Enchasing the mechanical properties of heavy pseudo-alloys of tungsten by high-voltage electric pulse impact

N S Ermakova, S S Bashlykov, E G Grigoriev and V I Golstev
National Research Nuclear University MEPhI, Kashirskoe shosse 31, Moscow, 115409,Russia
E-mail: natalia_ermakova2503@mail.ru

Abstract. The article presents a study of the effect of the high-voltage electric pulse modes of impact under pressure on the structural and mechanical properties of compacts of heavy tungsten alloy VNZh 7-3. Identified an increase in density of material, in microhardness and tensile strength with voltage increase in high-voltage discharge. The optimum exposure mode determinate, which provides the highest level of strength and ductility of the sintered material.

1. Introduction
Tungsten alloy VNZh 7-3 (90W-7Ni-3Fe) is 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 [1, 2]. The aim of this study was to investigate the possibility of the high-voltage sintering of tungsten-based powders and subsequent achievement of high mechanical properties of heavy pseudo-alloys of tungsten.

The principle of high-voltage electric pulse consolidation (HVEPC) is passing of a high-voltage discharge passage (30 kW) with a high current density (≈100 kA·m⁻²) and short pulse duration (less than 300 µs). This current pulse is obtained by a capacitor bank and passed through a powder filling during the application of external pressure. The rapid increase in temperature at the areas of contact of the powder particles leads to their instantaneous welding. Due to the short sintering time, complete or substantially complete sealing occurs with minimal changes of the microstructure that are undesirable.

As the starting material the powder with composition of 90W-7Ni-3Fe was selected. Average particle size of heavy tungsten alloy VNZh powder was determined by using a laser particle size analyzer. The average particle size was equal 6.03 µm. Figure 1 shows the results of the measurements. Powder density measured with a pycnometer was equal 17.13 g / sm³.
2. Method of study of structural and mechanical properties of the compacts of heavy tungsten alloy VNZh 7-3 (90W-7Ni-3Fe)

High-voltage electric discharge sintering was conducted in a ceramic matrix with diameter 8 mm for the first batch of samples with cylindrical shape and 10 mm for the second batch of samples with disk shape. The pressure applied to the filling in all the experiments was equal to 45 MPa, the number of pulses was equal to 1. The value of the applied voltage varied from 4.5 kV to 5.8 kV.

After sintering of the powders the microstructure of compacts was studied in a scanning electron microscope, the density was assessed by hydrostatic weighing, and micro-hardness by the Vickers hardness test. Compression testing of cylindrical samples was carried out in accordance with GOST 25.503 standard. The ultimate tensile strength of the material was determined by tensile compression in the center plane of the disk samples by the Brazilian test method [3, 4]. This method applies for assessment of the tensile strength of brittle rock materials. Substantiation of application of this test method to small-sized samples of metallic materials has been provided in the study [5].

3. Experimental results

The first batch of samples was produced in the cylindrical shape with a height to diameter ratio h/d≈3/2. The dependences of density and microhardness of the samples on the charge values are shown in Figures 2 and 3.

![Figure 1. The powder particle size distribution](image1)

![Figure 2. Influence of sintering mode on the density of cylindrical samples](image2)

![Figure 3. Influence of sintering mode on the microhardness of cylindrical samples](image3)
As can be seen from the graphs, the value of the relative density of the sintered compacts is in the same range of values and amounts to 94.9% to 95.9% of theoretical. The microhardness of samples increases with increase of applied voltage.

Compression testing showed that all tested alloys bear compressive stress at room temperature without failure. Figure 4 shows a characteristic diagram of the compressive deformation, which indicates the appearance and development of plastic deformation at the voltage above 1250 MPa. Due to the brittleness of tungsten as a BCC metal, increasing the plasticity of the heavy tungsten alloy is one of the objectives of the current research. Microstructure of the sample obtained by a scanning electron microscope is shown in Fig. 5. The average grain size is approximately 10 microns, i.e. high-voltage sintering contributes to maintaining a fine-grained structure, more uniform distribution of iron-nickel binder and almost total absence of porosity.

![Figure 4. Deformation curve (the voltage equals 5.6 kV)](image1)

![Figure 5. Microstructure of the sample obtained by SEM.](image2)

The second batch of samples had a disk shape with a diameter of 10 mm and a thickness of 4.5 to 5.8 mm. Figures 6 and 7 shows the dependences of density and microhardness on the value of pulse voltage. With the increase of the applied voltage an increase in density and microhardness of compacts is observed. The highest values of both characteristics are achieved at the maximum value of discharge 5.8 kV, although stabilized density values obtained at 5.6 kV. Further increase in the microhardness by increasing discharge voltage obviously impractical because it will lead to embrittlement of the material.

![Figure 6. Influence of sintering mode on sample density](image3)

![Figure 7. Influence of sintering mode on sample microhardness](image4)
Disk compression testing in the center plane by the Brazilian test method was designed to evaluate the tensile resistance of the material under the action of tensile stress and at the same time to identify the plasticity of the material. Figure 8 shows the dependence of the tensile strength of the material on the level of the pulse voltage.

![Graph showing tensile strength vs voltage](image)

**Figure 8.** Dependency of the tensile strength on the applied voltage

The graph shows an increase of tensile strength of samples at the increasing voltage up a value of 5.4 kV with a subsequent recession. The increase and decrease in strength occurred during the development of plastic deformations, which preceded the brittle failure of the samples. A number of samples did not experience failure due to a developed plastic flow that can be seen clearly in Fig. 9b. The maximum value of the sample strength was at voltage of 5.4 kV.

4. Conclusions
The studies of compacts obtained from a powder of heavy tungsten alloy VNZh 7-3 (90W-7Ni-3Fe) by the method of high-voltage pulse discharge, revealed the optimum pulse voltage value that results in high structural properties and characteristics of strength and ductility of the material.

References
[1] Povarova K B, Alymov M I and Drozdov A A 2008 Heavy tungsten alloys Heavy tungsten alloys produced from nanopowders Voprosy Materialovedeniya [Problems of Materials Science] 2 (54) 94-99
[2] Afanaseva S A, Belov N N, Biryukov I A et al 2012 Impact properties of tungsten-based alloys at high-speed interaction Russian Physics Journal 55 (11) 35-40
[3] ASTM D3967-95a. Standard Test Method for Splitting Tensile Strength of Intact Rock Core Specimens
[4] Wang Q Z, Jiaa X M, Koub S Q, Zhangh Z X, Lindgvistg P A. 2004 The flattened Brazilian disc specimen used for testing elastic modulus, tensile strength and fracture toughness of brittle rocks analytical and numerical results. Int. J. of Rock Mechanics and Mining Sciences 41 (2) 245-253
[5] Golstev V I, Grigoriev, Osintsev A V, Plotnikov A S, Ermakova N S, Gribov N Testing of small-sized samples with the Brazilian test for assessment of brittle strength of metallic materials IOP: Conference Series (Current issue)