NARODOWE CENTRUM NAUKI

PRELUDIUM-18

2019/35/N/ST8/03697

Badanie degradacji wielofazowych materiałów ogniotrwałych w kontakcie z ciekłym metalem z wykorzystaniem mikrotomografii komputerowej i modelowania numerycznego w geometrii 3D

Investigations of multiphase refractory materials degradation in contact with molten metal using micro-computed tomography and numerical modeling in 3D geometry

dr inż. Jakub Józef Stec

Principal Investigator

Akademia Górniczo-Hutnicza im. Stanisława Staszica w Krakowie

Wydział Inżynierii Materiałowej i Ceramiki

MAIN RESULTS

One of the most widely used engineering materials is steel, which is produced using blast furnaces. Due to its wide range of applications, its price is very important to us, and it results, among others, from production costs. Since the production process using a blast furnace is continuous and lasts many years, extending its duration allows reducing the cost of the final product.

To extend the lifetime of the blast furnace, we need to develop refractory materials that are more resistant to degradation during blast furnace operation. One of the significant factors that destroy refractory materials is their infiltration through liquid metal. In order to design more resistant refractories, we need to carefully study and describe the factors responsible for the infiltration process. Numerical modeling comes to our aid here, which allows for the study and analysis of complex processes at relatively low costs.

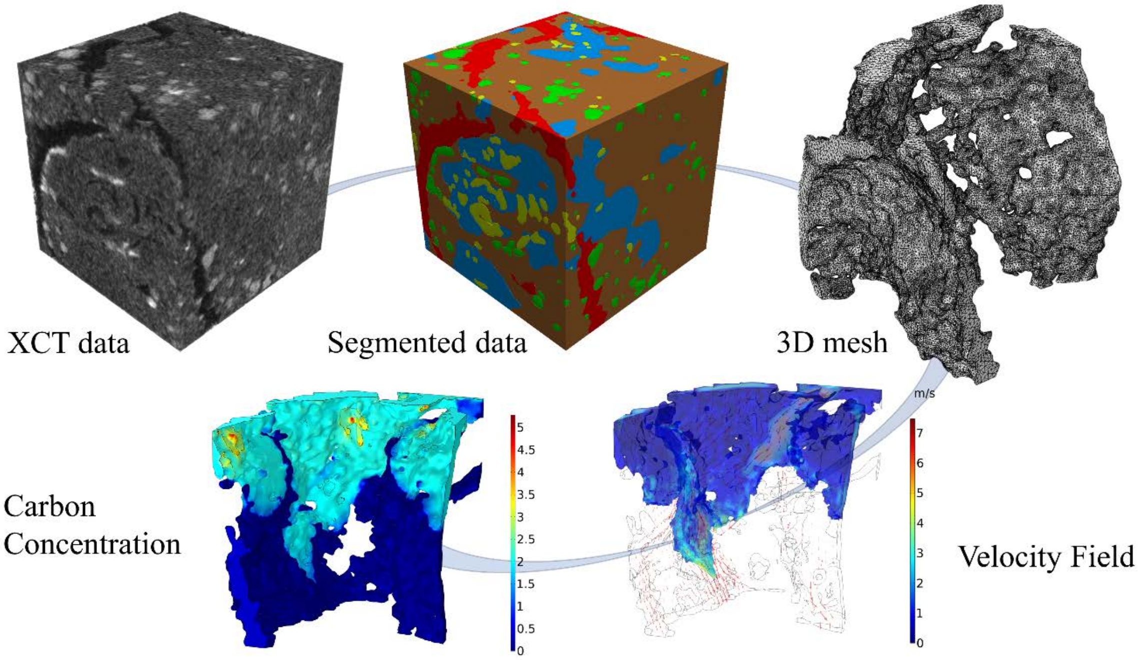

Fig. 1 Workflow of the project.

The aim of the project was to develop an advanced model of infiltration of refractory material with liquid metal, which would allow for the analysis of the evolution of the process as well as selective dissolution of the material. To make this possible, the properties of micropore carbon materials, such as porosity and permeability, were tested using methods such as: mercury and helium porosimetry, gas permeability and computed microtomography (XCT) – Fig. 2 [1]. The use of XCT allowed the creation of three-dimensional geometries that represent real pores in the refractory material.

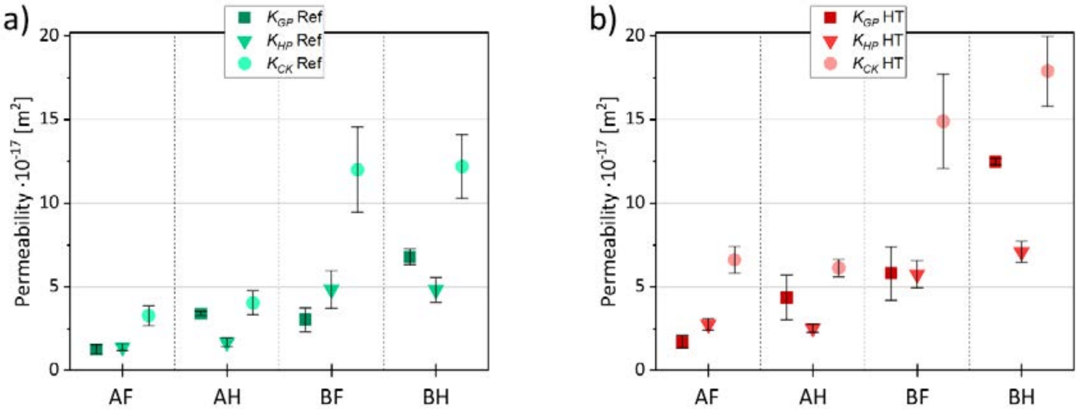

Fig. 2 Average permeabilities obtained using gas permeability (KGP) and two models based on mercury intrusion porosimetry results: build-in model (KMIP) and modified Carman-Kozeny equation (KCK). Left graph present results for samples before annealing (green).

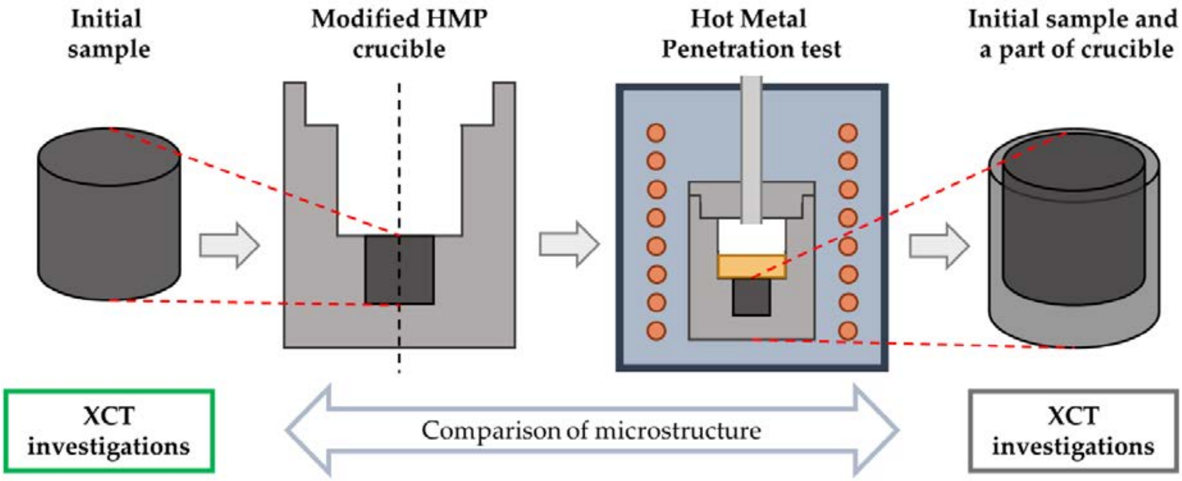

Fig. 3 Scheme of the designed new investigation method—the XCT–HMP test.

A research method enabling the comparison of exactly the same volume of material before and after the liquid metal infiltration process was designed and positively verified – Fig. 3. and Fig. 4 [2]. In addition, the liquid metal wettability of individual phases present in the refractory material was tested.

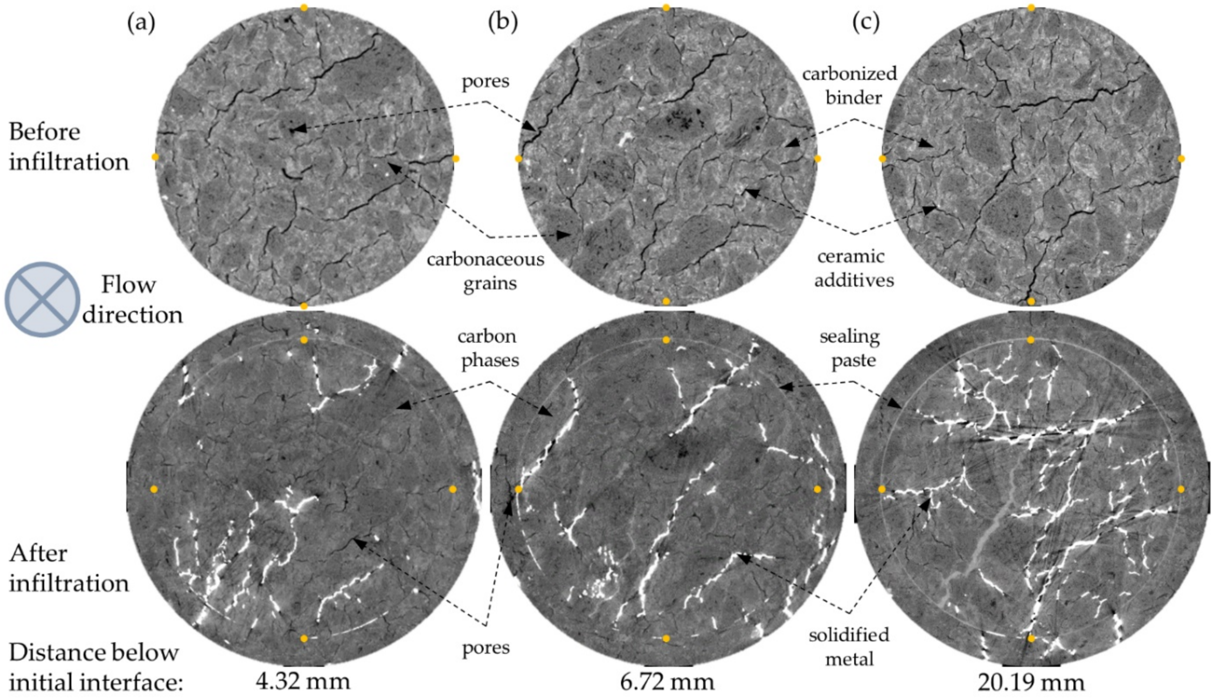

Fig. 4 Two-dimensional cross-sections in the plane perpendicular to the molten metal flow of the sample before (top row) and after the HMP test (bottom row) at various distances from the initial molten metal/sample interface: (a) 4.32 mm (b) 6.72 mm and (c) 20

Experimental studies were used to develop an infiltration model combined with selective dissolution of refractory material elements. The developed model was used to study the influence of the initial metal composition as well as the internal structure of the refractory material [3]. The results showed that the initial composition of the metal does not significantly change the course of the evolution process, but it is responsible for the amount of material that can dissolve in the metal. The analysis of the structure of the refractory material, and specifically its different wettability, showed that this is a factor that significantly affects the course of the infiltration process. The results obtained thanks to the developed model may allow for the design of more corrosion-resistant refractory materials.

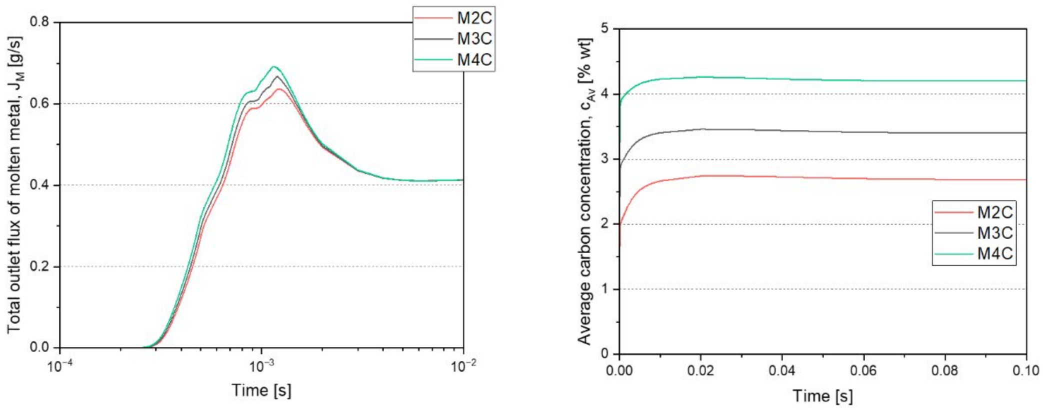

Fig. 5 Total outlet flux of the molten metal, J_M, for various initial carbon concentrations in molten metal (left). Average carbon concentration as a function of time for various initial carbon concentrations in molten metal (right).

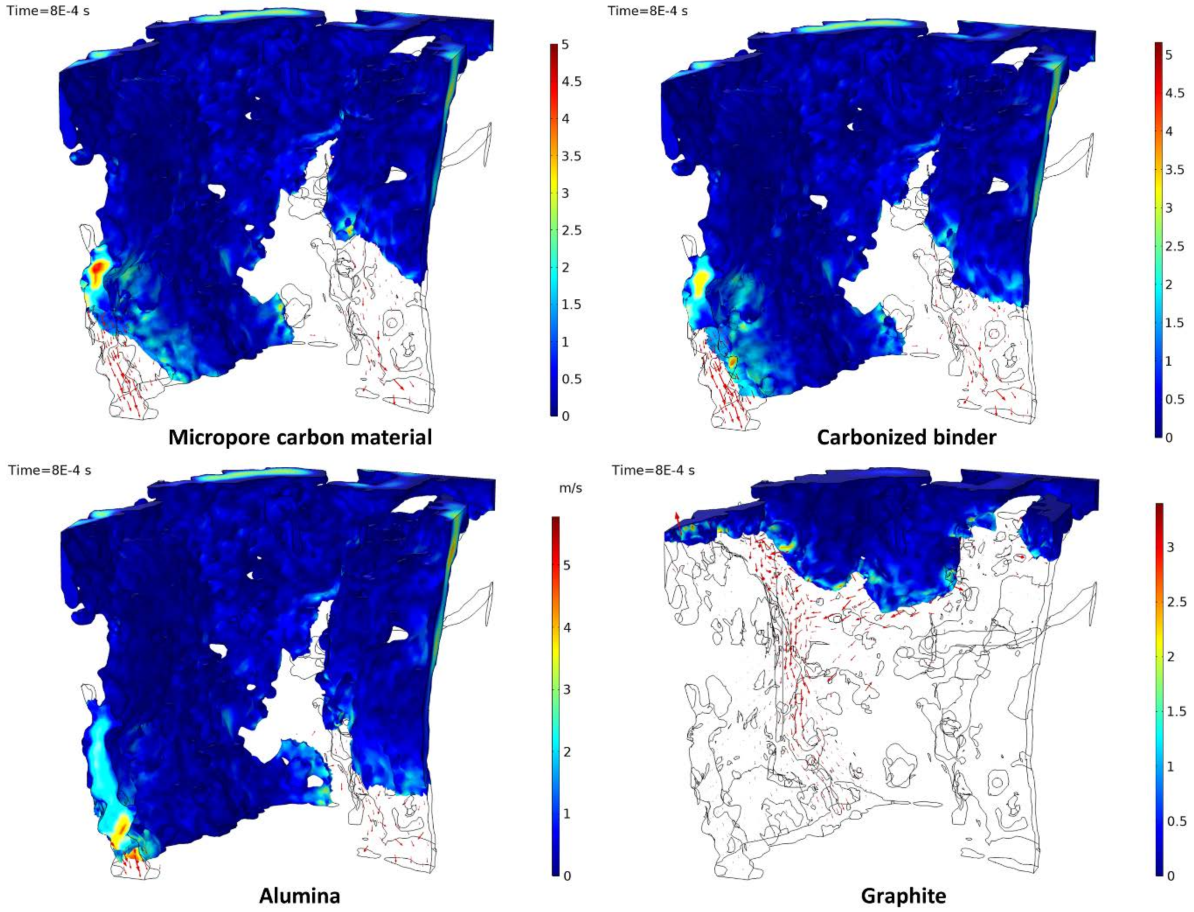

Fig. 6 Infiltration front propagation (velocity field) for various wetting conditions at time, t = 8·10-4s.

Results of the work done during project were published in the following papers:

[1] J. Stec, R. Smulski, S. Nagy, K. Szyszkiewicz-Warzecha, J. Tomala, R. Filipek, Permeability of carbon refractory materials used in a blast furnace hearth, Ceram Int. 47 (2021) 16538–16546. https://doi.org/10.1016/j.ceramint.2021.02.223.

[2] J. Stec, J. Tarasiuk, S. Wroński, P. Kubica, J. Tomala, R. Filipek, Investigation of molten metal infiltration into micropore carbon refractory materials using x-ray computed tomography, Materials. 14 (2021) 1–14. https://doi.org/10.3390/ma14123148.

[3] J. Stec, J. Tarasiuk, S. Wroński, P. Migas, M. Gubernat, J. Tomala, R. Filipek, Influence of wettability and initial metal composition on infiltration process of carbon refractory material – The evolutional model of molten metal infiltration into a 3D real microstructure acquired using X-ray computed tomography , Journal of European Ceramic Society. (n.d.).

Acknowledgments

This project was supported by the National Science Centre in Poland (NCN) no. UMO-2019/35/N/ST8/03697.