# EFFECT OF COLD SWAGING ON MECHANICAL PROPERTIES AND STRUCTURAL CHARACTERISTIC OF TUNGSTEN-BASED ALLOY

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**Abstract**

The aim of this paper was to verify changes in mechanical properties and structural characteristic of the 91W6Ni3Co powders mixture after cold swaging, before which the initial powders were pressed using cold isostatic pressing (CIP) and pre-sintered. Swaging was carried out at room temperature in one pass from the initial diameter of 30 mm to the final diameter of 25 mm. The investigation of the sample after pre-sintering and subsequent swaging was performed by microscopic and microhardness analyses, as well as by tensile testing. The results have shown the elongation of tungsten grains to increase with strain. The strength of the material after swaging was more than double comparing to the original state.

**Keywords**: Cold swaging, tungsten, microhardness, microstructure, powders

## 1. INTRODUCTION

Tungsten is a body-centred cubic lattice metal with high chemical resistance, extremely high density and a high melting point 3420 °C [1]. Nickel belongs to the transition metals, is hard and ductile. Pure nickel is highly reactive especially when powdered to maximize the exposed surface area, on which reactions can occur. However, larger pieces of the metal are slow to react at ambient conditions due to the formation of a protective surface oxide [2].

Considering processing of tungsten-based alloys, the W-Ni-Co ternary system featuring the strength up to 1700 MPa and alloys with Ni, Fe, Cu and Co matrix are the most commonly used [3, 4]. Considering the application, W-Ni-Cu and W-Ni-Fe ternary systems can for example be used as shielding materials and γ-ray apparatus for medical and industrial use.

W-based alloys are typically formed as composites from W-based powder mixtures. The matrix of such an alloy typically consists of metals with lower melting temperatures and ensures the binding function. The alloys usually contain 90 to 98 wt. % of tungsten. However, content of the melted phase below 3 % reduces ductility and toughness and the ability to eliminate pores [5, 6].

W-based alloys due to high density, high strength, extremely high melting point of tungsten, good corrosion resistance and easy machinability can be applied areas of aerospace, motorsport ballast and balancing components as well as can be used for dies and casting equipment and high-temperature tooling applications [7, 8, 9, 10].

Rotary swaging is a forging process, during which the cross-section of a sample is gradually reduced and the length increases by the influence of, typically four, swaging dies [11]. Due to the incremental character of swaging, large overall shear strains are imposed to the processed materials and the deformation mechanism within swaging can thus be considered similar to processes of severe plastic deformation. It is used to produce tubes, rods or wires, with or without shapes, under cold and hot conditions. The technology of rotary swaging is widely used e.g. in automotive industry or electrotechnics, because of the variety of swaged materials and their combinations and a wide range of internal and external shapes of the products [12]. For example, by application of swaged components, when compared to conventionally produced workpieces, reduction in weight and thus in fuel consumption and emissions, which are at present the primary requirements in the automotive industry, can be achieved.

The paper focuses on changes in mechanical properties and structural characteristic of the 91W6Ni3Co powder-mixture-based pre-sintered alloy after cold swaging. The investigation of the sample after both, pre-sintering and subsequent swaging, was performed by microscopic and microhardness analyses, as well as by tensile testing.

## 2. EXPERIMENT

The selected material was a 91W6Ni3Co rod pre-sintered from powder particles. The initial powders were pressed using cold isostatic pressing (CIP) and pre-sintered at 1540 °C for 20 h. The preparation procedures as well as powder processing were performed by UJP Praha, a.s. Then, swaging was carried out at room temperature in one pass from the initial diameter of 30 mm to the final diameter of 25 mm. The pre-sintered and successfully swaged rods are shown in **Figures 1 a)** and **1 b)**.

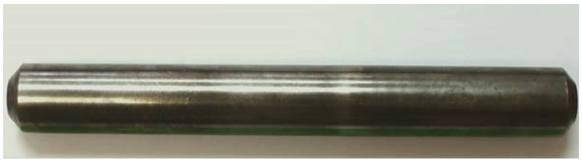
*a)*  *b)* 

**Figure 1** W-based alloy rod (a) before cold swaging; (b) after cold swaging

Samples of the rod after both the procedures, pre-sintering and subsequent swaging were subjected to analyses of chemical composition, microstructure, microhardness and tensile properties. These analyses allowed study changes in mechanical properties and structural characteristics of the material caused by swaging. The microhardness HV was measured for both with the indent load of 100 g for 15 seconds, the W particles and matrix, within the pre-sintered and swaged samples, the average values were calculated from 10 values measured along the cross-section of the samples (from centre to surface). Similarly, the tensile properties were measured before and after swaging. In order to determine differences in the strengths along the cross-section of the swaged sample, another tensile test was performed for two samples, one taken from the center and the other from sub-surface area of the swaged rod. All the analyses were performed at the Technical University of Ostrava within the Regional Materials and Technological Science Centre.

## 3. RESULTS AND DISCUSSION

### 3.1. Chemical composition

According to the results of Energy Dispersive Spectroscopy (EDS) analyses performed to verify the chemical compositions of W-grains, matrix, and the overall alloy, the sintered rod contained (overall) 92.62 wt.% of tungsten, 4.98 wt.% of nickel and 2.40 wt.% of cobalt. The rod had particles and a matrix, which can clearly be seen in **Figure 2 a)**, in which the numbers 1 and 2 denote the locations of EDS scanning for the particles and the matrix, respectively. The particles contained 100 wt.% of tungsten and the matrix contained 43.11 wt.% of tungsten, 37.97 wt.% of nickel and 18.92 wt.% of cobalt. **Figure 2 b)** shows an example of the graphical result of the EDS analysis of chemical composition performed for the entire material.

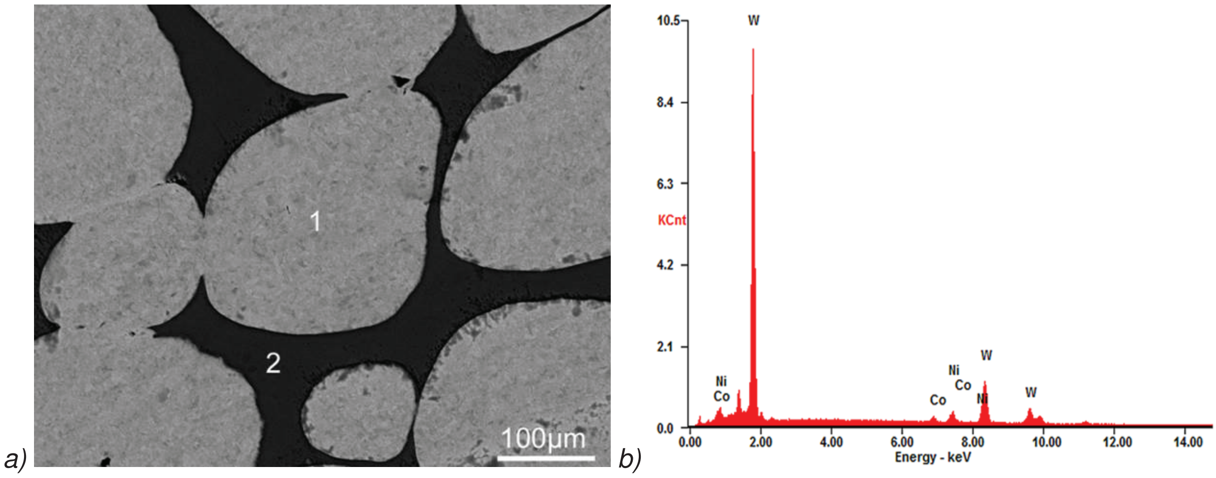



**Figure 2** (a) SEM scan of the pre-sintered material; (b) example of EDS analysis result

### 3.2. Microstructure

Microstructures of the sintered and swaged samples are shown in **Figures 3a)** and **3b)**, in which powder particles are clearly shown. Observations of microstructure were performed in order to investigate differences after both, pre-sintered and subsequent swaging. In the microstructure of the rod after swaging, particles elongated by the influence of swaging can clearly be seen. Due to the arrangement of dies during swaging, the strain is imposed to the swaged rod from surface towards centre. Therefore, the highest deformation occurs on the surface of the rod and the effect of swaging is higher on the surface than in the centre. Due to this fact, the microstructure was observed on the surface of the rod. In **Figures 3a)** and **3b)** can clearly be seen that before swaging tungsten particles were more or less equiaxed, while after swaging the grain elongated. A similar microstructure featuring elongated tungsten particles after swaging for a W-based alloy was reported e.g. by Durlu et al. [13].

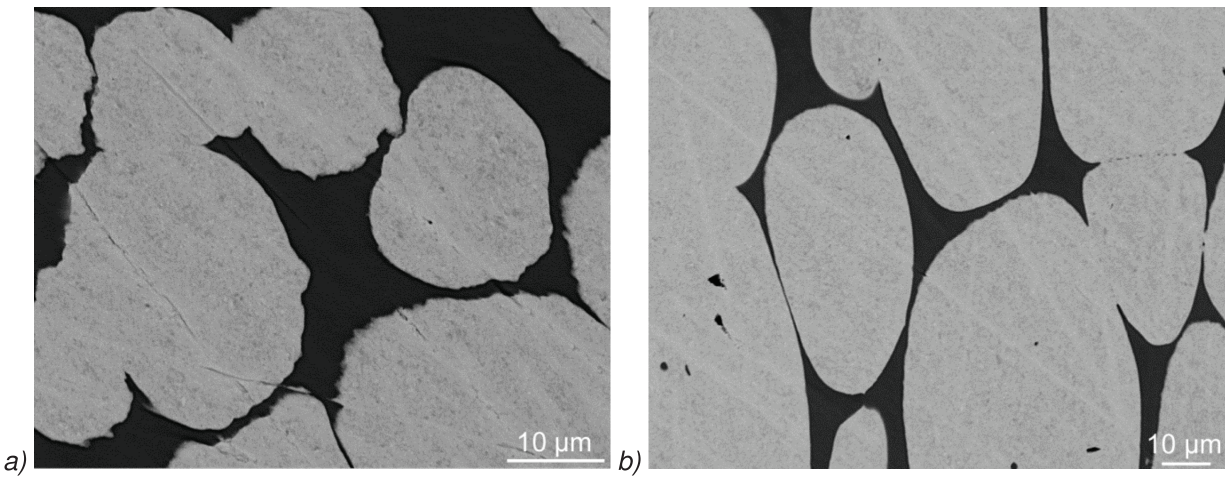



**Figure 3** Microstructures of the rod (a) before and (b) after swaging

### 3.3. Microhardness

The measurements of microhardness showed an increased microhardness for the swaged sample when compared to the pre-sintered one. From the results can be seen that microhardness of the swaged W grains and matrix was higher than of the pre-sintered W grains and matrix. Thus, the microhardness for the swaged sample was 609 HV for the W grains and 505 HV for the matrix, whereas before swaging the microhardness of the sample was 389 HV for the W grains and 297 for the matrix. The results are shown in **Table 1**.

The effect of swaging on microhardness of sintered W alloys was studied also by others. For example, Yu et al. [14] achieved the microhardness of 485 HV for the W grains and 375 HV for the matrix for the 93W-4.9(Ni, Co)-2.1 Fe alloy. However, the microhardness of the sintered sample was 476 HV for the W grains and 360 HV for the matrix. Yu et al. did the experiment with hot swaging. During hot swaging recrystallization can occur, but during cold swaging of W there is no recrystallization, maximum recovery. Therefore, the increase in the microhardness in our cold swaging experiment was higher than reported by Yu et al. for their hot swaging experiment. The substantial increase in the values proves the shear strain to significantly affect the grains, which is similar to the laboratory severe plastic deformation testing [15]. However, rotary swaging can easily be applied practically.

**Table 1** Microhardness values $HV_{0.1}$ for the pre-sintered and swaged W grain and matrix

| | **grain W** | **matrix** |
|---|---|---|
| sintered | 389 ± 9 | 297 ± 9 |
| swaged | 609 ± 9 | 505 ± 11 |

### 3.4. Tensile test

Comparison of the stress-strain curves for the pre-sintered and swaged samples can be observed in **Figure 4**, which clearly shows very significant strengthening due to deformation hardening for the swaged sample. The strength of the rod before deformation was about 860 MPa, while after deformation it reached 1680 MPa, which was almost twice as high. However, plastic properties rapidly decreased.

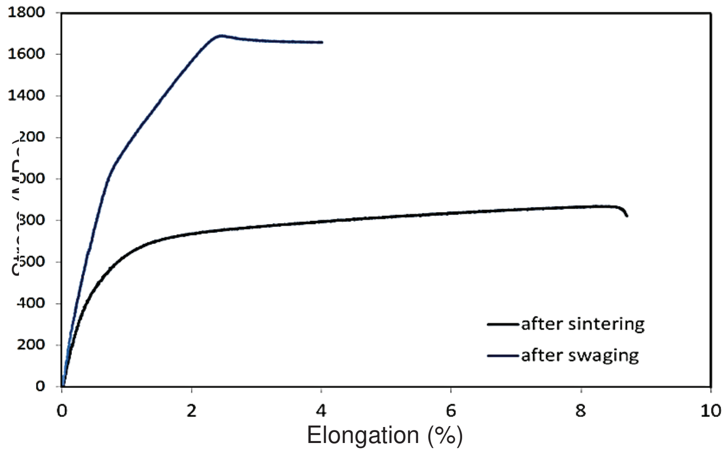



**Figure 4** Stress-strain curves for W91-Ni6-Co3 before and after deformation

When compared the central region of the swaged sample to the peripheral one, the surface region had been of a higher strength (1850 MPa) than the central region (1580 MPa). On the other hand, the central region exhibited a larger deformation to fracture (4.5 %) than the sample taken from the surface region (3.5 %). An example of a tensile test specimen after fracture can be seen in **Figure 5**.


**Figure 5** Tensile test sample after fracture

Similar analyses were reported by Yu et al. for sintered and swaged W alloy (93W-4.9(Ni, Co)-2.1 Fe) [14]. The results also showed markedly increased ultimate tensile strength and a decreased ductility. Their samples exhibited the highest ultimate tensile strength of about 1490 MPa. However, Yu et al. performed the experiment under hot conditions. The sample in our experiment was subjected to swaging under cold conditions and thus the increase in strength was more significant. Increase in strength after swaging of W-based alloys was reported also by others (e.g. 13]).

## 4. CONCLUSIONS

This study was focused on cold swaging of W-based pre-sintered rod. The results showed that W particles elongated by the influence of swaging, especially in the surface region where the strain was the highest, since the deformation was imposed from the edges towards the centre of the rod. The microhardness increased after swaging for both, the W grains and matrix. For the swaged sample it was 609 HV for the W grains and 505 HV for the matrix, while before swaging it was 389 HV for the W grains and 297 for the matrix. Tensile tests results showed that the strength of the rod before deformation was about 860 MPa, while after deformation it reached 1680 MPa, which was almost twice as high. However, plastic properties rapidly decreased.

Based on the results can be concluded that the effects of cold swaging on microstructure and mechanical properties of the pre-sintered W alloy were increased tensile strength and microhardness and slightly elongated tungsten grain size in the longitudinal direction with a slight reduction in tungsten grain size in the transverse direction.

## ACKNOWLEDGEMENTS

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