Ultrasonic-assisted extraction of critical raw materials from tungsten carbide waste

P. Guedes[1,2], E.P. Mateus[1], A.N. Alshawabkeh[3], A.B. Ribeiro[1]

[1] CENSE, Departamento de Ciências e Engenharia do Ambiente, Faculdade de Ciências e Tecnologia, Universidade Nova de Lisboa, 2829-516 Caparica, Portugal
[2] Instituto de Tecnologia Química e Biológica António Xavier, Universidade Nova de Lisboa, Av. da República, 2780-157 Oeiras, Portugal
[3]Department of Civil and Environmental Engineering, Northeastern University, 360 Huntington Ave, Boston, MA 02115, USA
Keywords: ultrasonic probe, tungsten, cobalt, recovery
Presenting author email: abr@fct.unl.pt

The tungsten carbide–cobalt (WC–Co) hard metal or cemented carbide, referred to as a composite material, is usually composed of WC particles embedded within a Co binder. In recent decades, with the rapid development of society and industry, the production of cemented carbides has increased, while the reserves of cobalt and tungsten decrease yearly [1]. W and Co are part of the EU 2017 Critical Raw Materials List [2]. Therefore, it is necessary to recover cobalt and tungsten from the cemented carbides scraps. According to a U.S. Geological Survey, nearly 55% of the tungsten consumed in the United States in 2017 was utilized in cemented carbide [3]. It is envisaged that recycling of tungsten carbide will considerably grow in the future, being necessary to find efficient and green methods for the cemented scrap recovery.

Ultrasound waves are high frequency (>20 kHz) sound waves beyond the threshold of human hearing. The basic principle of ultrasound-assisted extraction (UAE) is acoustic cavitation and micro-streaming. When high power ultrasound waves propagate through any medium, a sequence of compressions and rarefactions is induced in the molecules of the medium causing pressure alteration. The developed negative pressure during the rarefaction phase advances above tensile strength of the fluid causing the formation of cavitation bubbles from the gas nuclei of the medium. These bubbles grow over a number of cycles until they become unstable and finally violently collapse/implode - acoustic cavitation phenomenon [4,5]. This implosion generates high temperature and pressure which in turn results into high sheer energy waves and turbulence causing combination of mechanical effect on the material [5,6]. It also develops strong micro-streaming currents that may alter the characteristic of the medium. Thus, UAE can provide added benefit by increasing the extraction yield at lower temperatures and thus decreasing extraction time resulting in a better-quality product. Additionally, commercial scale-up of UAE process is achievable with good return on capital investment [5].

Two types of ultrasound equipment are most commonly used for extraction purposes, namely, ultrasonic water bath and ultrasonic probe system fitted with horn transducers. The factors affecting the efficiency of ultrasonic treatments can be divided into three categories: (1) process factors such as frequency, amplitude, power and treatment time; (2) media factor such as pressure, temperature, viscosity and polarity of solvent and (3) product factors such as moisture content, particle size and compound of interest [5].

In the work here presented, the extraction of W and Co from WC-Co powder was tested using an ultrasonic probe system. The WC-Co powder was suspended in different solvents (nitric acid, sodium hydroxide and sodium sulphate). As UAE process variables we tested the amplitude (10, 30 and 50%,) and different pulse time (ON/OFF periods; 3/57, 6/54, 12/48 seconds).

The data obtained so far show that the best results for the extraction of W from the WC-Co powder (Figure 1) were achieved with the application of a 50% amplitude with ON/OFF pulses of a 6/54 (seconds) using either sodium sulphate or nitric acid as medium.

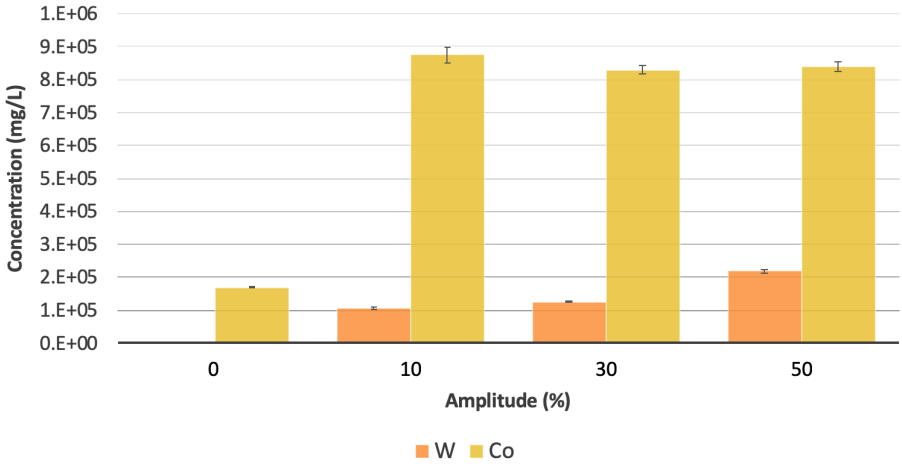

Figure 1. Amount of tungsten (W) and cobalt (Co) extracted after application of ultrasonic ON/OFF pulses of 6/54 seconds (nitric acid was used as medium).

The UAE has shown to be a promising extraction technique which may save time and costs. The mechanism through which it aids extraction, the various parameters affecting the efficacy and integration with other novel technologies for by-product valorisation should be further exploited.

Acknowledgements

This work has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement No. 778045; and from FCT/MEC through grants UID/AMB/04085/2013, Research unit CENSE "Center for Environmental and Sustainability Research". P. Guedes acknowledges Fundação para a Ciência e a Tecnologia for her Post-Doc fellowship SFRH/BPD/114660/2016.

References

[1] P. Schade, 100 Years of Doped Tungsten Wire, Int. J. Refract. Met. Hard Mater. 28 (2010) 648–660.
[2] European Commission, 2017 list of Critical Raw Materials for the EU, (2017).
[3] U.S.G.S. U.S. Department of the Interior, Mineral Commodity Summaries 2018, 2018.
[4] B.K. Tiwari, Ultrasound: A clean, green extraction technology, TrAC Trends Anal. Chem. 71 (2015) 100–109.
[5] B. Kumari, B.K. Tiwari, M.B. Hossain, N.P. Brunton, D.K. Rai, Recent Advances on Application of Ultrasound and Pulsed Electric Field Technologies in the Extraction of Bioactives from Agro-Industrial By-products, Food Bioprocess Technol. 11 (2018) 223–241.
[6] A.C. Soria, M. Villamiel, Effect of Ultrasound on the Technological Properties and Bioactivity of Food: A Review, Trends Food Sci. Technol. 21 (2010) 323–331.
[7] B. Leśniewska, E. Świerad, A. Łukowski, J. Wiater, Ultrasound Assisted Extraction for Determination of Mobile Fractions of Copper in Soil, Rocz Panstw Zakl Hig. 65 (2014) 67–74.