# EXPERIMENTAL VERIFICATION OF MECHANICAL PROPERTIES OF THUNGSTEN HEAVY ALLOYS AFTER HOT ROTARY SWAGING AND ANNEALING

[1]Ludmila KRÁTKÁ

*[1]VSB - Technical University of Ostrava, Ostrava, Czech Republic, EU,*
*ludmila.kratka@vsb.cz*

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**Abstract**

This study deals with the experimental processing of a tungsten heavy alloy prepared by powder metallurgy using the technology of rotary swaging. Rotary swaging took place at a temperature of 900 ° C. After processing by rotary swaging, the material was further subjected to annealing. Emphasis was placed on the mechanical properties of the material before processing, after processing and after annealing. In the study we also deal with the influence of forming and annealing on the structural arrangement of tungsten heavy alloy.

**Keywords:** Rotary swaging, tungsten heavy alloy, mechanical properties

## 1. INTRODUCTION

Tungsten heavy alloys (THA), in our case W-Ni-Fe, are exceptional in their physical and mechanical properties, such as high density (17-19 g / cm$^3$) or high strength (maximum strength up to 1900 MPa). THAs are used primarily as a protection against harmful radiation or to block kinetic energy. The advantageous use of tungsten heavy alloys is, for example, as shielding in the manufacture of therapeutic devices in oncology, counterweights in aeronautics or for the manufacture of kinetic penetrators used by the military [1-4].

In the vast majority of cases THA is produced using powder metallurgy. The powders are isostatically pressed into the required shape, usually in the form of rods. The rods are then sintered in a protective atmosphere ($H_2$, $Ar_2$, vacuum), in the temperature range of 1000-1500 °C. Other alloying elements with a lower melting point (Ni, Co, Mo, Re) are also added to the powder mixture with a tungsten content above 90% by weight, which forms a matrix around the tungsten grains when sintered by melting the grain boundaries, thus forming a homogeneous material. Alloying elements in THA ensure the plasticity of the material, a negative effect is a reduction in strength. For optimal strength and plastic properties, we can use a change in chemical composition or improvement of properties through plastic deformation [5-9].

Suitable technologies are processes that are continuous, such as ECAP-conform [10] or rotary swaging (RS). These processes run continuously and are therefore suitable for series production. Due to its versatility, the rotary swaging technology is suitable for various branches of industry. RS is characterized by high-frequency blows of swaging dies that rotate around the blank. This process can be carried out both cold and hot to produce solid semi-finished products or to produce hollow or shaped parts. RS is a suitable technology for processing difficult-to-process materials (Ti, THA) and composites (Al / Cu) [1,11-15].

The aim of this work is to investigate the material behavior of the studied tungsten heavy alloy during hot rotary swaging and to compare the effects of rotary swaging and subsequent annealing on the structure and mechanical properties of clinkers.

## 2. MATERIAL AND EXPERIMENTAL METHOD

A selected pseudo alloy 90W7Ni3Fe with a chemical composition of 90 wt.% W, 7 wt.% Ni, 3 wt.% Co (determined by SEM-EDX analysis) was prepared from powders with a mean grain size of 2.78 μm, containing ~ <13 ppm Mo, Cr, Al, Ca and other impurities. This process is characterized by mixing the powders followed by cold isostatic pressing at 400 MPa and sintering at 1525 °C for 20 minutes under a protective atmosphere followed by controlled cooling in an oven and final cooling in water. The protective atmosphere during sintering is hydrogen and during cooling argon. This preparation procedure was performed in ÚJP Praha a.s.

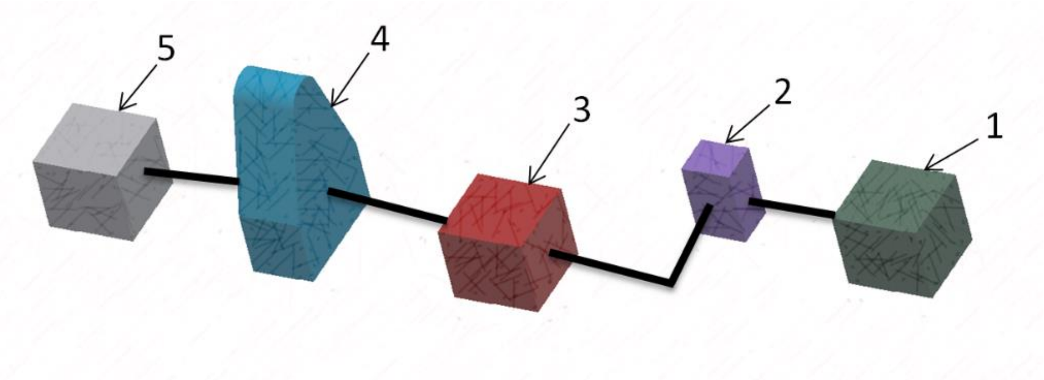


**Figure 1** Scheme of a laboratory semi-automated line; 1 Tungsten clinker dispenser; 2 Robotic stacker; 3 Induction heating; 4 Swaging machine; 5 Container of finished pieces

The sintered pieces were then processed in an experimental semi-automated line (**Figure 1**) by rotary swaging, the initial temperature being 900 °C. The forming temperature was selected on the basis of our previous experimental studies [3,4]. Our previous studies have shown that treatment at temperatures above 900 °C has led to massive oxidation causing rapid embrittlement during WNiFe treatment. The initial diameter of the sintered pieces was 30 mm, the length was 100 mm. Both were gradually reduced in three successive steps to a final diameter of 17.5 mm. The samples were then annealed at 1230 °C for 15 min and then cooled. The following structural analyses were performed on cross-sectional sections of formed pieces with a focus on the development of a (sub) structure. Observations were made by scanning electron microscopy (SEM EBSD analysis). The samples were sanded on SiC sandpapers and subsequently polished with Eposil F (Saphir 520, ATM, Germany). EBSD analyses were performed in the subsurface sample area, 1 mm from the outer edge of the observed rod, using a Tescan Lyra 3 device (TESCAN Brno sro, Brno, CZ) with a NordlysNano EBSD detector (Oxford Instruments, Abingdon-on-Thames, UK). Scanning was evaluated using ATEX software (Win10 version) [16]. The tensile tests determined the strength values of the material.

## 3. RESULTS

### 3.1. Structural analysis

**Figure 2** shows a tungsten pseudo-alloy after sintering. Well-defined tungsten grains are surrounded by softer matrices. During sintering, the tungsten grains assume a spherical shape, these tungsten grains are surrounded the NiFe matrix during sintering to form a homogeneous material that is suitable for further processing. In **Figure 3** the structural states after the processing by the rotary swaging technology are shown. We can see In **Figure 3** a) the NiFe matrix is significantly deformed in the surface area and hard tungsten grains are deformed at the same time. In **Figure 3** b) we can observe the same phenomenon of significant deformation of the matrix. Tungsten grains deform in this region only in the region of elastic deformations. This phenomenon is caused by the typical distribution of the inserted deformation along the cross section, which is characteristic for this technology.

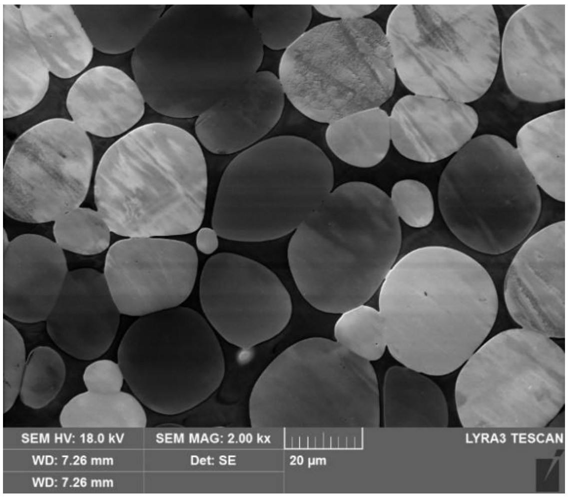


**Figure 2** Structural state after sintering

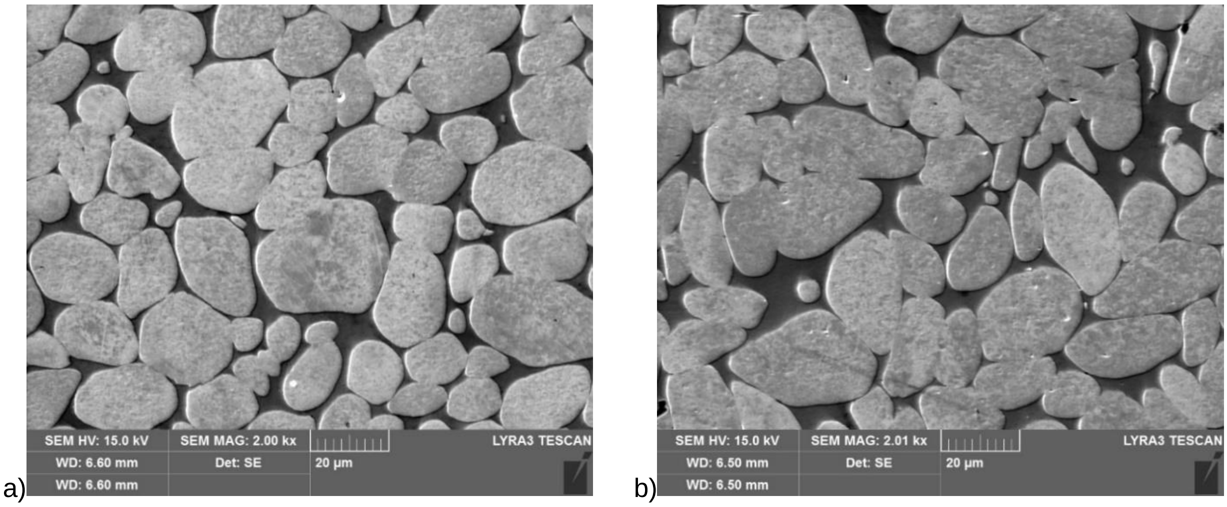


**Figure 3** Structural state after swaging a) surface, b) centre

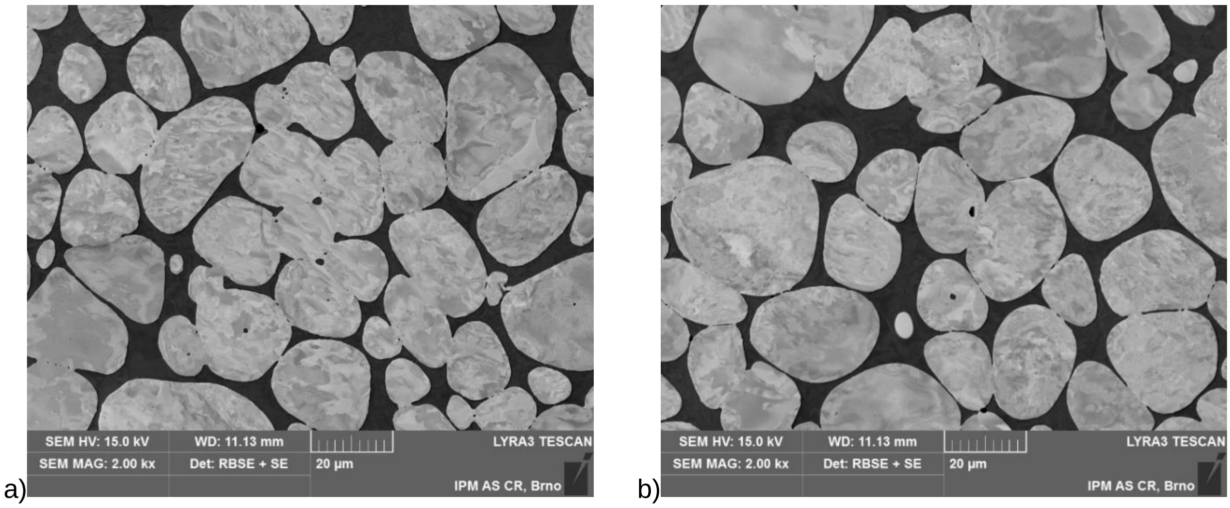


**Figure 4** Structural state after swaging and subsequent annealing a) surface, b) centre

The structure is shown after swaging and subsequent annealing In **Figure 4** a), from the structure it is evident that it is very close to the state after sintering. During rotary swaging, there is a very significant deformation of the matrices in the surface layers and a large approximation of the tungsten grains, which in some cases join together during annealing to form groups of agglomerates. In **Figure 4** b) the structure in the central area is shown. This structure is almost identical to the structure after sintering.

### 3.2. Mechanical properties

**Table 1** Mechanical properties of WNiFe

| **Sample** | **Ultimate tensile strength** [MPa] |
|---|---|
| After sintering | 1210±10 |
| After rotary swaging | 1785 ±10 |
| After swaging and annealing | 1220±10 |

**Table 1** implies from measured strengths that the mechanical properties are greatly improved during forming. The value of the strength of the sample after swaging and subsequent annealing shows that the sample has returned to its original state, i.e. to the value of the strength after sintering. This phenomenon is a plus if we continue to reduce to smaller diameters.

## 4. CONCLUSION

The paper describes real experimental forging of clinkers prepared by powder metallurgy and further processed by the process of hot rotary swaging. For the realization of rotary swaging, it was necessary to preheat the tungsten clinker to a temperature of 900 °C. For these purposes induction heating was used. This was followed by the processing of clinkers to a diameter of 17.5 mm. The strength of these clinkers was measured to ≈1785 MPa. After swaging, the clinkers were annealed and their strength returned to ≈1220 MPa.

The structural analyses show that both monitored states differ mainly in the distribution of tungsten grains. Compared to the structure after sintering, in swaged clinkers the tungsten grains in the NiFe matrix are still clearly defined, while in the case of annealed pieces it is evident that during annealing in surface areas the individual grains melt and join into irregular agglomerates of tungsten grains in the NiFe matrix.

The comparison of strength analyses shows that rotary swaging is a very advantageous technology for processing THA clinkers prepared by powder metallurgy. The results show that the strength of the material increased by approximately 500 MPa. Subsequent annealing has confirmed the assumption that the material returns to its original state and is thus suitable for further processing by rotary swaging to smaller diameters.

## ACKNOWLEDGEMENTS

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