FINITE ELEMENT ANALYSIS OF THE THERMAL RUNAWAY IN TUNGSTEN CARBIDE GRANULAR COMPACTS: ROLE OF THE CARBON SURFACE NANOLAYER

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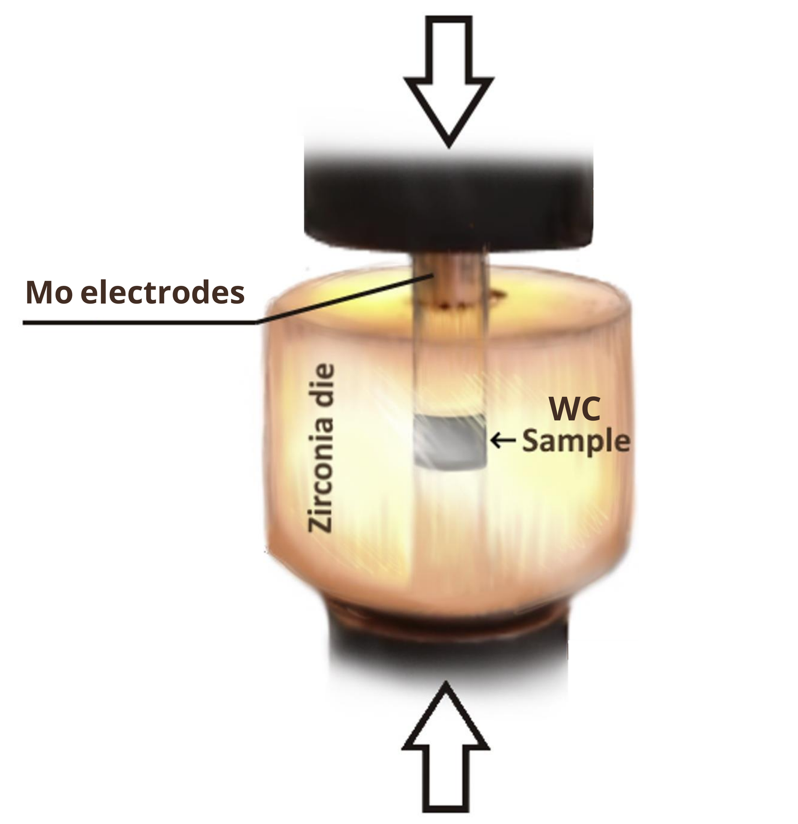
INTRODUCTION

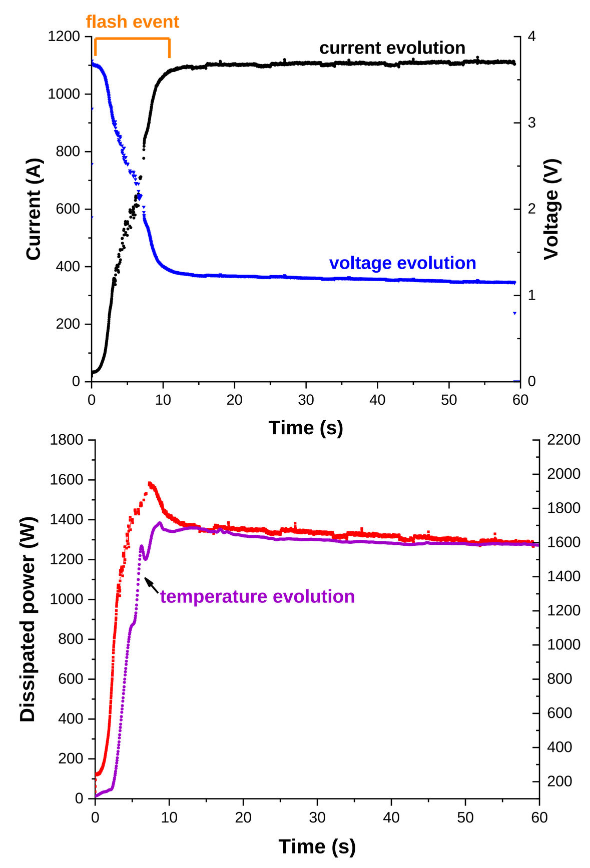
The application of a low voltage to tungsten carbide green bodies allows ultrafast sintering in less than 10 s [1]. A transient thermal runaway is responsible for exceptional heating rates of the order of 10^4-10^5 °C/min, which induces almost instantaneous densification. The present work aims at disclosing whether the thermal runaway phenomenon can be activated in a PTC ceramic, like tungsten carbide, thanks to the green resistivity reduction during the first instants of sintering. Such phenomenon was simulated by finite element method (FEM) to understand how the electric current flow interacts with the evolving green particles structure. A multi-physic FEM analysis was set up to concurrently describe the electrical field and the temperature evolution profile during the sintering process. A thermal runaway effect is induced in tungsten carbide green compacts by the current flowing in a medium whose resistivity decreases as it evolves to a denser structure. However, FEM solutions diverge from experimental evidence in correspondence of the threshold voltage and time necessary to activate the phenomenon. When the carbon nanolayer present on the conductive particles surface is considered, the results match the experimental findings [2]. The local overheating occurring at the surface carbon contacts is fundamental for accelerating the negative evolution of the resistivity, hence the ultrafast heating of tungsten carbide during sintering.

EXPERIMENTAL

Flash sintering setup - experimental

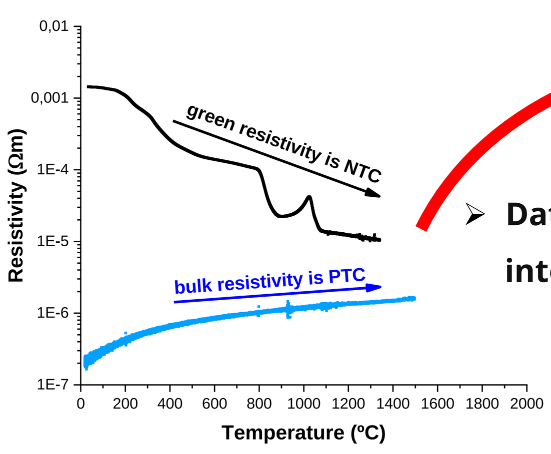
Pressure + Electric current





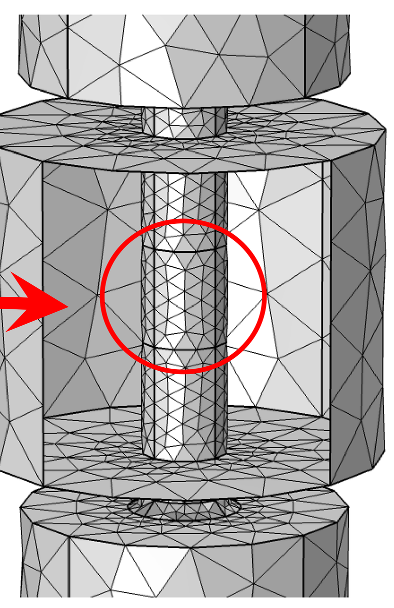
Flash in WC occurs at 3,7 V and 1000 A

Thermal runaway driven by green resistivity evolution



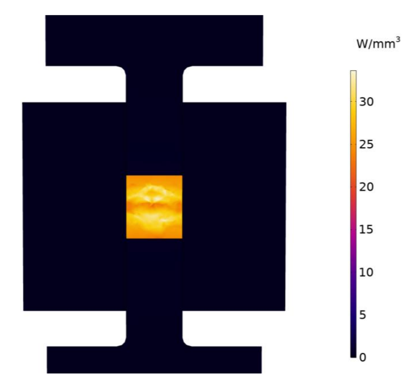
FEM - simulation

COMSOL® 5.6 multi-physic analysis

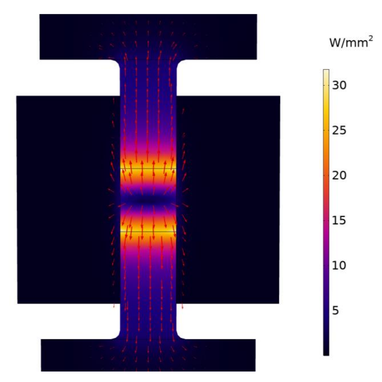


- Data imported into the model

- Heat generate by Joule heating (W_{in})

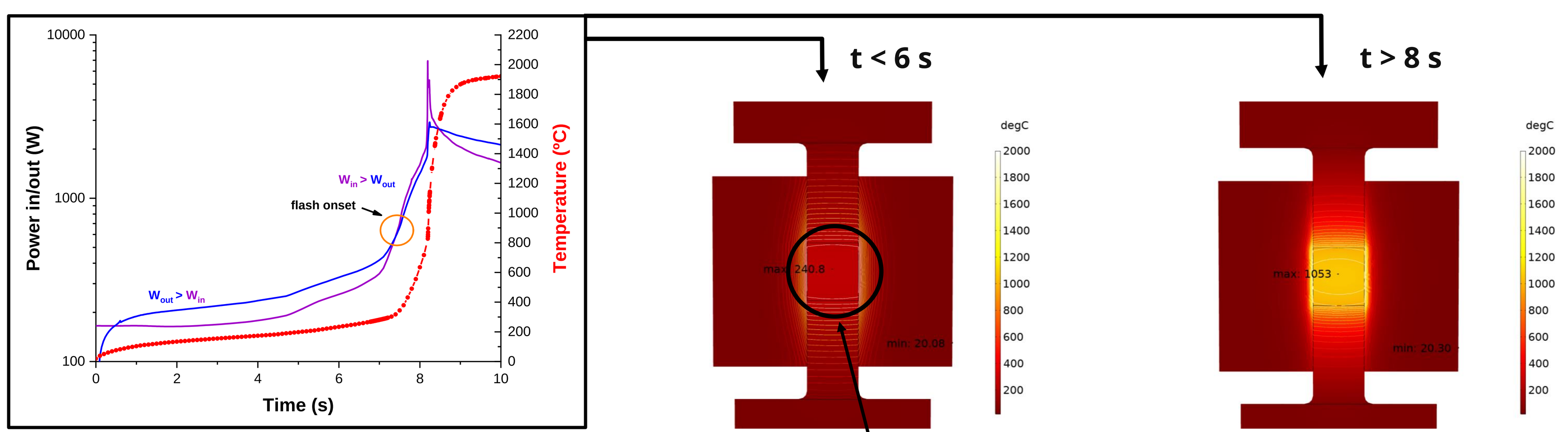


- Heat loss by conduction, convection and thermal radiation (W_{out})

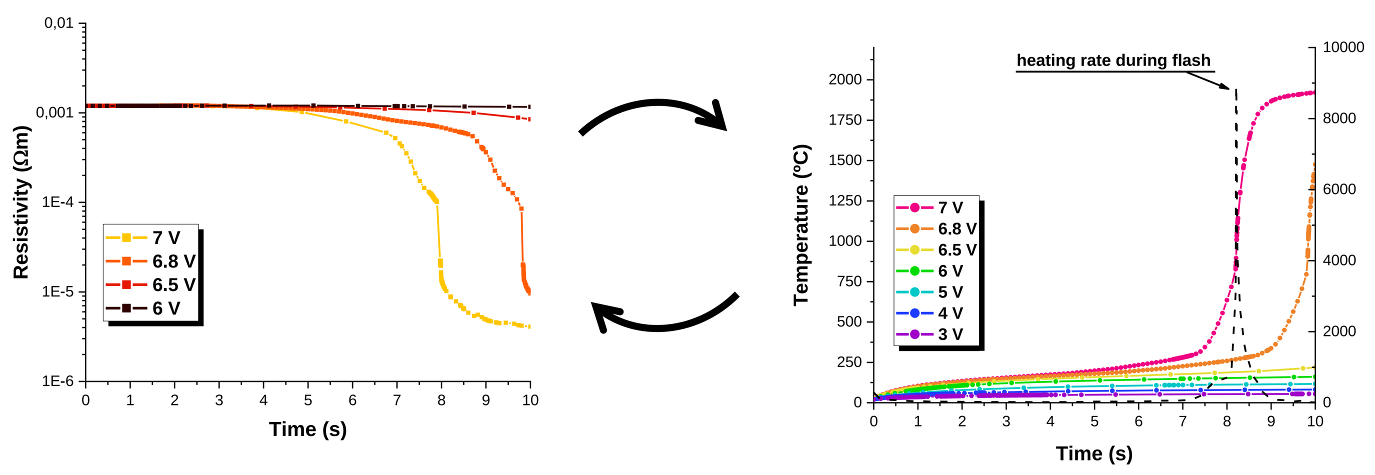


RESULTS & DISCUSSIOMS

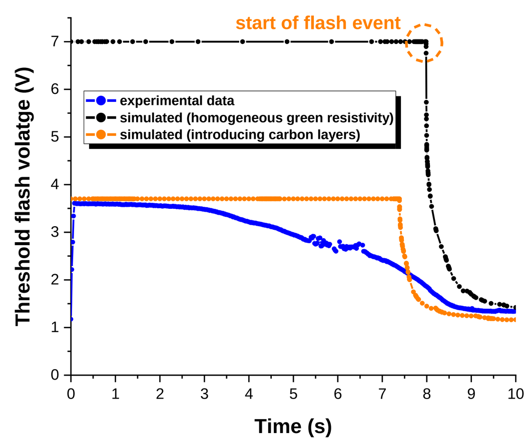
Simulation of the flash event



- The flash occurs when the heat generated in the WC sample overcomes the heat dissipated by the electrodes
- Thermal runaway of Joule heating is correctly activated but only at voltages > 6,8 V



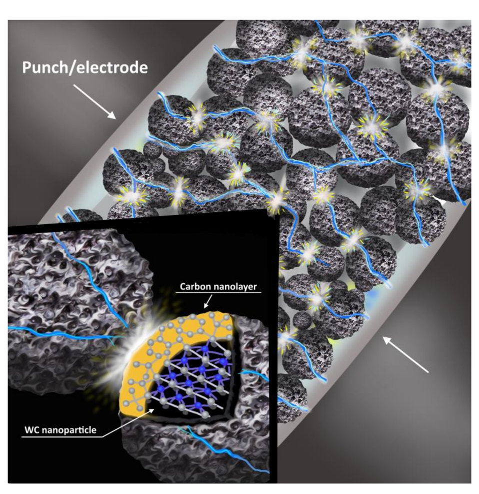
Overheating at surface carbon layer



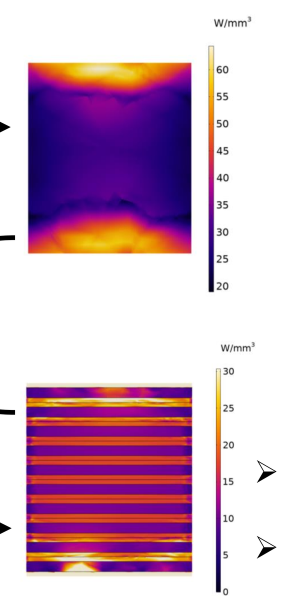
- Considering the green resistivity homogeneous
- Double threshold flash voltage

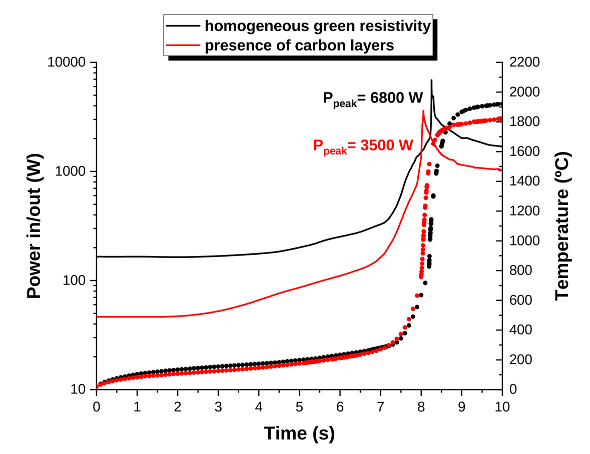
Why ???

- Heating is not uniform in WC green bodies ➡ How to model the localized overheating?



- Homogeneous green resistivity
- Same average resistivity
- Different resistivity for particle and carbon layers





- The thermal runaway is activated at 3,7 V
- Electrical power required is reduced
- The average temperature is still very high

CONCLUSIONS

- Flash sintering process was succesfully simulated by finite element method (FEM) for conductive PTC ceramic like WC.
- Thermal runaway in WC green samples is accelerated by the presence of resistivity carbon layers on the particle surface.

REFERENCES

[1] I. Mazo, A. Molinari, V. M. Sglavo, Materials & Design, 2022, 213, 110330, Electrical resistance flash sintering of tungsten carbide, https://doi.org/10.1016/j.matdes.2021.110330.

[2] I. Mazo, L. Vanzetti, J. Molina-Aldareguia, A. Molinari, V. M. Sglavo, Role of surface carbon nanolayer on the activation of flash sintering in tungsten carbide, http://dx.doi.org/10.2139/ssrn.4201823.

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