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# TRIBOLOGICAL BEHAVIOUR OF CO-W UNDER DRY AND LUBRICANTING CONDITIONS

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Abstract: The dry and lubricating wear was investigated for steel and Co-W samples in the view of revealing the best performance of tungsten alloys. The tribological behaviour was studied under bi-directional ball-on-flat sliding tests: 10 N and 50 000 cycles. The given research identified that Co-W coatings have superior wear resistance than those of uncoated samples (steel ST3) under dry and also under lubricating conditions. Thus, wear volume of Co-W samples is decreasing two times under dry conditions and ten times under lubricating conditions. The use of new type of solid lubricant (sugar film) is discussed.

Keywords: tribological behaviour, Co-W alloys, electrodeposition, lubricant

## 1. INTRODUCTION

Iron group metals induced electrodeposition with tungsten alloys has increasing impact over the many decades. The papers in this field starting from the early 1930 are continuously growing [1] due to the fact that those alloys possess performant properties as tribological, mechanical, magnetic and electrical ones, that point out them as particularly attractive for substitution of hard chromium coatings in different industrial branches [2]. The replacing embraces processes where lubrication or dry friction conditions take place, for example in hydraulic equipment [2]. Citrate complexes were identified to be suitable for producing tungsten alloys by induced electrodeposition [3], also other types of electrolytes have also been found useful [4-9]. It is possible to obtained nanocrystalline or XRD-amorphous electrodeposits from such electrolytes. The "nanocrystallinity" often is responsible for abovementioned performant properties of tungsten alloys and it depends on the electrodeposition technique used [8], the chemical composition and pH of the electrolyte [10, 11] the current density [12], as well as on the substrate [13]. Thus, mechanical behavior of tungsten alloys depends on the deposit structure, composition as well as the electrodeposition operating conditions. The factors influencing the tribological and mechanical behavior can be categorized into internal and external factors [1]. Internal factors include recrystallisation temperature, crystal structure, grain boundary effects, etc., which significantly influence the shear strength of a material [14]. For nanocrystalline alloys, at least two key aspects contribute to hardening of such alloys: (a) formation of a solid solution (i.e., solid solution hardening), and (b) small average grain size [15]. Decreasing of the grain size from micrometer range down to nanometer range ~ 15 nm, leads to the hardness increase (the Hall-Petch relation is preserved) [16]. But for iron group metals with tungsten alloys this value could be even smaller, thus, in [16] is stated that the reverse of Hall-Petch relation is observed for nickel-tungsten coatings with particles sizes below eight nm. Such values of particles size are smaller than that for pure nickel, thus can be concluded that alloying has prominent effect on shifting the breakdown of Hall-Petch relation. External factors like temperature, humidity, indentation size effect and contact conditions [17] are also attributed to the measured values, hence they should be taken into consideration when evaluating tribological properties, e.g., depending on the electrodeposition conditions impurities as carbon, sulfur or hydrogen can be incorporated into the coating [18] and have an impact on contact conditions during sliding and on hardness values as well. Thus, the comparison of tribological and mechanical properties is sometimes quite complicated. In order to evaluate in the right manner different materials they should be tested under the similar tribological or mechanical

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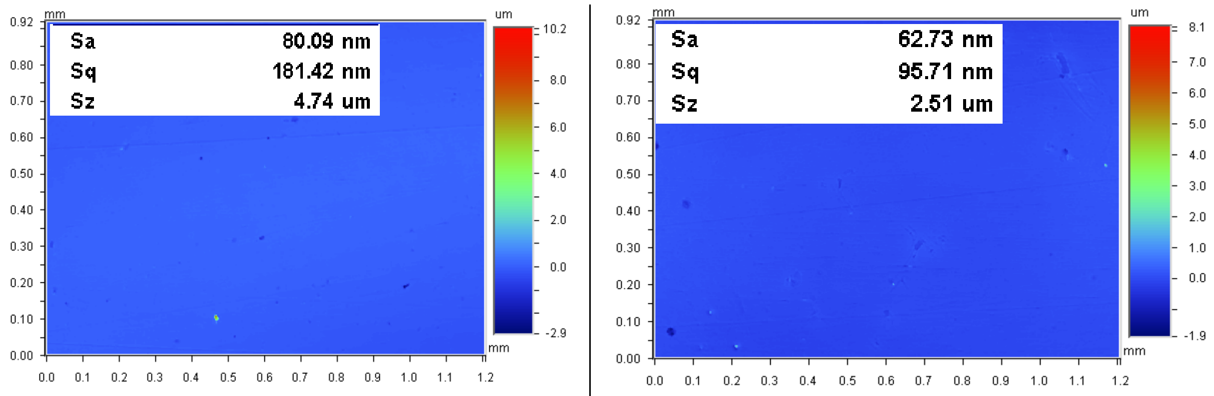
conditions. The aim of this study was to reveal the common trends and differences in testing Co-W alloys under dry and lubricating conditions.

## 2. EXPERIMENTAL

Investigations were carried out on steel ST3 (as reference material) and electrodeposited Co-W alloy (with 30 at. % of tungsten). Co-W coatings were obtained by electrochemical deposition on steel substrate from citrate-borate electrolyte, the details on the methodology can be found in [1]. Steel substrate was mechanically polished with diamond paste to a mirror shine. After that steel was washed in an ultrasonic bath with alcohol and then with acetone. In this way the surface roughness below 100 nm was obtained (Fig. 1). The roughness of deposited cobalt-tungsten coatings had rather small values in order to have strong impact on tribological data. The roughness of electrodeposited coatings was studied by non-contact white light interferometry (WYKO NT 3300). This method was also used to define the wear depth/volume after fretting tests.




| **Steel** | **Co-W** |
|---|---|

**Figure 1.** Non-contact white light interferometry images of surface of steel and as-electrpdeposited cobalt-tungsten coatings.

Study of friction and wear behavior of Co-W electroplated coatings and steel was carried out in dry bi-directional ball-on-flat sliding tests (fretting mode I) [19], and also coated with a thin (3 μm thick) oil and sugar films. The conditions of tests are provided in Table 1. The coated samples were oscillated against a rigidly fixed corundum ball counter-body (elastic modulus 300 GPa) of 10 mm diameter. All tests were performed in ambient air at 23 ± 2 °C and 50 % relative humidity. Prior sliding tests the samples were properly cleaned in ethanol and air-dried. After the sliding tests, the samples were cleaned ultrasonically to remove wear particles before measuring the wear track profiles.

**Table 1.** Wear test conditions.

| Normal load, N | Counter-body moving amplitude, μm | Frequency of reciprocating motion, Hz | Number of cycles |
|---|---|---|---|
| 10 | 200 | 5 | 50 000 |

The oil film thickness was controlled with pipetman by adding corresponding amounts of the oils (10-30 μl) on 1 cm$^2$ of the metallic surfaces or sugar solution. Prior thin films formation on the surface, above-mentioned volumes of the oil has been pre-diluted in diethyl ether with ratio from 1: 1 to 1 10000. Then 10 μl of the oil solution was placed on the warm surface of the samples (40 °C) to evaporate the ether. In order to form sugar film, sugar was dissolved in ethanol, and then corresponding amount (10-50 μl) was placed on the framed working surface of 1 cm$^2$ and waited till ethanol evaporates. The resulting oil/sugar film coverage was analyzed with metallurgic microscope XJL 101.

## 3. RESULTS AND DISCUSSIONS

The evaluation of the steel samples and Co-W coatings were carried out under dry and lubricant conditions using different oils as rapeseed and SAE. The oils were containing 0.1 % of the iron particles. The oil film thickness was chosen in such a way that it significantly exceeds the roughness of the substrate, but not less than 3 μm thickness. Also, the possibility to use Co-W coatings in sugar industry by applying the sugar film on top was estimated. To compare the data with lubricating conditions Fig. 2 a shows the dependence of friction coefficient at dry friction. The friction coefficients on steel and Co-W alloy were not so different from each other and were around 0.48 and 0.43 respectively. Regardless of this fact, the Co-W coatings wear resistance is much higher than in the case of steel samples. Thus, for steel the wear depth was around 4.1 μm and wear volume of $294 \cdot 10^3$ $\mu m^3$, but for Co-W coatings these values were of 1.6 μm and $103 \cdot 10^3$ $\mu m^3$, respectively after 50 000 cycles. This demonstrates that Co-W coatings can be used at dry conditions as good protective coating for steel.

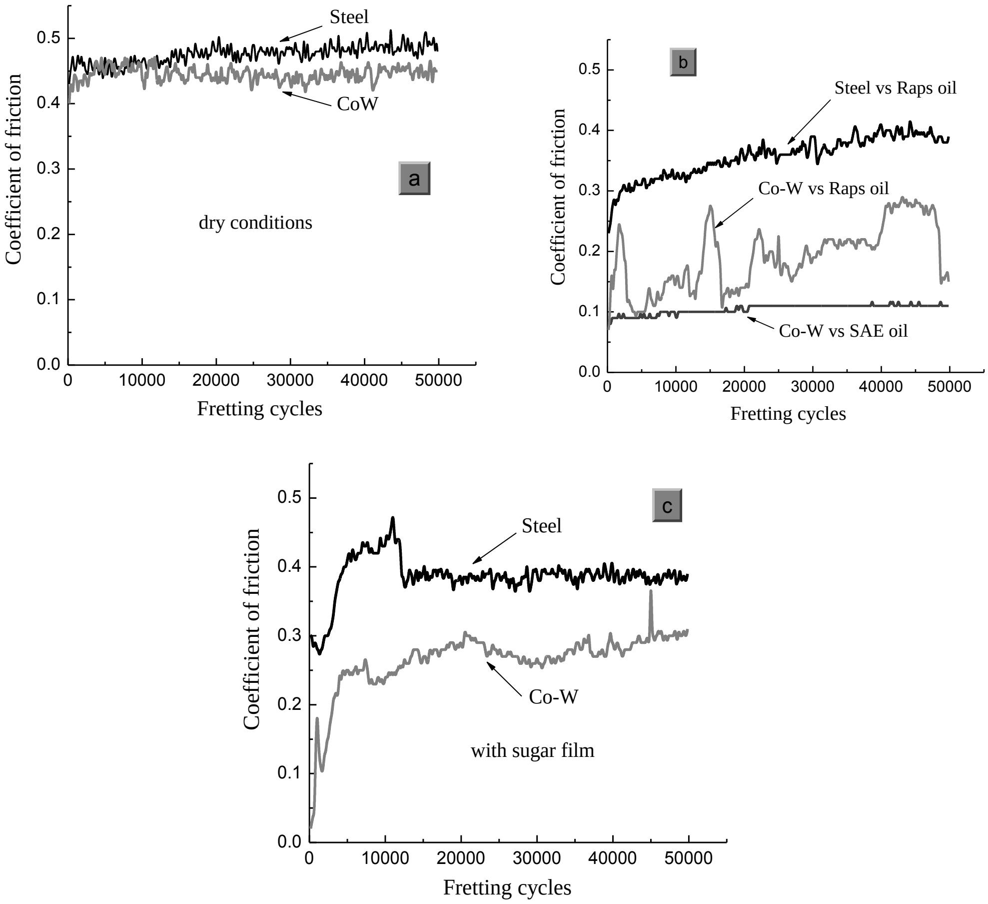



**Figure 2.** Evolution of coefficient of friction on steel and Co-W samples: (a) dry fretting, (b) in the presence of rapeseed and SAE oils films, (c) in the presence of sugar film.

Under lubricating conditions, the coefficient of friction has been reduced by approximately twice for Co-W coatings with rapeseed oil film on top, and for the steel is reduced by approximately 30 % (see. Fig. 2 b), while with SAE 10 film on top the coefficient of friction reduces even more essentially with app. 4 times. After fretting tests wear volume and wear depths were estimated under lubricating conditions in the presence of oils (Fig. 3). As can be noticed, steel samples even under lubricating conditions have large wear tracks and decreased wear resistance, namely by app. 7 times wear volume for steel is higher than for Co-W coatings. This behavior can be linked to the high oxidation speed of steel samples - tribooxidation, even with oil films on top. Thus, the third body in contact will be iron oxides which are working as abrasive material and cause the appearance of deep grooves on the top of the steel samples (Fig. 3). As far as for Co-W alloys, in this case oil films have probably better adhesion to the substrate, preventing in this case the tribooxidation, and even after 50 000 of cycles

Co-W coatings can resist 10 N load applied without any severe worn out. The results can be even slightly improved for Co-W alloys if to use SAE 10 oil, where wear volume reach the value of $22 \cdot 10^3\,\mu m^3$.

Interesting results were obtained while using sugar film as solid lubricant. In this case, sugar film seems to be plays a role of protective film for Co-W coatings decreasing even more the wear depth and wear volume of those coatings in comparison with dry and oil lubricating systems (Fig. 4). Notably, that for steel samples sugar doesn't have the same effect and the wear is approximately the same that it was under dry conditions, and again severe tribooxidation is occurring in this case. This fact also reflects in the coefficient of friction (Fig. 2 c), where for friction coefficient for steel is close to dry conditions, but for Co-W this value is close to rapeseed oil film conditions. Such interesting behavior of Co-W coatings with sugar film on top can be regarding as new type of protective film which can find its use and increase cobalt-tungsten alloys wear resistance.

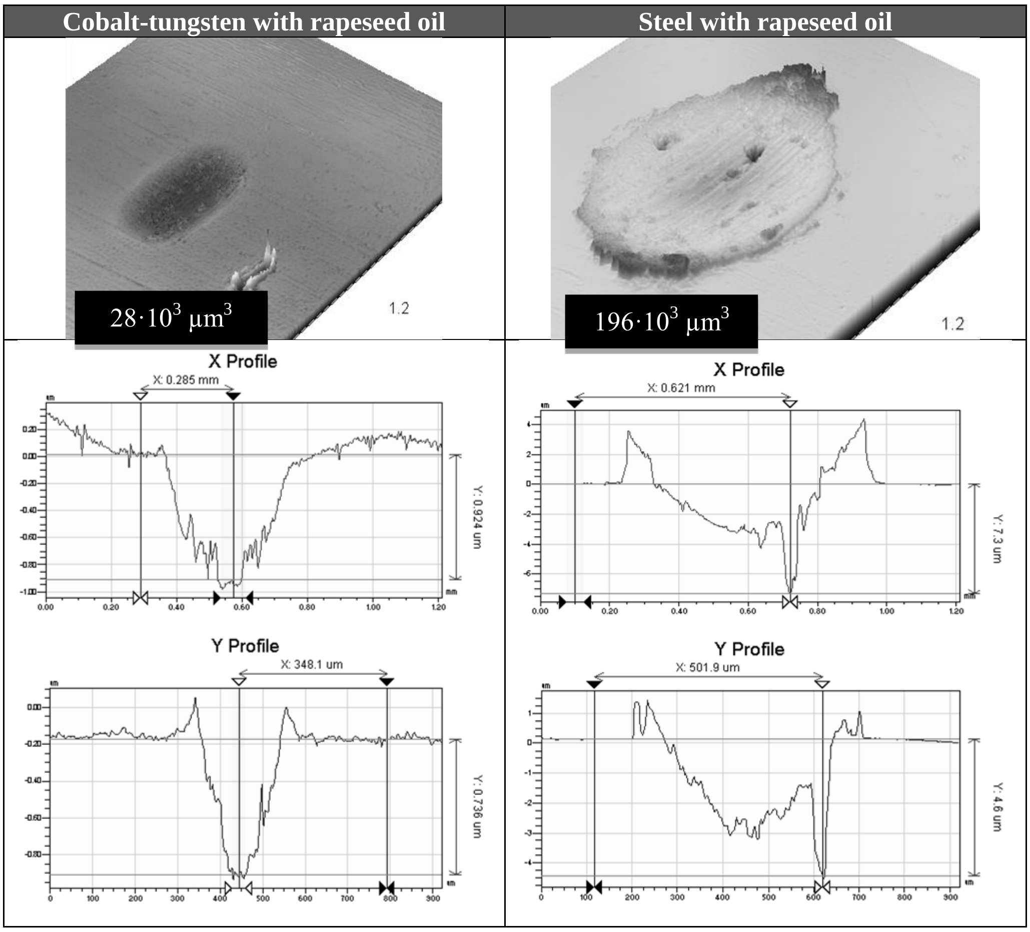



**Figure 3.** 3D-images and XY profiles of Co-W and steel samples after friction in the presence of rapeseed oil film; values of wear volume are mentioned on the images.

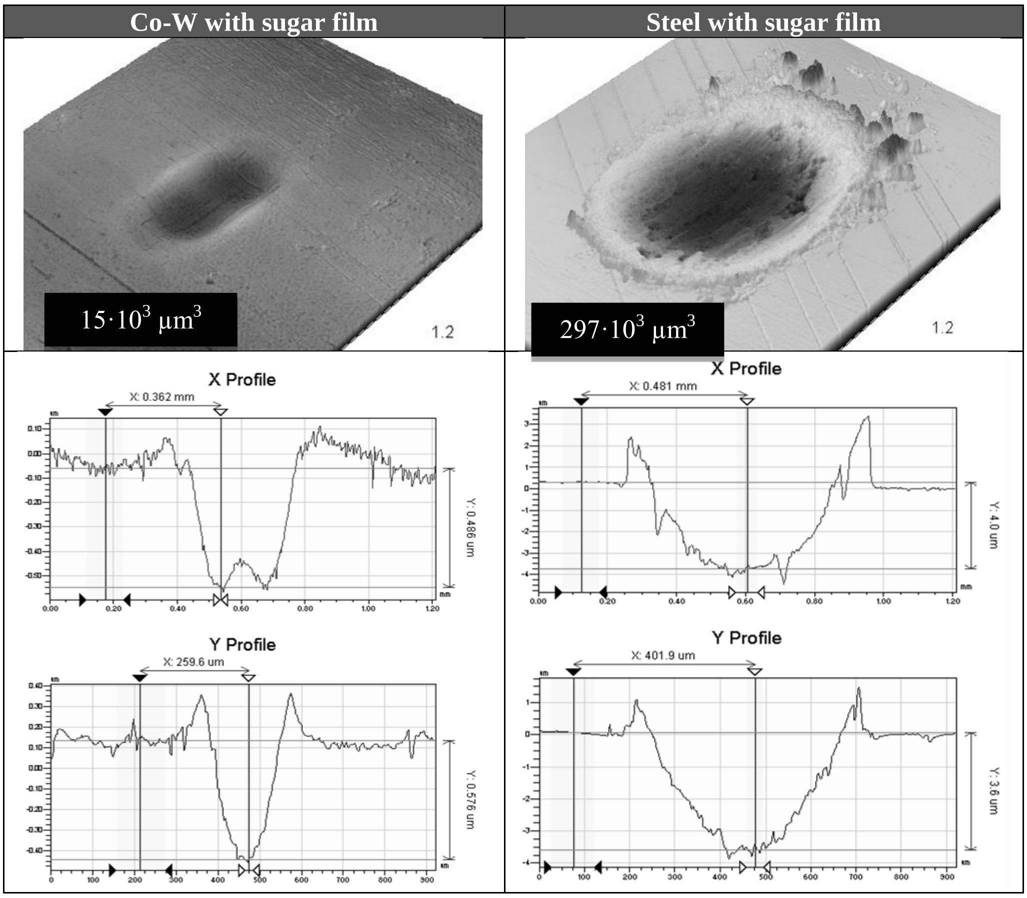



**Figure 4.** 3D-images and XY profiles of Co-W and steel samples after friction in the presence of sugar film; values of wear volume are mentioned on the images.

## 4. CONCLUSIONS

The possibility to use Co-W under lubricating conditions have been studied, namely, lubrication with oils and with solid lubricant as sugar. The data were compared with uncoated substrate – steel ST3, under dry and lubricating conditions. The process of lubricant application has been identified and differences in tribological behaviour of uncoated substrate and Co-W coatings have been established. Namely, steel samples undergo severe tribooxidation, which leads to large wear volume and high values of the wear depth. Instead, Co-W coatings have reasonable wear resistance under dry conditions and even performant under lubricating conditions. Special case – the use of solid lubricant as sugar film, provides a new alternative for increasing of the tribological performance of Co-W alloys.

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