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Sintering Behaviors of ZrC, NbC, and TaC Mono- and Binary Carbides

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Nuclear Thermal Propulsion (NTP) Fuel Options & Sintering Method

- 3 key candidates for NTP fuels:
  - Ceramic-metallic (ceramic fuel particles/Mo-30W matrix)
  - Ceramic-ceramic (ceramic fuel particles/ZrC or other ceramic matrix)
  - Solid Solution Carbides ← focus of this presentation
- Lacking information on carbide densification parameters
  - What sintering conditions lead to fully dense (>95% ideal density) material?
    - Spark plasma sintering (SPS; also known as Field Assisted Sintering Technology) used to examine sintering parameters
    - SPS parameters: 30 MPa, 15 minute hold time, 100°C/min heat up rate

- Powders sourced from US Research Nanomaterials Inc.

Carbide	Size (nm)
NbC	500
TaC	300
ZrC	400-1200

- ZrC Impurities (>1 wt%)

Impurity	Amount (wt%)
ZrO_x	~3%
Hf	~3%
W	~2.5%

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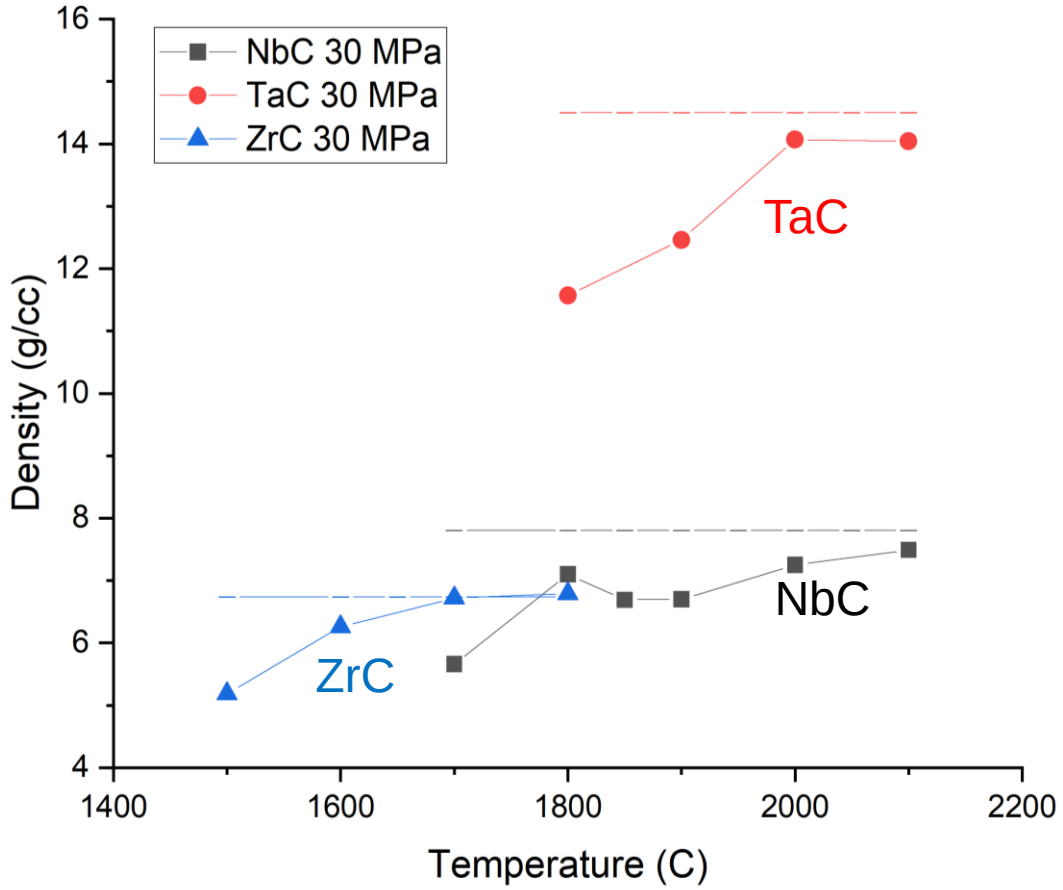
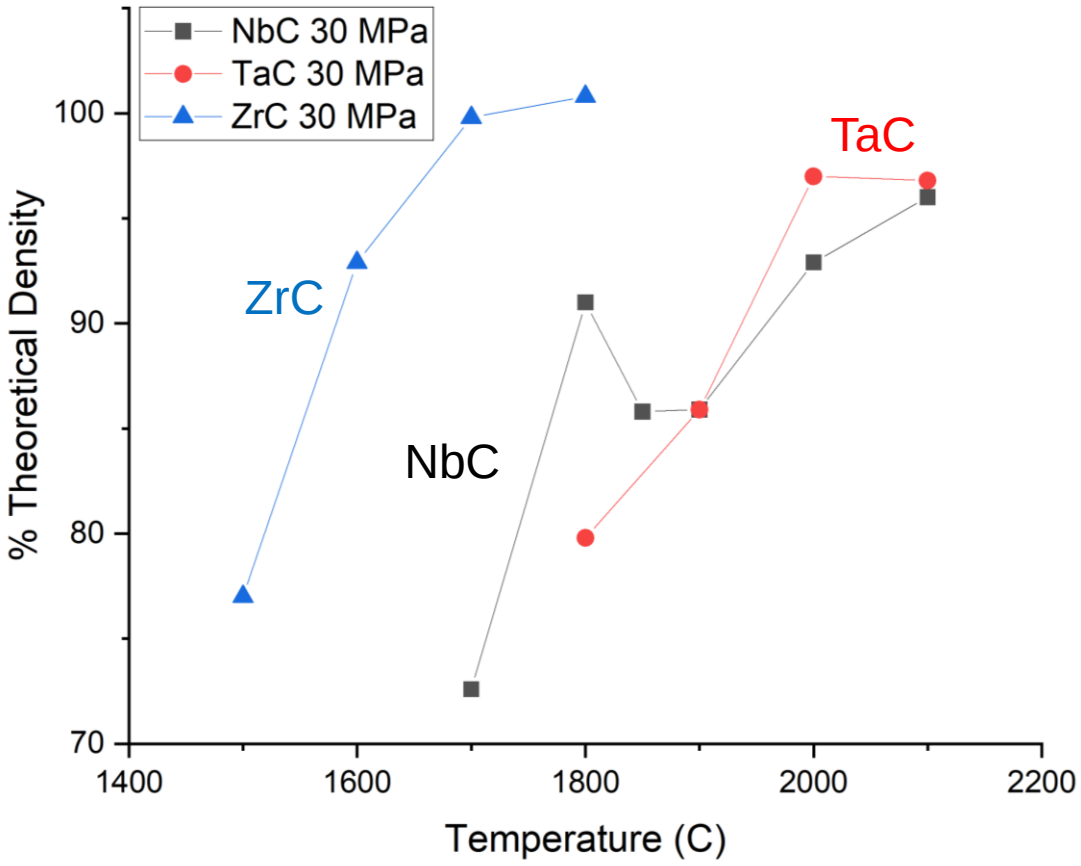
Monolithic NbC, TaC, ZrC Sintering Behavior

Densities of NbC, TaC, ZrC



Densities of samples were calculated using the Archimedes density method

Normalized Densities of NbC, TaC, ZrC



Theoretical densities were calculated using the lattice parameters obtained by powder XRD

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=> Monolithic carbide sintering temperatures scale with carbide melting points

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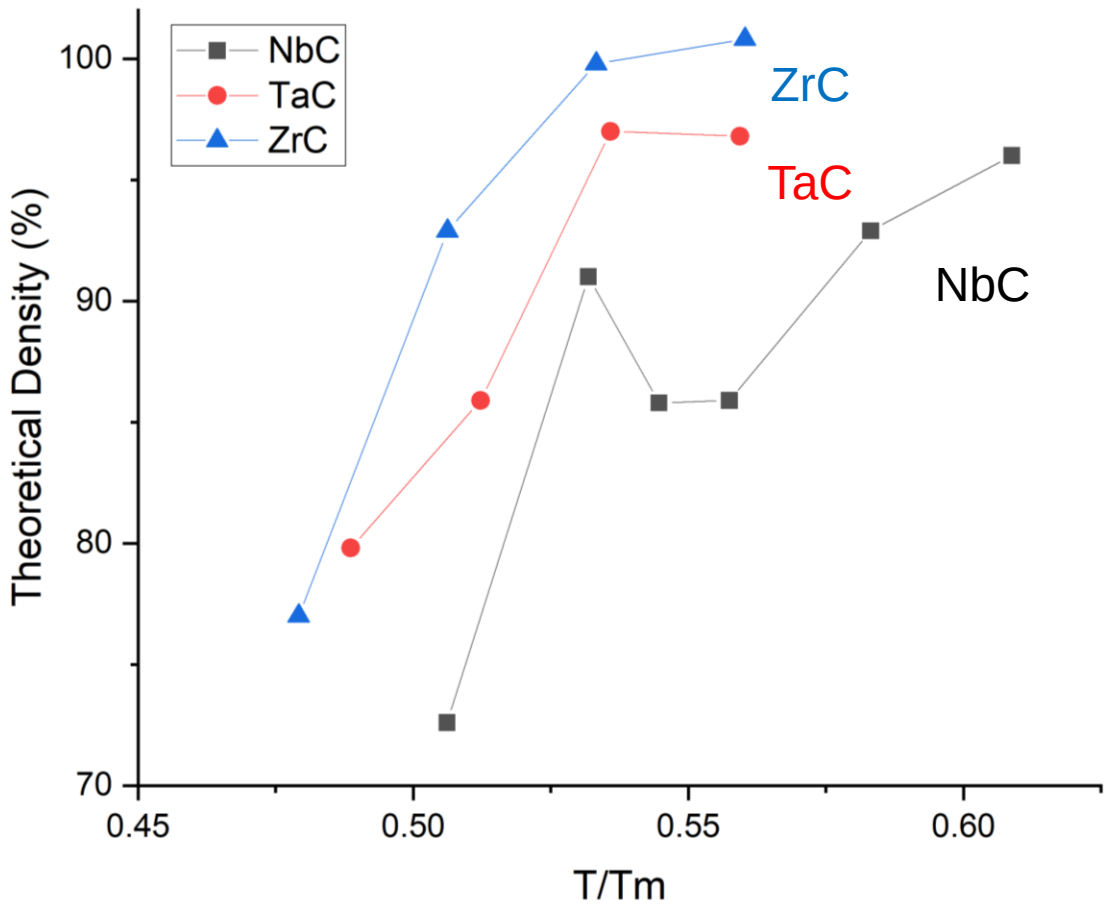
Monolithic NbC, TaC, ZrC Sintering Behavior

SPS Conditions Needed to Exceed 95% TD

Carbide	Melting Temp (°C)	Temp (°C) for >95% TD
NbC	3625	2050
TaC	3969	2000
ZrC	3427	1650

30 MPa and 15 minute hold time

Normalized sintered density vs. T/T_m



⇒ Densification of ZrC (~1650°C) occurs at much lower temperatures than for NbC and TaC (~2000-2050°C)

⇒ Normalized sintered density scales with homologous sintering temperature (T/T_m)

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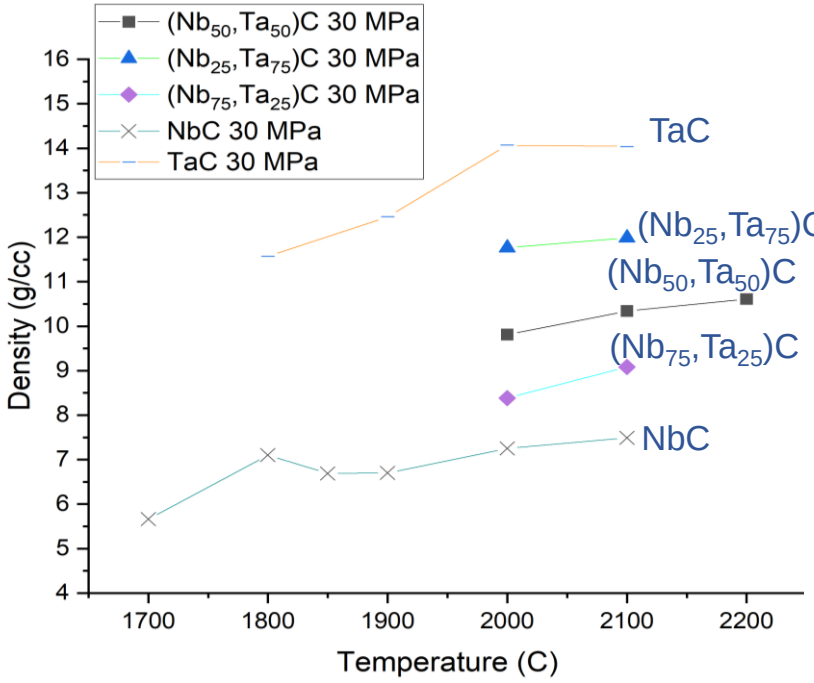
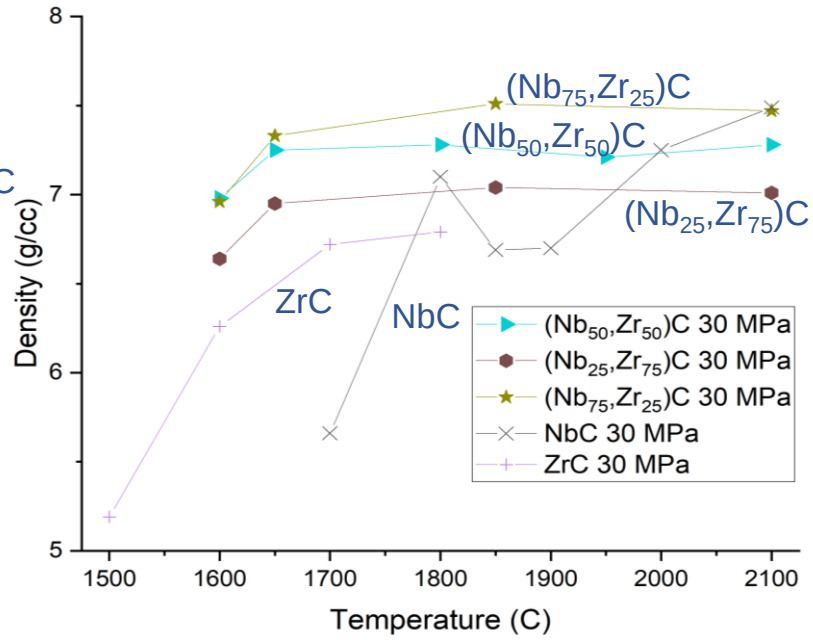
Bi-Carbide Sintering Behavior

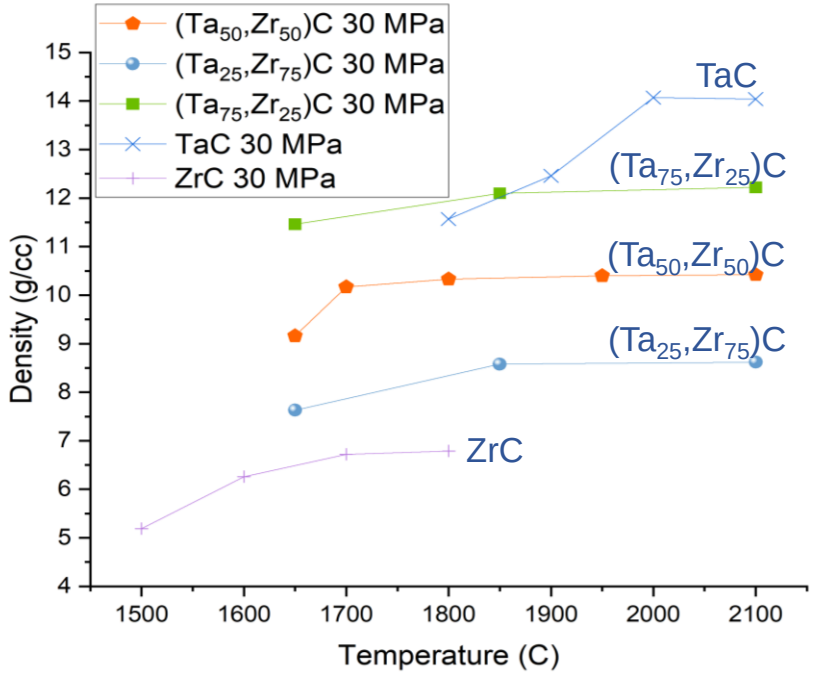
Densities of $(Nb_x,Ta_x)C$



Densities of $(Nb_x,Zr_x)C$



Densities of $(Ta_x,Zr_x)C$



=> Bi-carbide densification changes proportional with stoichiometry

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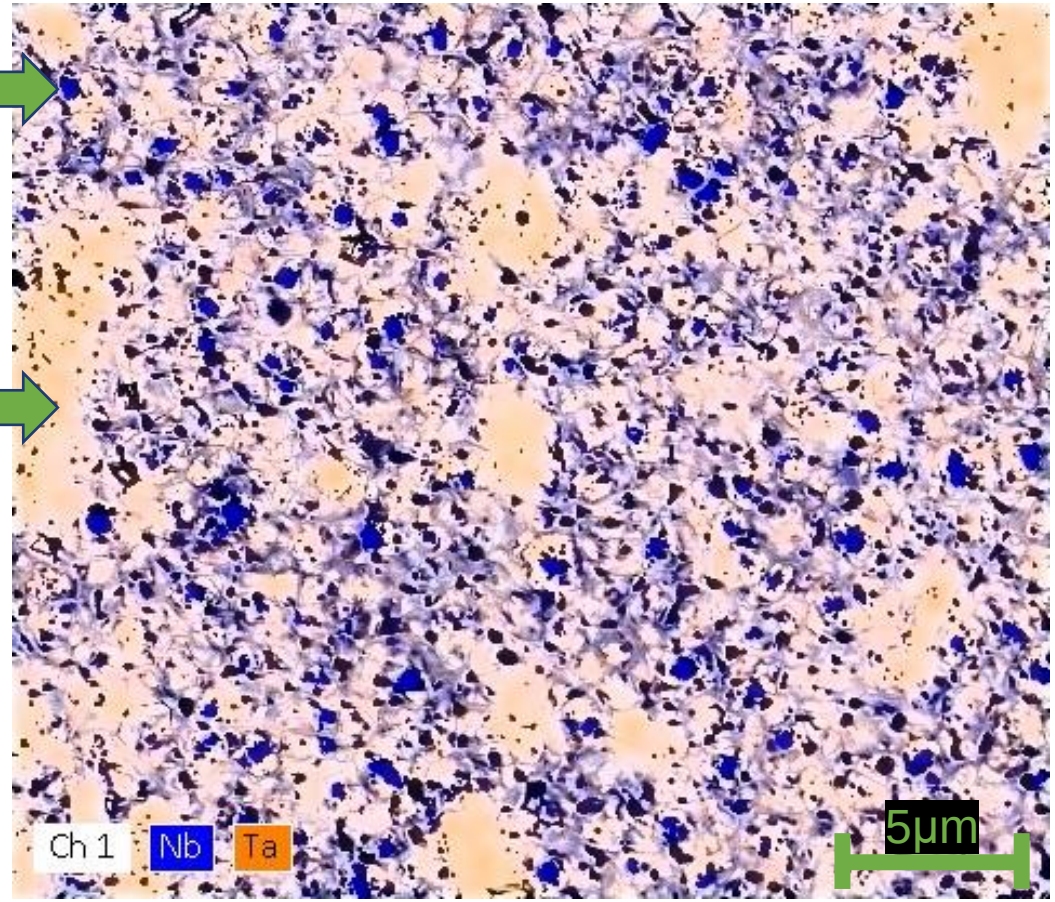
Representative Bi-Carbide Sintering Microstructure

$(Nb_{50},Ta_{50})C$ sintered to ≈96% TD

Fine-scale Nb rich area

Ta rich area



Carbide	Powder Size (nm)
NbC	500
TaC	300

Nb

Ta

⇒ Heterogeneity observed within >95% TD sintered specimens

A.T. Nadermann et al. NETS presentation 41709, Mon., May 8, 2023

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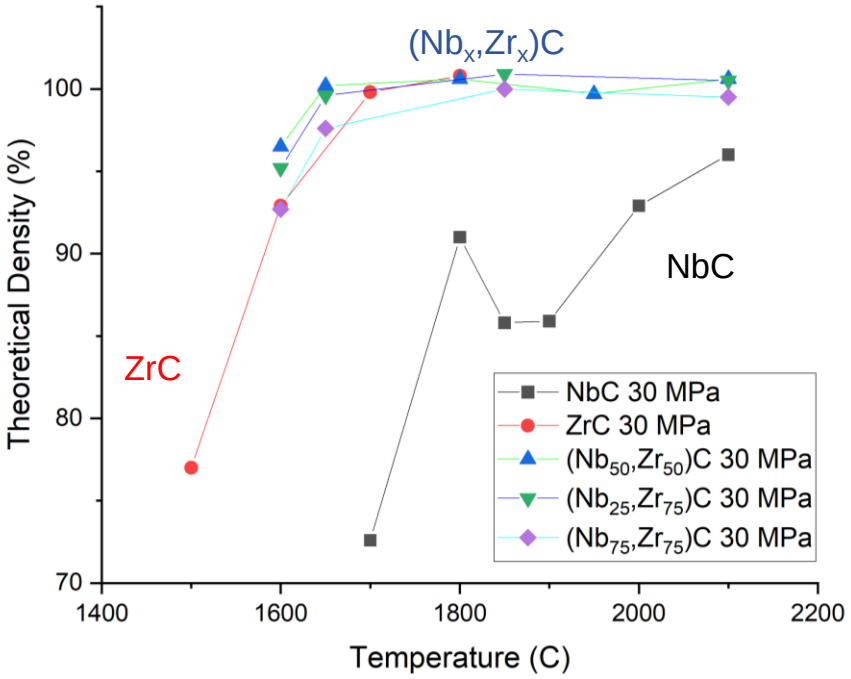
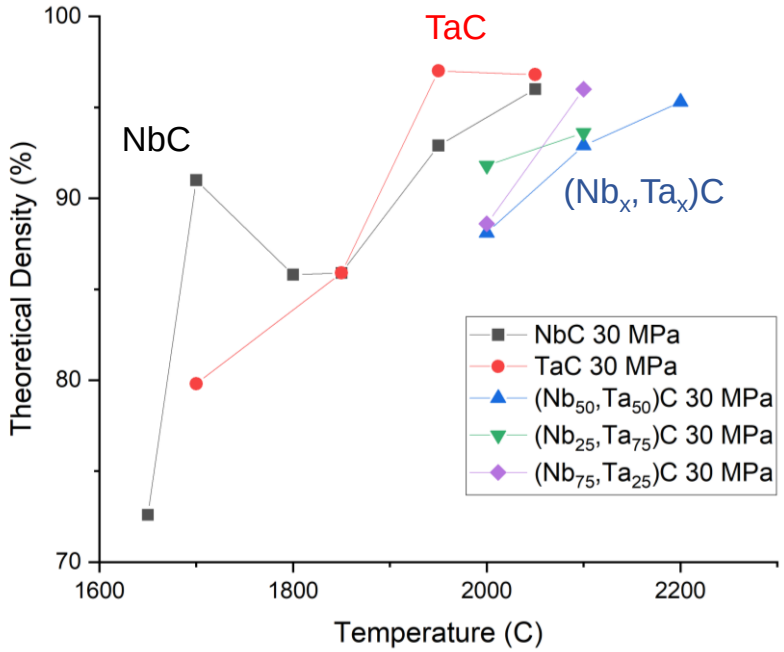
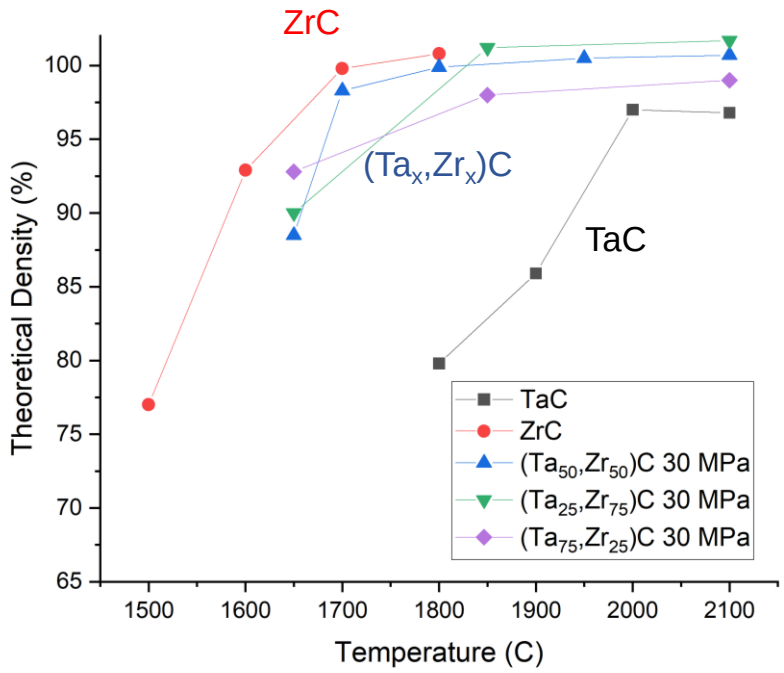
Binary Carbide Sintering Conditions (% ideal density)







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⇒ Sintering conditions for full densification is controlled by the carbide with the lower melting point

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Future Work

- Determine sintering activation energies
- Investigate sintering behavior of tri-carbides

Acknowledgements

- This project was funded by the NASA SNP Program
- Grant Number 80NSSC21K2011

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