KnE Materials Science

MIE-2017
15th International School-Conference "New materials – Materials of innovative energy development, characterization methods and application"
Volume 2018

Knowledge E
Engaging minds

Conference Paper

The HVEDC Method for the Production of Tungsten Based Alloys

N. S. Ermakova, S. S. Bashlykov, and E. G. Grigoriev

Laboratory of Electromagnetic Field-Assisted Methods for Processing of Novel Materials, National Research Nuclear University MEPhI (Moscow Engineering Physics Institute), Kashirskoe shosse 31, Moscow, 115409, Russia

Abstract

The purpose of this study is to investigate HVEDC method for the production of tungsten-based alloys. It is established that the method of high-voltage electro-discharge compaction, in addition to some economic and time benefits, contributes to a minimal change in the microstructure and does not lead to grain growth, thereby improving mechanical characteristics.

Keywords: powder metallurgy, tungsten heavy alloys, high-voltage electro-discharge consolidation.

Corresponding Author:
N. S. Ermakova
natalia_ermakova2503@mail.ru

Received: 21 December 2017
Accepted: 15 April 2018
Published: 6 May 2018

Publishing services provided by Knowledge E

Selection and Peer-review under the responsibility of the MIE-2017 Conference Committee.

1. INTRODUCTION

Tungsten based alloys are used in instrumentation engineering, defense industry, to make protective shields and containers for storing radioactive substances, radiological equipment for radiation and contamination monitoring, for production of various kinds of weighting agents, electrical contacts and much more. Heavy alloys are produced by methods of powder metallurgy, in particular, using electromagnetic fields. However, their properties differ greatly depending on the choice of the sintering method.

2. MATERIALS AND METHODS

The method of high-voltage electro-discharge compaction (HVEDC) is a method to obtain compacts from powders in which a short powerful high-voltage pulse of electric current and mechanical pressure are simultaneously applied to the powder blank. [1-5] The duration of the current pulse, as a rule, is no more than 10^{-3} seconds, and the amplitude of the current density in the pulse is $j > 10^4$ A/cm^2.

As shown in Fig. 1, the powder material 1 is placed in a die 2 of non-conductive material. Punch electrodes 3 transfer the pressure to the powder preform from the pneumatic press and simultaneously serve as current leads from the current pulse generator to the compressible powder 1. To create powerful current pulses, a battery of high-voltage pulse capacitors is used, the discharge of which provides a powerful energy release in the powder compact. Figure 2 shows the necessary details for consolidation.

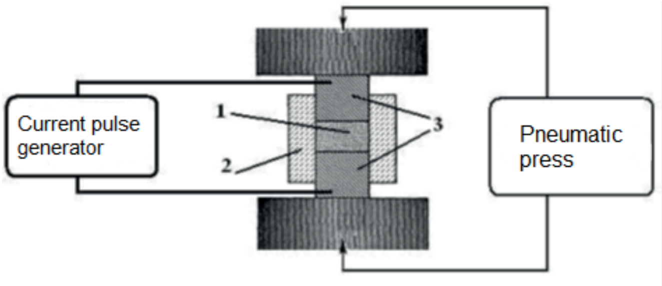

Figure 1: Scheme of HVEDC.

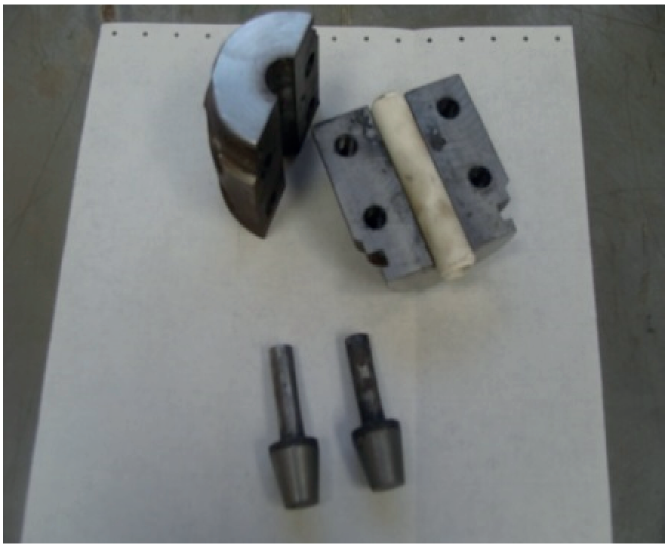

Figure 2: Die and punches for HVED.

The process of high-voltage electro-discharge compaction of powder materials includes some technological operations:

- dosing of the starting powder by weight;
- backfilling of the metered powder in the assembly, consisting of a matrix and a lower punch;
- inserting the upper punch into the assembly and mounting the assembly on the stationary rod of the working device;
- supplying pressure from the pneumatic system to the upper movable rod of the working device, which, when lowered, transfers pressure through the upper punch to the powder; The pressure applied to the gas manometer is controlled;

- charging the battery of capacitors to the required voltage by means of a charger;
- feeding on ignitrons from the control module of the initiating pulse, closing the high-voltage circuit and discharging the capacitor bank through the pressurized powder;
- deactivation of the pressure applied by the pneumatic system, and extraction of punches and consolidated sample from the matrix.

As a rule, the whole process of HVEDC is carried out without the use of a protective atmosphere or vacuum. In the present work, all experiments are performed in the air.

The density of the samples was determined by the hydrostatic weighing method.

The microhardness of the samples was measured by the Vickers method using a HVS-1000 microhardnesser with an automatic loading of the indenter.

As the starting material the powder with composition of 95W-3Ni-2Cu was selected. The composition of the powder is given in Table 1. Average particle size of heavy tungsten alloy powder was determined by using a laser particle size analyzer. The average particle size was equal 6,03 μm. Figure 3 shows the results of the measurements. Powder density measured by a pycnometer was equal 18.4 g/cm^3.

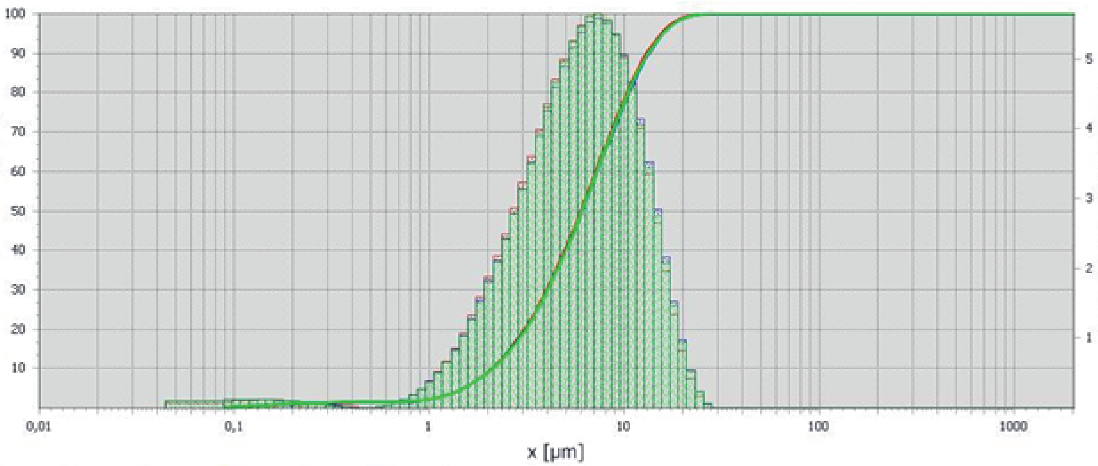

Figure 3: Powder particle size distribution.

Table 1: Data on the source alloy powder W-Ni-Cu.

A method for producing a powder		Mechanical mixing of metal powders W, Ni, Cu
Bulk density, g/cm^3		3,92
Composition, wt. %	W	other
	Ni	3,12
	Cu	2,21

3. RESULTS AND DISCUSSION

3.1. Macroscopic modeling of the EDC process

The mathematical calculation is performed by connecting the Joule Heating and Thermal Expansion multipath module, which includes the following sections:

The Electric Currents module calculates the distribution of the electric field, current and potential in conducting media. Electric Currents solves the equation of current conservation, based on Ohm's law, using the scalar electric potential as a dependent variable.

$$J = -\frac{\partial \rho}{\partial t} \tag{1}$$

$$\vec{E} = -\nabla U \tag{2}$$

where J – the electric current density, ρ – the bulk density of the external electric charge, U – the electric potential difference, and E – the electric field strength.

The Solid Mechanics module is needed for general structural analysis of 3D, 2D or axisymmetric bodies. The Solid Mechanics interface is based on the solution of the Navier equations, and results such as displacements, stresses and deformations are calculated.

The interface "Heat transfer in solids" provides functions for modeling the heat transfer by conductivity, convection and radiation.

As the object of modeling, a tungsten powder was placed in an alumina matrix. The non-stationary problem of passing an electric pulse through a powder was considered. The powder was modeled using the Poroelasticity module, in which the backfill was considered as a material with predetermined values of porosity and electrical conductivity. The heat transfer is set from all surfaces according to the law

$$q_0 = h(T_{\text{ext}} - T) \tag{3}$$

where h – the heat transfer coefficient.

The results of calculations showed that the passage of a damped sinusoidal signal with a period of 200 μs leads to a heating of the powder to 1300 °C. Figure 4 shows the dependence of the temperature averaged over the volume on the sample.

The temperature distribution at the end of the pulse is uneven, as shown in Fig.5. This result can be explained by the fact that the process takes place in powder, and, moreover, is extremely fast. For a more accurate calculation it is necessary to apply micro modeling.

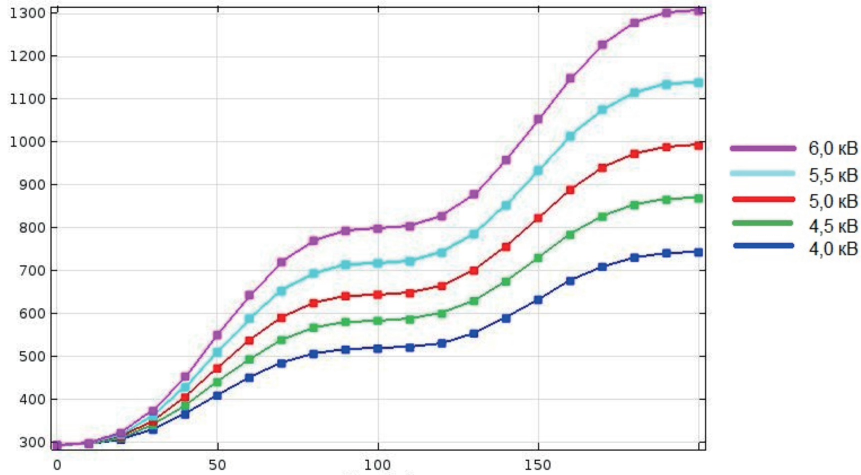

Figure 4: The time dependence of the sample's temperature at different voltages on the capacitors.

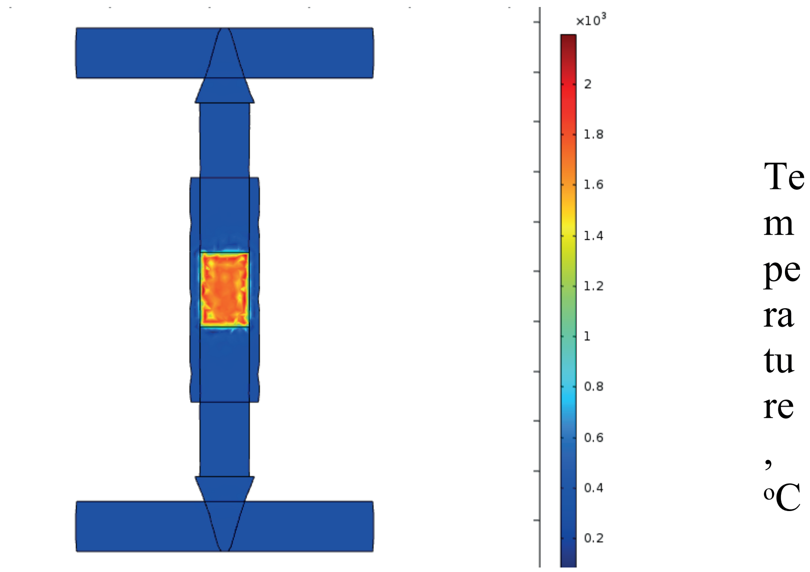

Figure 5: Thermal distribution in the sample at time T = 200 μs.

The calculated data are consistent with the experiments. The comparison shows that when a voltage of over 6 kV is applied, melting and extrusion of the iron-nickel binder from the sample are observed. Thus, it can be judged that the data obtained during the calculation are correct.

3.2. Experimental results

High-voltage electro-discharge compaction was carried out on a 95W-3Ni-2Cu powder. Subsequent processing included grinding and polishing. Appearance and microstructure of the samples are shown in Figures 6 and 7, respectively.

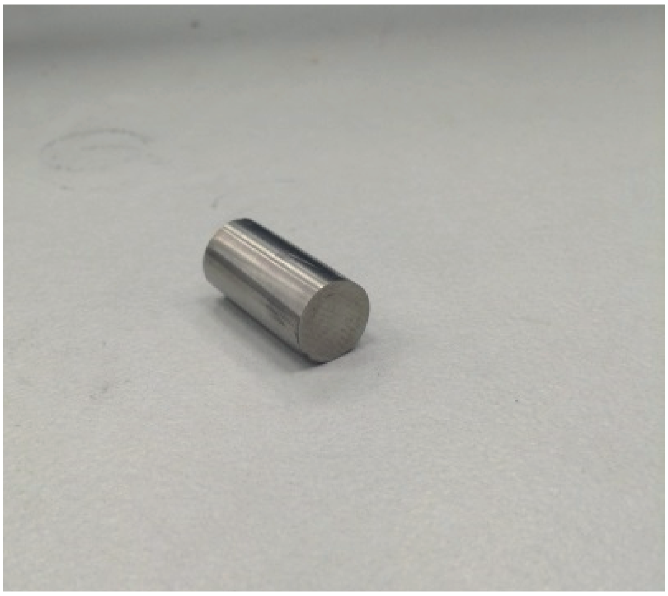

Figure 6: Appearance of the sintered W-Ni-Cu sample.

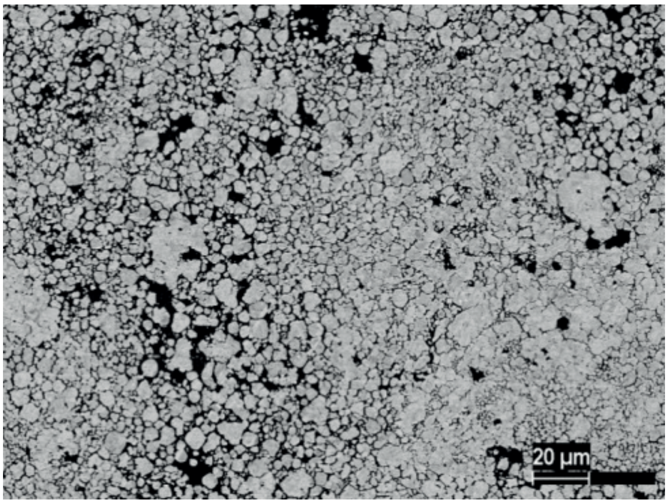

Figure 7: Microstructure of a W-Ni-Cu sample obtained in a scanning electron microscope.

The short duration of the pulse at the HVEDC provides a high rate of consolidation of the powder material, which makes it possible to do it in most cases in the air without using a protective atmosphere or vacuum. In this way, electro-discharge compaction advantageously differs from other consolidation methods using low-voltage current pulses, where, due to the relatively long duration of the heating process, oxidation of the sealable material can occur. The high consolidation rate with HVEDC also allows the properties and composition of the starting powder to be fixed in the product. Data on the density and microhardness are shown in the Table 2 and figures 8 and 9.

Compression tests were carried out. The strain curves are shown in Figure 10.

Table 2: Data on the density and microhardness.

Sample number	1	2	3	4	5
U, kV	5,0	5,2	5,4	5,6	5,8
ρ_{sample}, g/cm^3	17,003	17,178	17,499	17,769	17,794
ρ_{theory}, g/cm^3	18,40	18,40	18,40	18,40	18,40
$\rho_{relative}$, %	92,4	93,4	95,1	96,6	96,7
$HV_{0,1}$	303,92	393,84	425,46	449,74	470,12

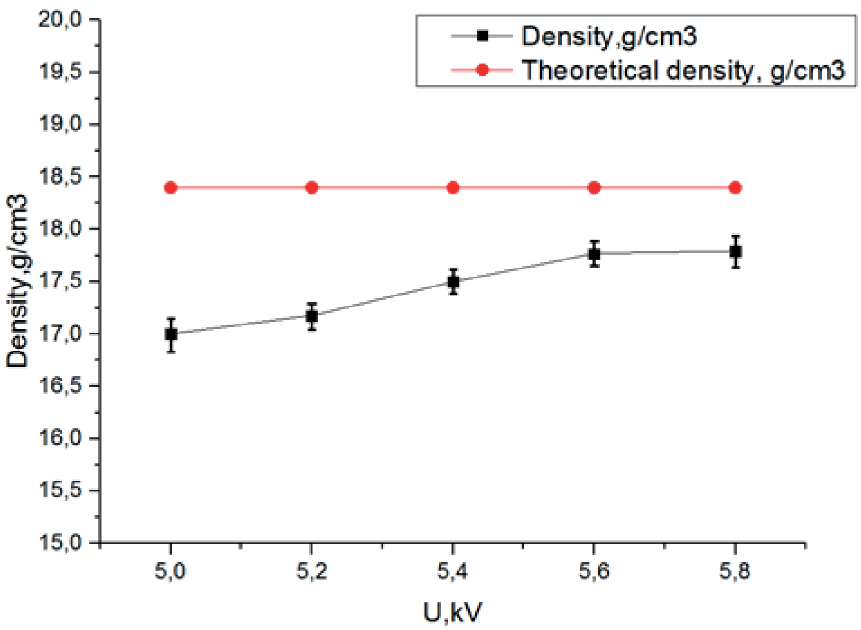

Figure 8: Density of samples at different current pulses.

Compression tests showed deformation in the axial direction, which indicated the presence of plastic flow and the absence of brittle failure at stresses above 1600 MPa. Thus, it can be concluded that it is possible to improve the strength characteristics of materials based on tungsten by high-voltage electro-discharge consolidation.

4. CONCLUSIONS

The process of high-voltage electro-discharge consolidation of powders of heavy tungsten alloys of W-Ni-Cu and the mechanical properties of the obtained alloys (density, microhardness, strength and plasticity) were studied experimentally and using the computer simulation method. Based on the results of the experiments and their analysis, the following conclusions can be drawn:

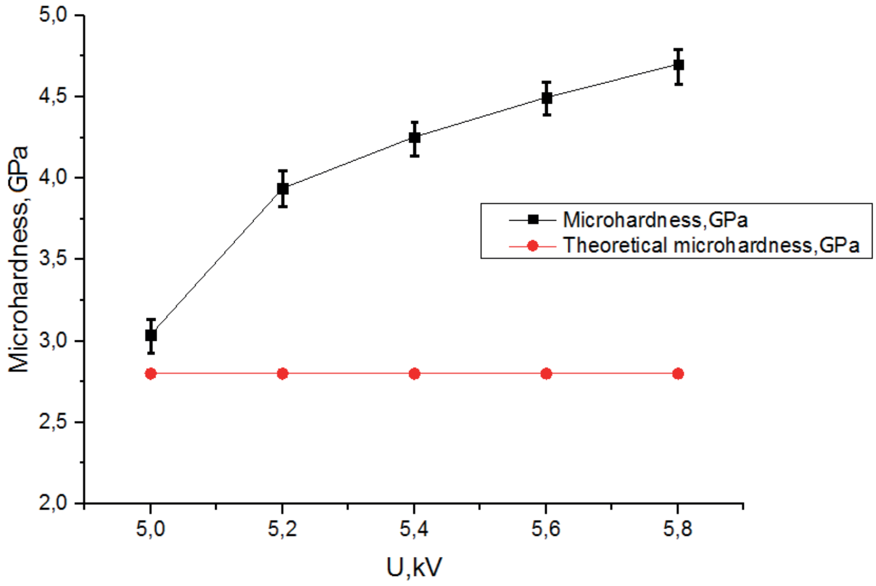

Figure 9: Microhardness of samples at different current pulses.

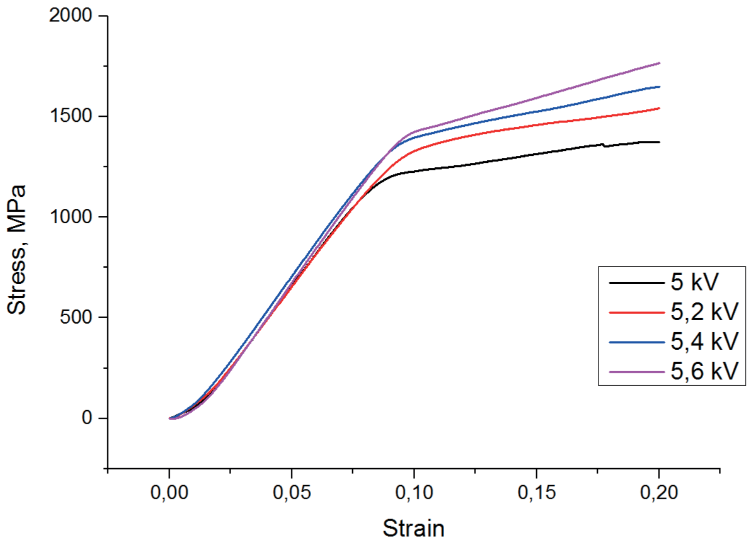

Figure 10: Deformation curves for different modes of the consolidation.

1. The computer simulation method in Comsol Multiphysics establishes a range of optimum temperature values in the process of high-voltage electropulse consolidation of heavy alloy.

2. During the calculation, the non-uniform nature of the temperature distribution was revealed, the average temperature in the interior of the sample was calculated. It was found that when a high-voltage pulse with a voltage of more than

6.0 kV is applied, the temperature in the sample exceeds 1500 °C and leads to the melting of the binder, which is confirmed by the observation of the oblong on the surface of the sample during the experiments.

3. Optimum parameters of high-volumetric electropulse sintering have been revealed, which make it possible to achieve a density of up to 96% of the theoretical density. For the investigated alloys, the value of the applied voltage should be in the range from 5.4 to 5.6 kV with an applied pressure of 200 MPa.

ACKNOWLEDGMENT

The research was carried out within the state assignment of the Ministry of Education and Science of the Russian Federation (project No. 11.1957.2017/4.6).

References

[1] Grigoryev, E. G. & Rosliakov A.V. (2007). Electro discharge compaction of WC-Co and W-Ni-Fe-Co composite materials. Journal of Materials Processing Technology, Vol. 191, No. 1-3, (August 2007), pp. 182-184

[2] Orru R., Licheri R., Locci A. M., Cincotti A., Cao G. Consolidation/ synthesis of materials by electric current activated/assisted sintering // Materials Science and Engineeringc R. 2009. Vol. № 63. C. 127–287.

[3] Maizza G., Tassinari A. Modelling of micro/macro densification phenomena of Cu powder during capacitor discharge sintering // The proceedings of the COMSOL conference. 2009.

[4] Grigoryev E.G., Olevsky E.A. Thermal processes during high voltage electric discharge consolidation of powder materials // Scripta Materialia. 2012.

[5] Williams D.J., Johnson W. Neck formation and growth in higthvolage discharge forming of metal powders //Powder metallurgy. 1982. Vol. № 25. C. 85–89.