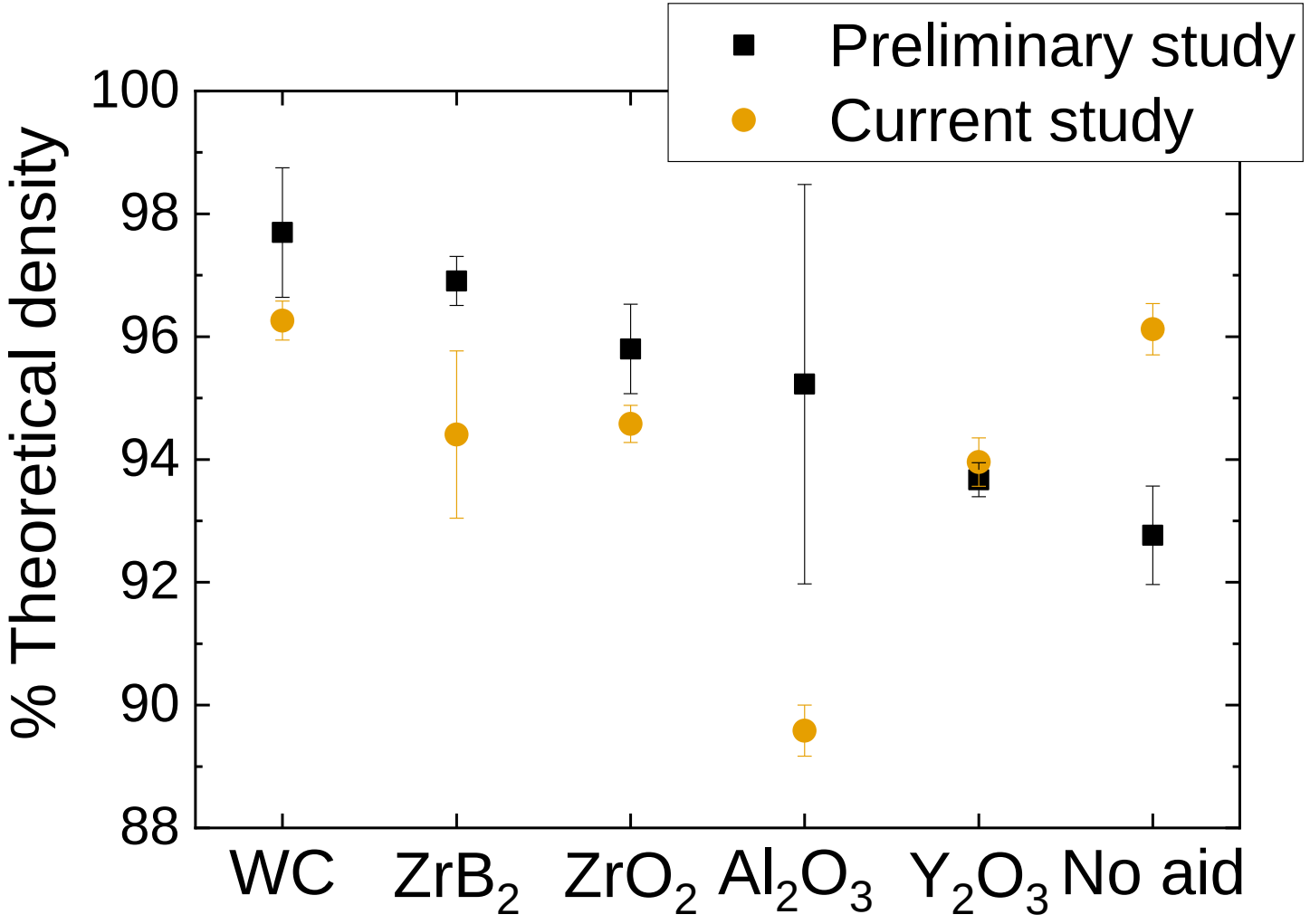
Suspension pH did not affect densification



Suspension pH did not affect densification



Uncontrolled processing variables may lead to inconsistencies between repeat attempts

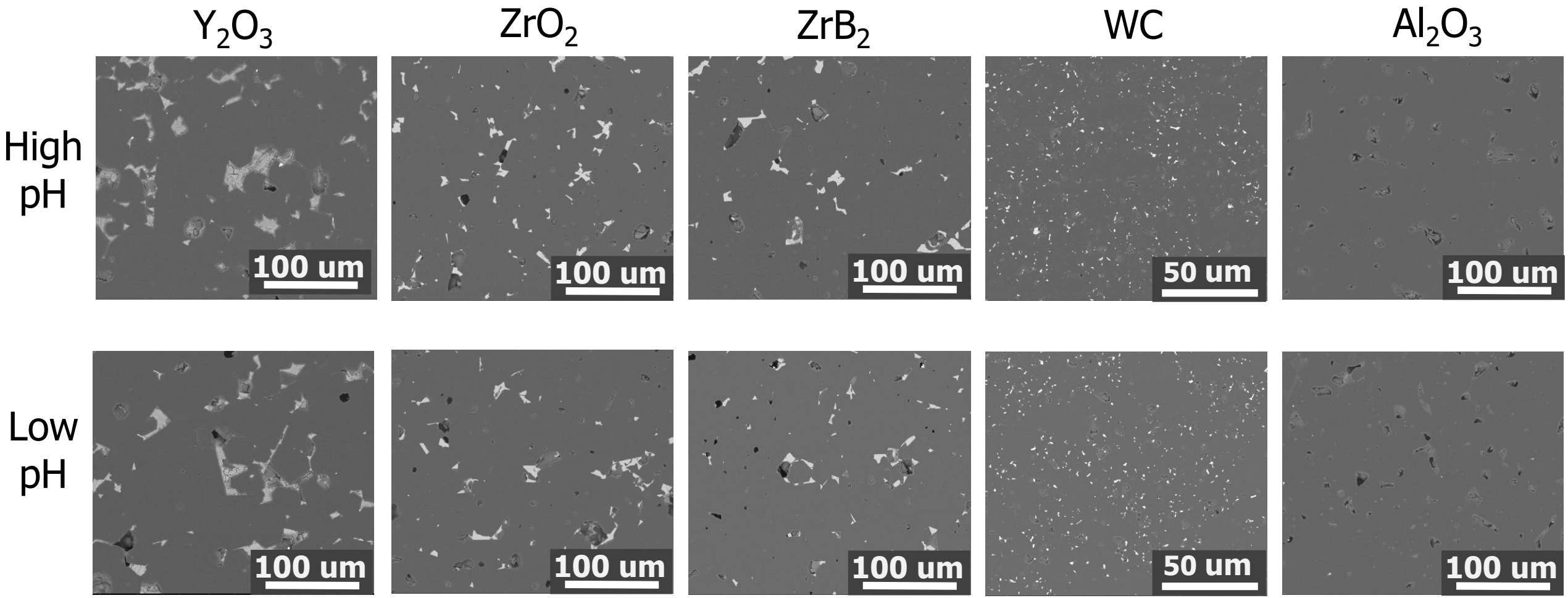


Same…

- Particle loading
- Ceramic powders
- Fabrication methods
- Furnace
- Sintering conditions

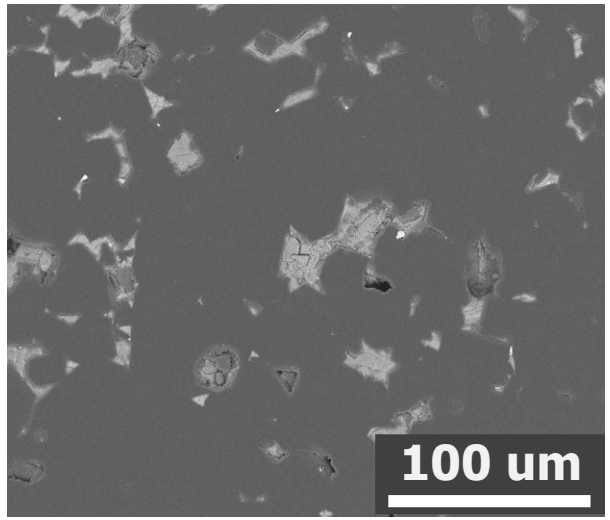
Results suffer from significant unknown processing variations or large inherent variability

Microstructural evaluation confirms that sintering aid dispersion is not affected by pH



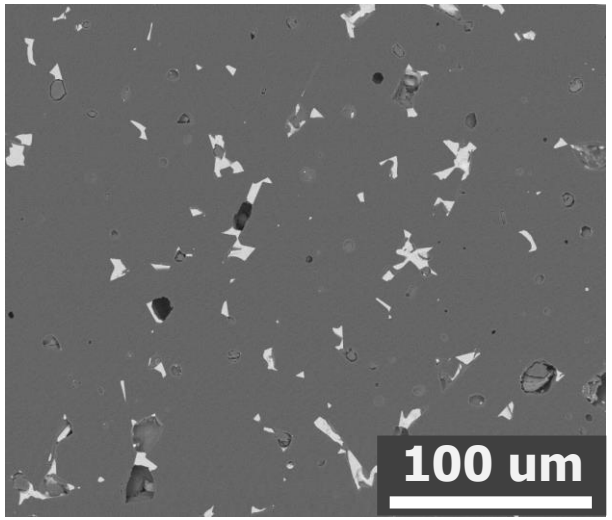
The sintering aid with the least negative effect on densification was the most finely dispersed

Y_2O_3



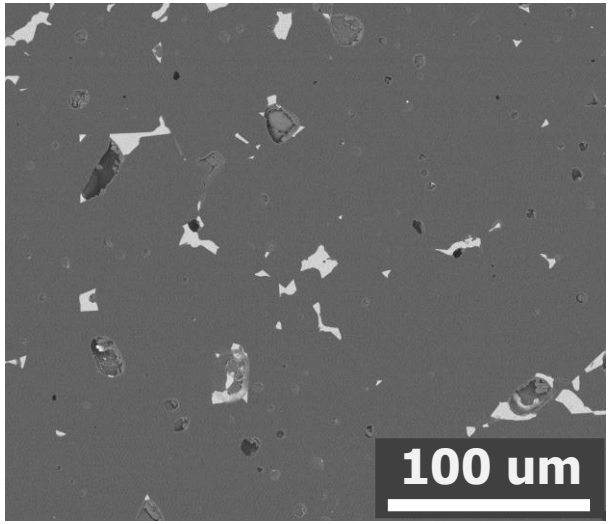
94.0 ± 0.4 %TD

ZrO_2



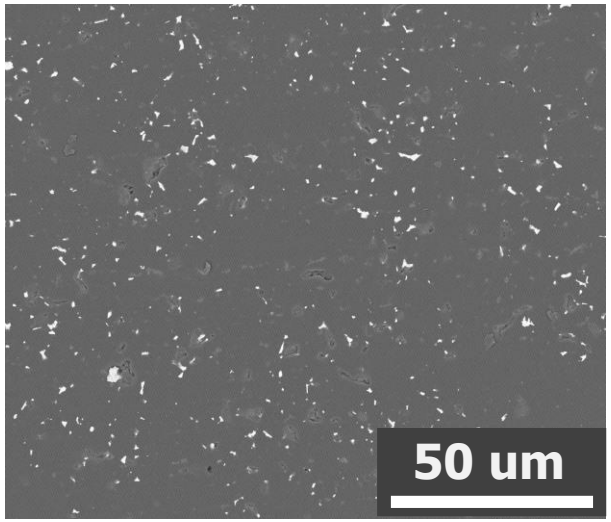
94.6 ± 0.3 %TD

ZrB_2



94.4 ± 1.4 %TD

WC

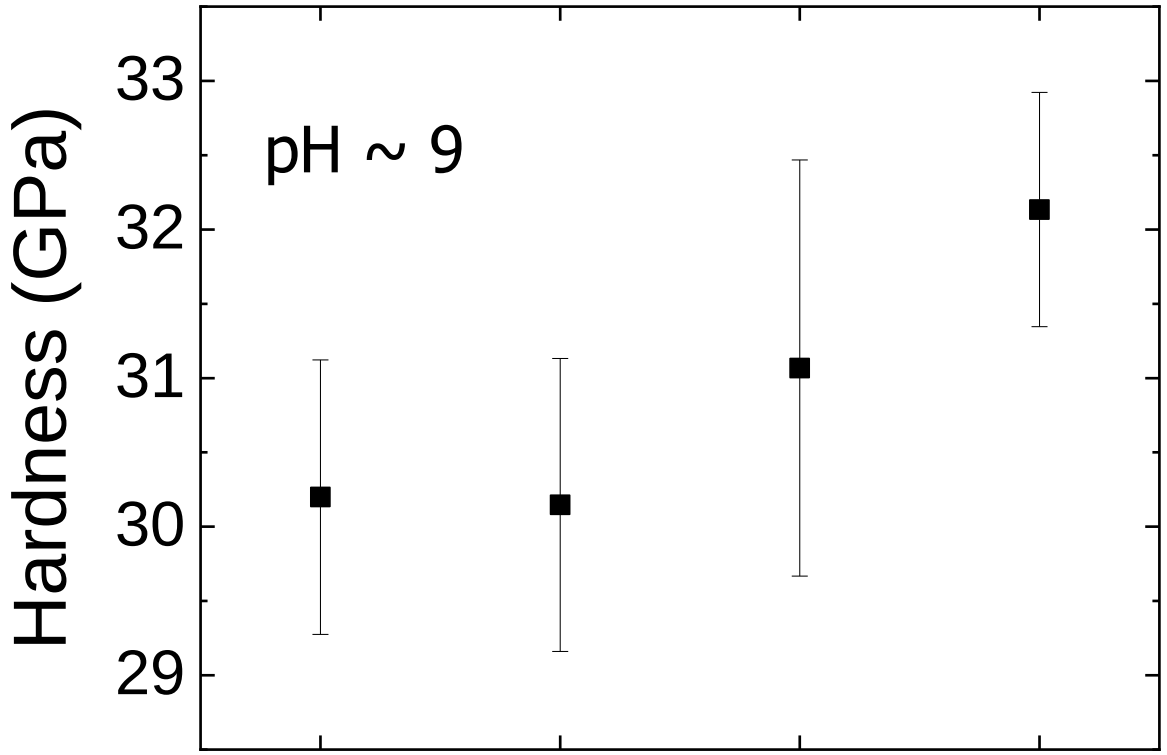


96.3 ± 0.3 %TD

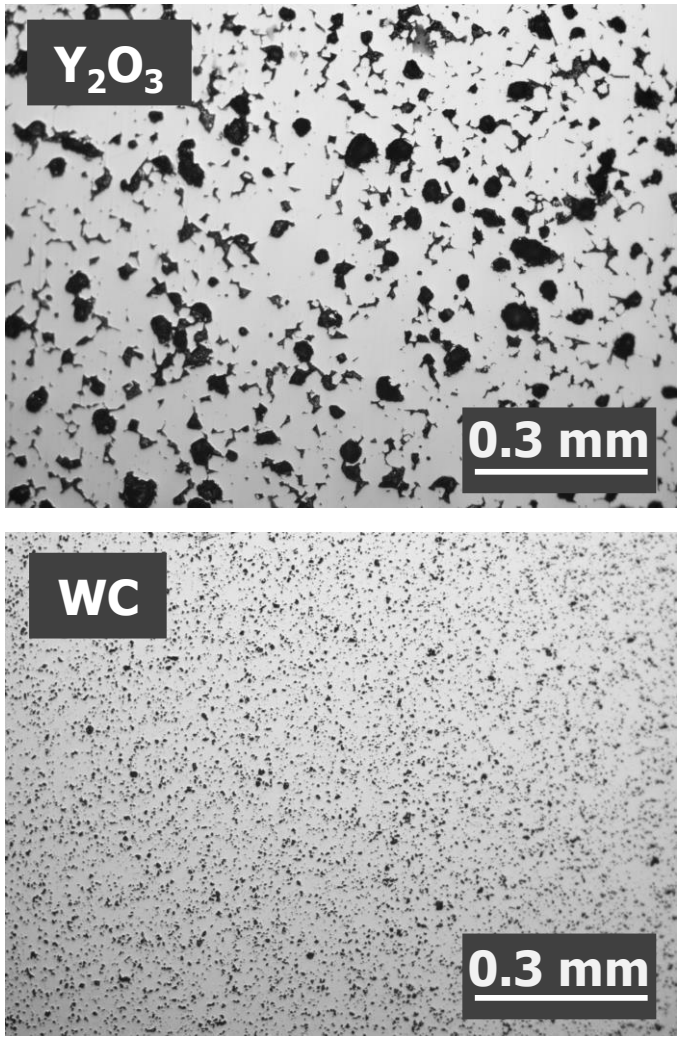
Micron or greater sized particles

Nano sized particles (150-200 nm)

B_4C with sintering aids has Vickers hardness from 30-33 GPa

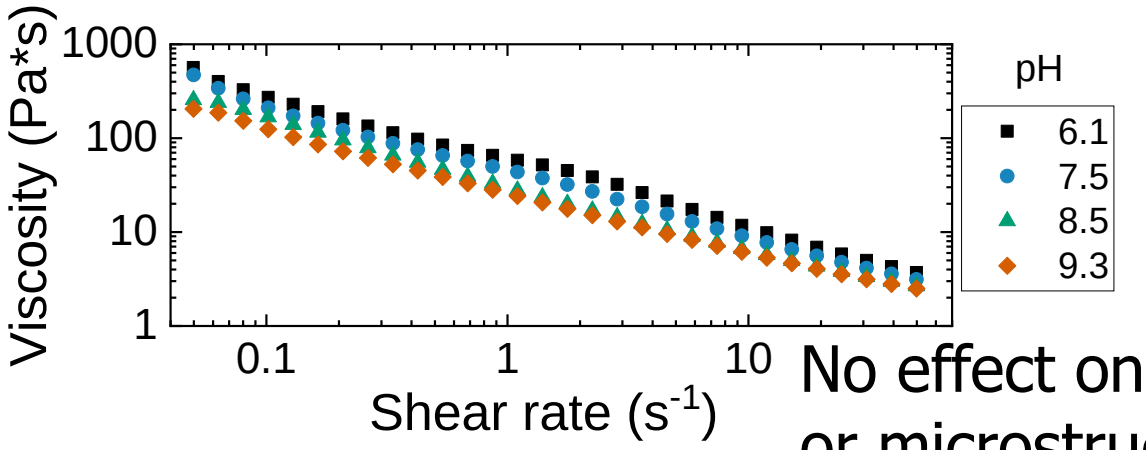


	ZrO_2	ZrB_2	Al_2O_3	Y_2O_3
%TD	94.6 ± 0.3	94.4 ± 1.4	89.6 ± 0.4	94.0 ± 0.4

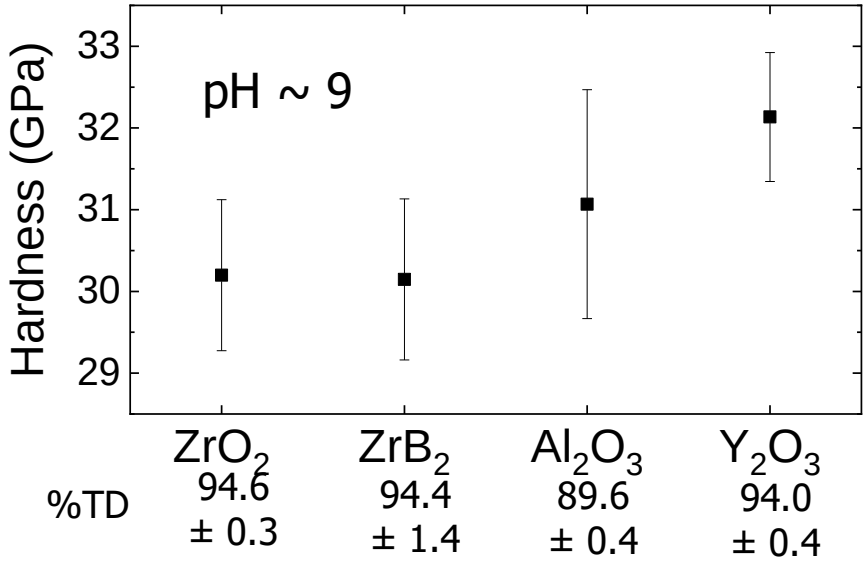


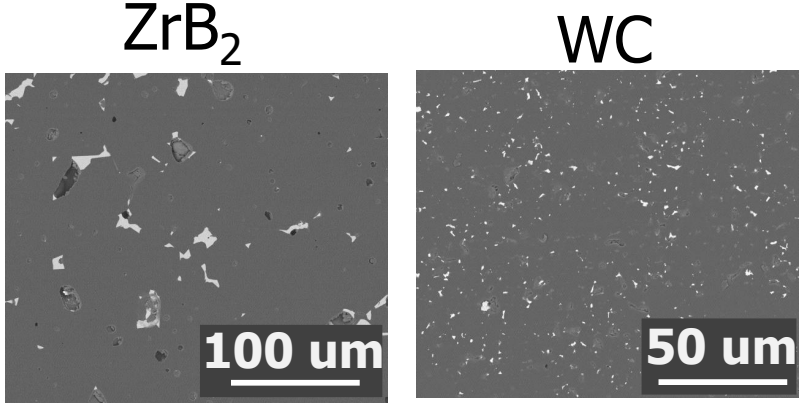
Severe grain pullout from polishing prevented hardness measurements of WC and no aid

Summary and future work



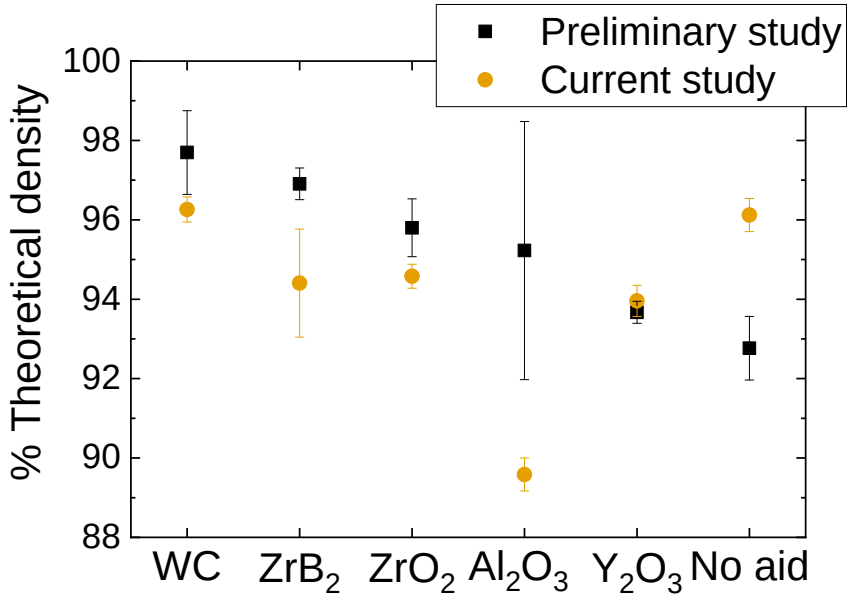
No effect on density or microstructure





94.4 ± 1.4 %TD

96.3 ± 0.3 %TD



Acknowledgements

ACerS Engineering Ceramics Division

CTTSO
Brady Russell
Eric Walzer

JHU/APL
Adam Maisano
Bruce Tretheway
Morgan Trexler

Purdue Faculty
Prof. Rodney Trice
Prof. Jeffrey Youngblood

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