Carbon-doped FeMn binders for tungsten carbide

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Context

The use of cobalt as a binder for tungsten carbide (WC) raises more and more questions of environmental, health and societal ethics [1][2]. Research to replace it by FeMn-based binders are promising [3][4]. However, eta phase generation leads to a drop of mechanical properties of WC-FeMn composites, and although carbon-doping techniques of the composite material exist, the homogeneity of the resulting microstructure is often unadequate.

Objectives

Aim of this study: determination of the effect of the carbon doping of the binder on the final microstructure and mechanical properties of WC-FeMn composites. **Process adaptation**: to obtain a more homogeneous microstructure, milling cycles will be adapted so that carbon doping takes place only within the binder.

Compositions: WC-10Fe, WC-9Fe1Mn and WC-6Fe4Mn. Doped and undoped variants of each will be created.

Characterizations: Microstructure and mechanical properties comparison.

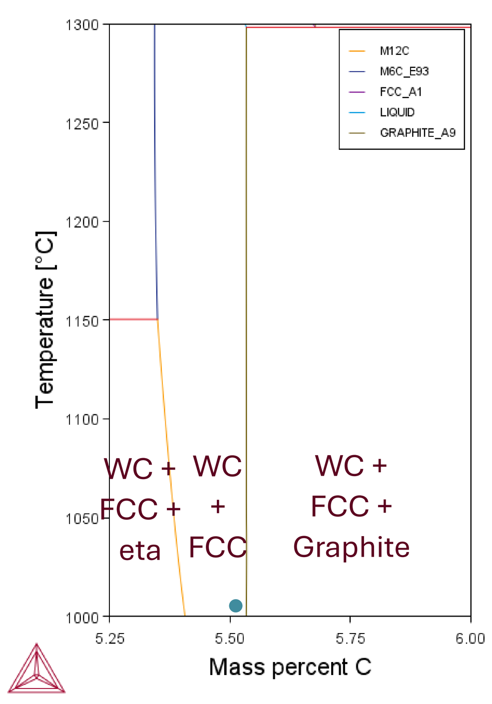
Materials & Methods

Processing: Powder metallurgy

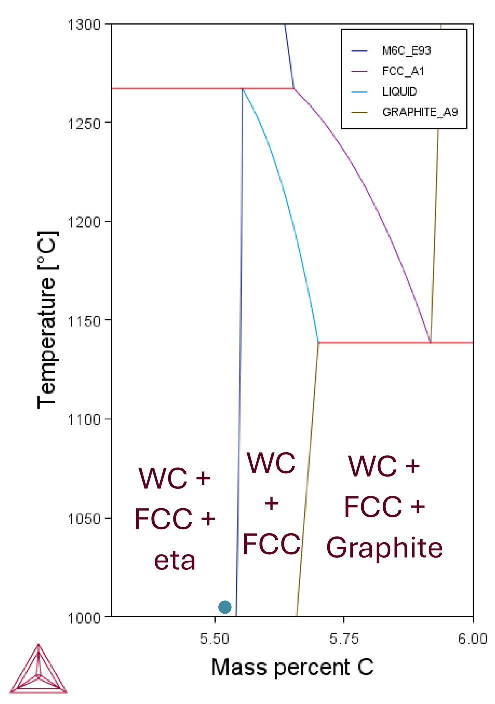
- Two successive milling cycles will take place in a planetary mill:
  - The first will mix the iron, manganese and carbon powders.
  - The second will then mix the resulting doped binder with tungsten carbide powder.
- **Sintering**: Vacuum sintering (1 hour at 1400°C – H_2/Ar atmosphere).
- **Samples characterization** : porosity rate and densification determinations. Microstructure observation (SEM), hardness (HV_{30}) and indentation fracture toughness (Palmqvist) measurements.

Results

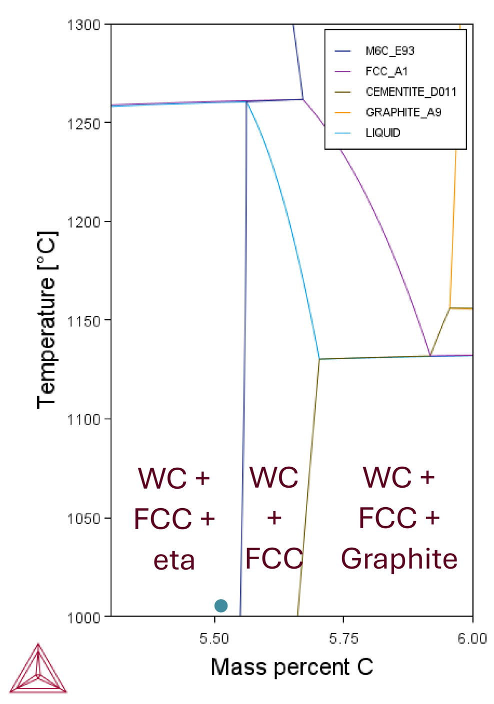
WC-10Co



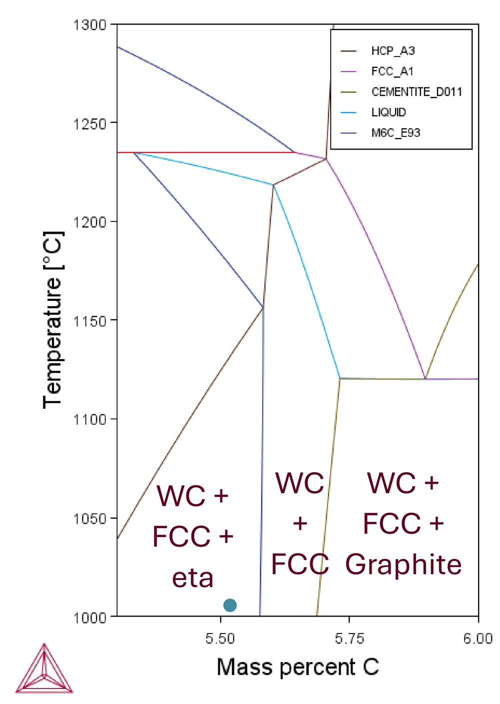
WC-10Fe

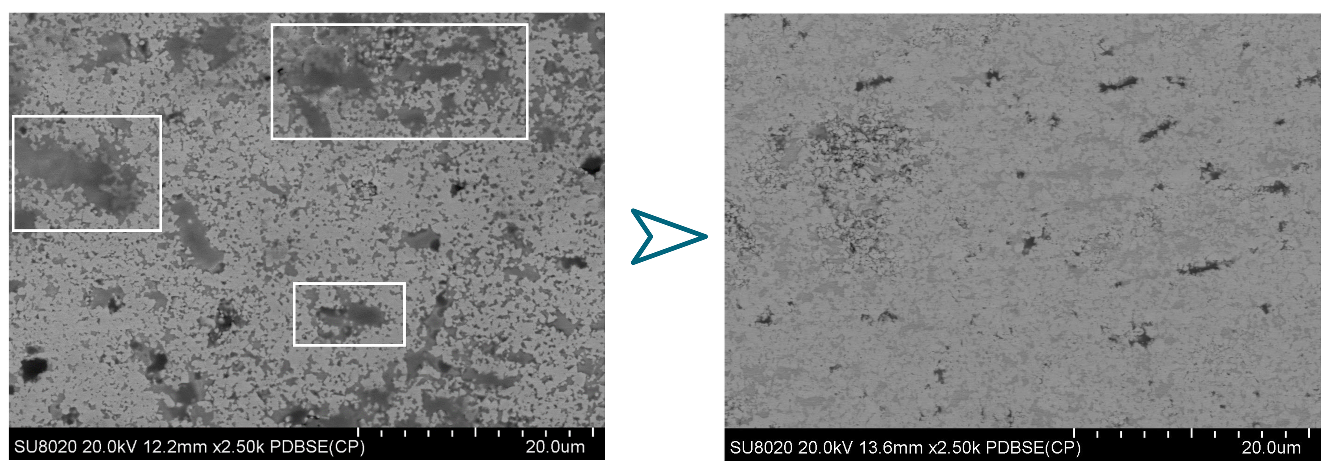


WC-9Fe1Mn

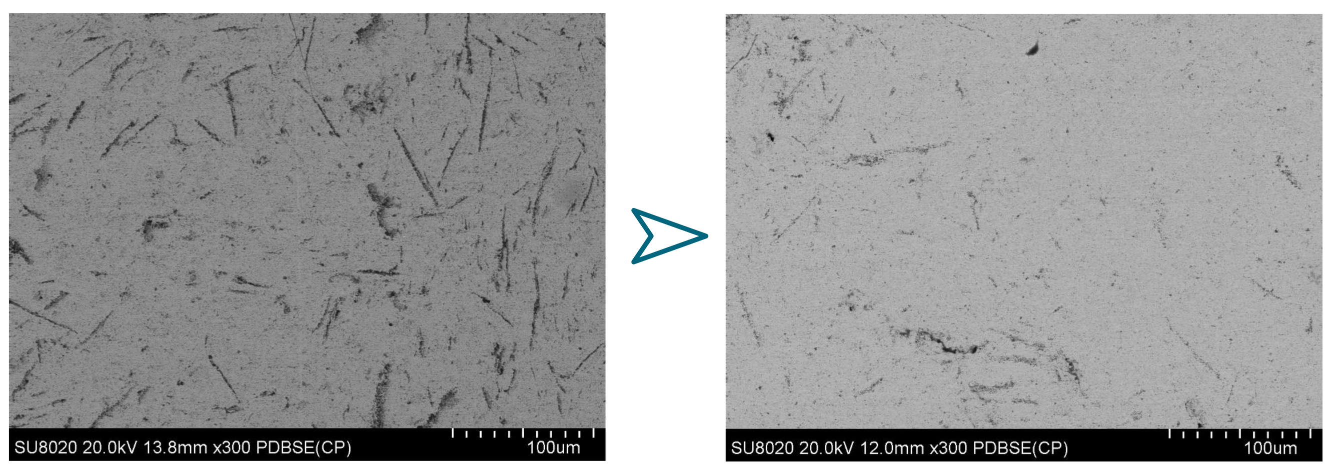


WC-6Fe4Mn





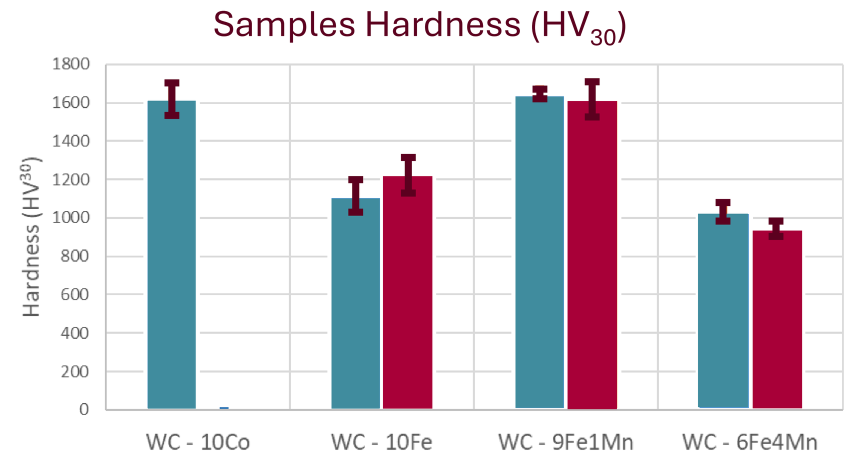
WC-10Fe + C phase distribution (standard milling VS two-step milling)



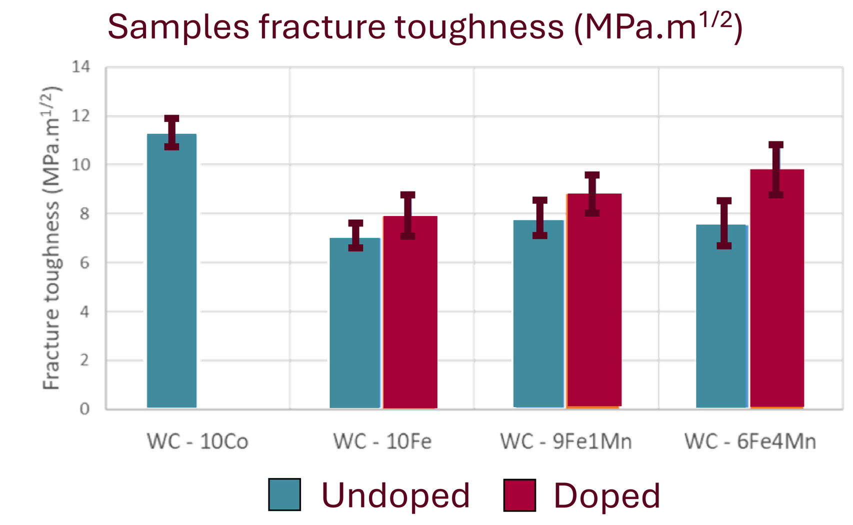
WC-9Fe1Mn (left) and WC-9Fe1Mn + C (right) - eta phase observation

Sample composition	ImageJ densification rate
WC-10Co	*97.2 ± 3,7 %*
WC-10Fe	*75.8 ± 5.3 %*
WC-10Fe+C	*86.4 ± 6.7 %*
WC-9Fe1Mn	*94.2 ± 6.1 %*
WC-9Fe1Mn+C	*95.9 ± 7.5 %*
WC-6Fe4Mn	*69.8 ± 2.7 %*
WC-6Fe4Mn+C	*86.5 ± 2.8 %*

Samples Hardness (HV_{30})



Samples fracture toughness (MPa.m$^{1/2}$)



Conclusions and perspectives

- Using a succession of two distinct milling cycles to create WC-FeMn (+C) composites leads to a more homogeneous microstructure.
- Carbon doping of the iron-manganese binder reduces the proportion of eta phase generated during sintering.
- Carbon doping of the binder also improves the densification of the composites, leading to better mechanical properties.
- Main perspective: Although improved, the microstructure and mechanical properties of the samples do not reach those of WC-Co composites. Future investigations will enable to improve processing parameters and to refine the composition of WC-FeMn composites.

[1] European Commission, "Tackling the challenges in commodity markets and on raw materials," 2011.

[2] D. Leon, "Comparative Study of the Acute Lung Toxicity of Pure Cobalt Powder and Cobalt-Tungsten Carbide Mixture in Rat," 1992.

[3] Ojo-Kupoluyi & al. (2017). Mechanical properties of WC-based hardmetals bonded with iron alloys–a review. In Materials Science and Technology (UK) (Vol. 33, Issue 5, pp. 507–517). Taylor and Francis Ltd.

[4] D. Siemiaszko and A. J. Michalski, "Cemented carbides with a non-toxic binder Fe-Mn" 2009, doi: 10.13140/2.1.3473.2486.