Electrical Resistance Flash Sintering of Tungsten Carbide

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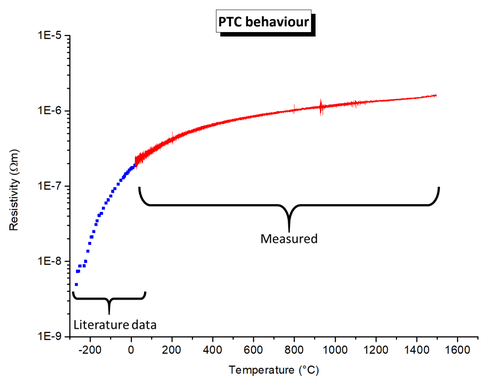
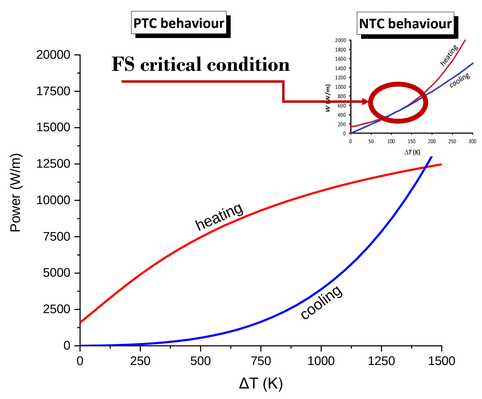
Abstract

The electrical resistance sintering process is explored here for the ultrafast consolidation of tungsten carbide (WC), a highly refractory ceramic with metallic-like conduction. This work aims to investigate the relationship between the electrical properties of the ceramic and the possibility to achieve the condition for "flash sintering". A specific setup has been developed to study the effect of pressure, high currents and low voltages applied directly to the powder compact on the sintering behavior.
The thermal runaway phenomenon that occurs during the flash sintering of ceramics usually requires a negative temperature coefficient for electrical resistivity (NTC). The possibility to activate it in a conductive ceramic, characterized by a positive temperature coefficient (PTC), was found in the very rapid reduction of the green compact electrical resistivity upon the initial densification.



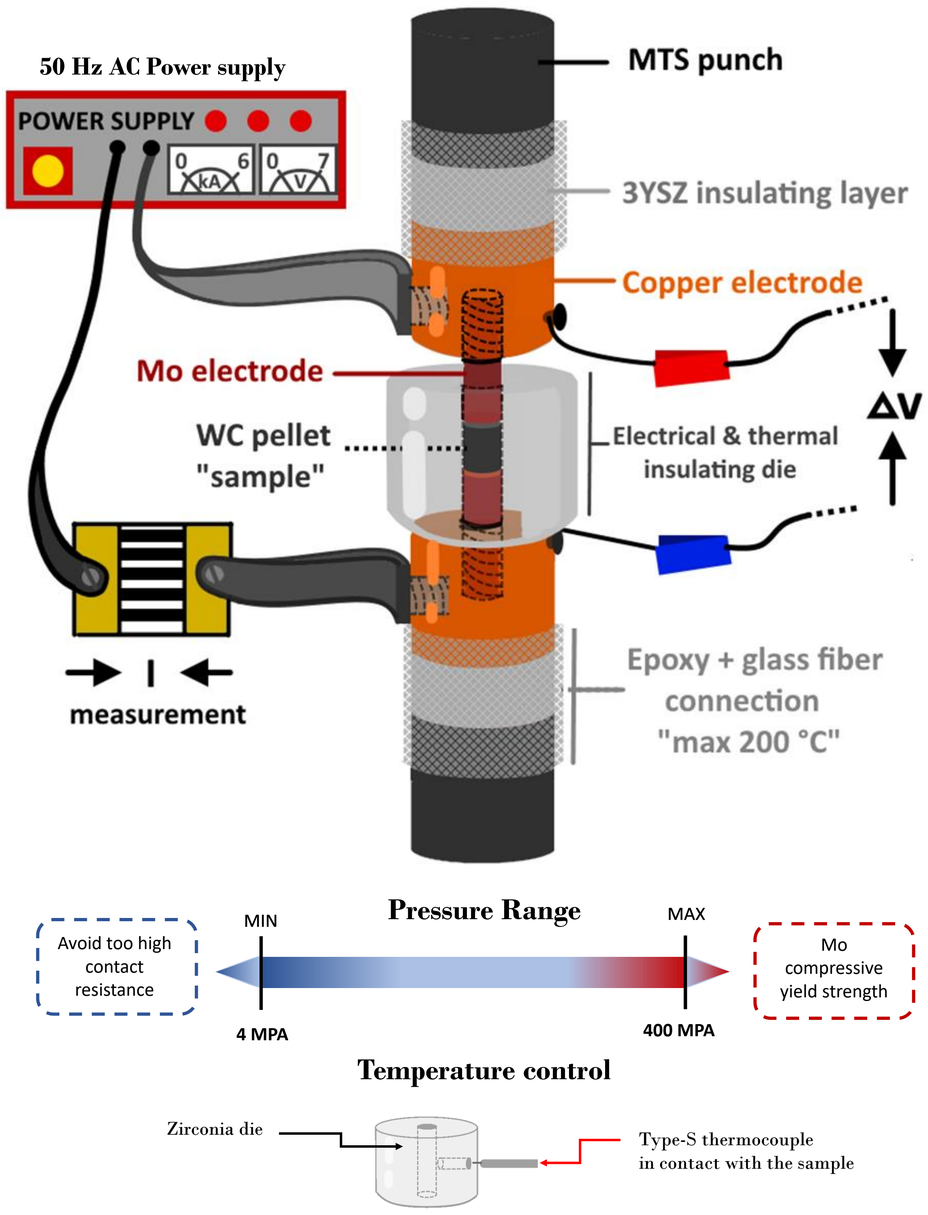
Evolution of the electrical resistivity with the temperature



Thermal runaway never occurs by increasing the sample temperature (ΔT)

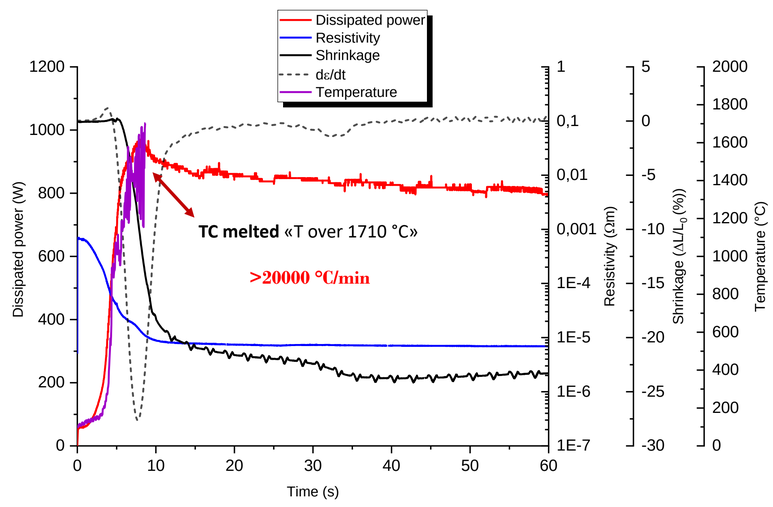
Materials & Methods

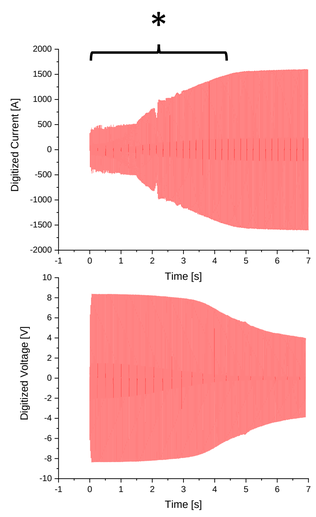
- Material Testing System (MTS): pressure application & shrinkage control
- Molybdenum electrodes: high electrical conductivity, melting point and compressive strength
- Zirconia matrix (3YSZ): electrical and thermal insulator die
- Pure WC nano powder (200 nm)



Results

1. Densification controls the thermal runaway





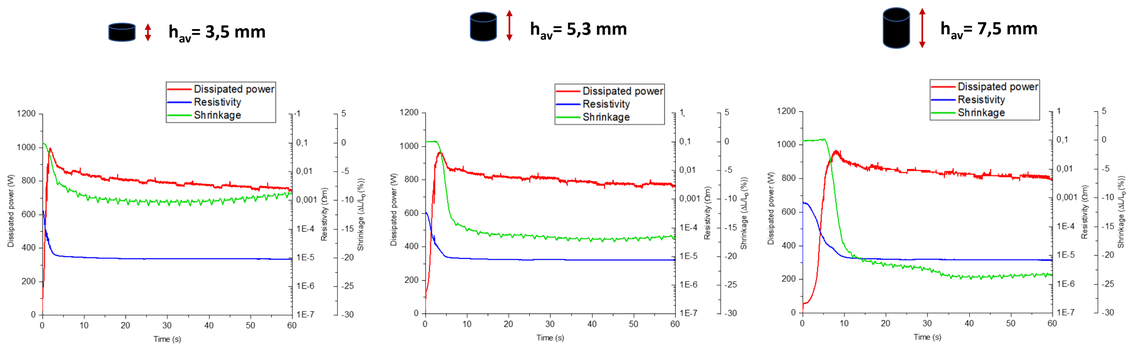
The WC pellet is sintered under 4 MPa and with a current limited to 2000 A.

A transition (*) of the current and of the voltage applied to the pellet occurs upon sintering.

What happens during this transition?

- The electrical resistivity drops with the densification
- A peak in the dissipated power is observed
- Densification rate is maximum at the power peak
- The transient is characterized by very high heating rate

2. Pellets volume influences the densification kinetic



Power peak = 985 (±11 W)

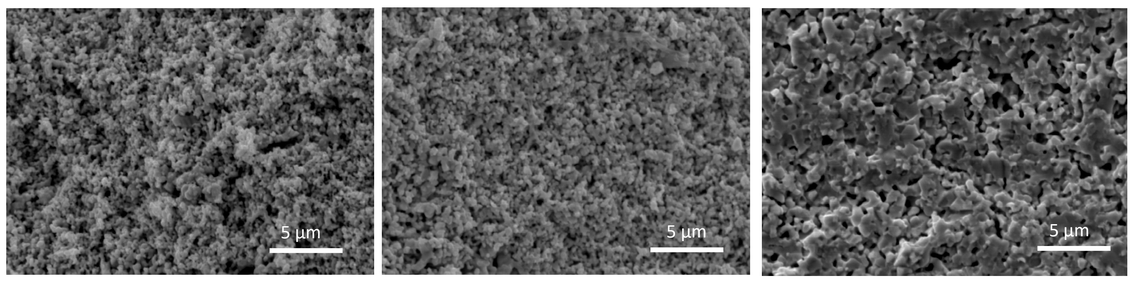
Relative power = **9748** (±250 mW/mm³)

Power peak = 963 (±5 W)

Relative power = **6477** (±181 mW/mm³)

Power peak = 949 (±17 W)

Relative power = **4448** (±460 mW/mm³)



RD_{av}= 53 (±1 %)

P_{app}=5 (±1 %)

RD_{av}= 60 (±1 %)

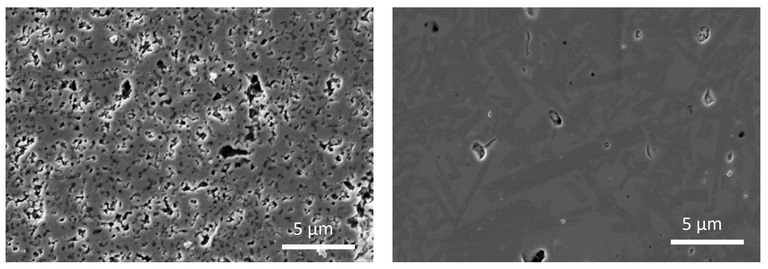
P_{app}= 4 (±1 %)

RD_{av}= 73(±1 %)

P_{app}= 2 (±1 %)

Differently from the expected results, a more intense relative power (mW/mm³) results in a much lower final density. Larger initial volume influences the time-scale of the resistivity evolution, resulting in a different time available for densification.

3. Pressure increases the final density



4 MPa

36 MPa

A much higher final density is observed by increasing the pressure during the transient evolution of the resistivity

97% theoretic density reached in less then 60 s

Conclusions

- The system assembled for flash/electric resistance sintering of WC allows to study the electrical effects in combination with the applied pressure.
- The flash sintering of tungsten carbide is found to relate to the electrical resistivity evolution with densification (instead of the temperature as in other ceramics).
- Low voltages and high currents are necessary to activate the flash event.
- Larger green compact volume correspond to longer time for the flash event to occur and, consequently, determines higher final density.

Flash sintering phenomenon
- Magnitude of electrical resistivity drop
- Time-scale of the resistivity evolution

ACKNOWNLEDGMENTS

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