Evaluation of a worn out WC–Co–TiAlN cutting tool used in industry

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Abstract. In this work, a cutting tool with premature wear was characterized by Rockwell hardness test, scanning electron microscopy (SEM) and energy-dispersive X-ray spectroscopy (EDS). In addition, electrochemical impedance spectroscopy (EIS) measurements were carried out in order to investigate the characteristic properties of the wear coating (TiAlN) of tool (WC–Co substrate). The substrate hardness was 90 HRA, which is in accordance with the observed microstructure of a cobalt matrix with tungsten carbides. SEM-EDS analysis confirmed the presence of a TiAlN coating and of typical features of an adhesive wear mechanism. EIS results revealed typical behavior of a porous WC–C substrate. Hence, premature wear of cutting tool could be explained in terms of an inadequate performance of the defects of coating deposited on the WC-Co substrate, as suggested by porosity revealed in the SEM images and the EIS measurements.

1. Introduction
Machining is one of the fundamental manufacturing processes widely used in industry. High efficiency and economic costs of the machining processes strongly depend on the performance of cutting tools. The development of cutting tool materials has been a dynamic research area in last decades. Indeed, WC–Co coated with high wear resistant film constitutes one of the more successful materials [1]. Thus, a cutting tool of WC–Co–TiAlN has been usually used in a manufacturing company to fabricate machine elements. It has been noted that cutting tools lifetime was lower than expected for this kind of advanced tool. Hence, an understanding of the poor performance of the cutting tools is necessary. Because the mechanical, physical and chemical aspects of the tool contacting surface are affected by the performance of the system, here is studied a cutting tool in order to determine the causes of its premature failure.

2. Experimental
2.1. Physical and chemical characterization
The worn out cutting tool is shown in figure 1. Worn surfaces are evident in all vertices of the tool. The cutting tool characterization was carried out using the hardness test, scanning electron microscopy (SEM) and energy-dispersive X-ray spectroscopy (EDS) using a FEI Quanta FEG 650. The hardness was measured on the Rockwell A hardness scale (HRA) according to ASTM Standard B294 [2]. A diamond indenter was used and a normal load of 60 kg-f was applied.
The samples for SEM-EDS analysis were prepared as follows. First, two samples were cut from one of the tool vertices with a diamond disc. One sample was used for analysis of the worn surface. The other one was used to analyze the cross section of the tool, in which the substrate and the coating are exposed. A metallographic preparation of the latter sample was performed in accordance to ASTM standard B665 [3].

2.2. Electrochemical characterization
All cutting tool surfaces which were not of interest for electrochemical measurements were covered by insulating chemically resistant enamel. Thus, the cutting tool was used as working electrode. Ag|AgCl|3MKCl and graphite rods were used as reference and counter electrodes, respectively. A three-electrode cell was used to perform the impedance measurements. The frequency range for impedance measurements was between 10 mHz and 100 kHz with signal amplitude of 10 mV. All solutions were deoxygenated with high-purity nitrogen gas for 20 min before measurements and all measurements were performed at room temperature.

3. Results and discussion
3.1. Physical and chemical characterization
The SEM images of the substrate microstructure and the cross section of tool are shown in figure 2. A typical microstructure of a WC–Co composite, where WC grains have bright contrast and form a continuous framework and they are embedded in a Co matrix (dark contrast), is observed in figure 2(a). EDS analysis confirmed the presence of tungsten and cobalt. Thus, a high-volume fraction can be estimated for the tungsten carbides (see small interparticle spacing); conversely, a very small quantity of Co is observed. This is in accordance with the morphology features published elsewhere [4].

Figure 2(b) shows the cross section of the cutting tool. Semiquantitative EDS analysis of the coating composition evidenced the presence of titanium, nitrogen and aluminum in a stoichiometry ratio of 1:1:1. In fact, a TiAlN coating is usually used for the WC-Co tools [1]. The coating thickness is in the range of 4 - 5 µm, which is agree with the recommended thickness for this kind of coatings [4].
Figure 2. SEM images of the WC-Co composite (a) and the cross section (b) of the tool.

Figure 3 displays a SEM image of the cutting tool worn surface. It can be noted that wear of tool edge resulted in the removal of the coating. A foreign material was detected (dark spots), which is different from the WC–Co substrate (bright contrast) and the TiAlN coating (gray contrast). SEM/EDS analysis showed that the chemical composition of the foreign particles was mainly Fe. Indeed, ferrous alloy could be transferred to cutting tool because Fe-bearing alloys are the most common material machined by these tools at industry. These features are an evidence of the adhesive wear mechanism acting on the cutting tool surface. This can be considered a severe mechanism, because transferred material inhibits an adequate cutting tool performance.

The WC–Co substrate average hardness was of approximately 90 HRA, which is an expected value for an optimized function of machining [4]. These results confirm that the coated cutting tool have features of an advanced material which must have an expected service life of at least ten times higher than non-coated tools [4]. In this way, the premature wear of this cutting tool is unusual and some explanation should be found.

Figure 3. SEM image of the worn out cutting tool.
3.2. Electrochemical characterization
The impedance features can be discussed in terms of Nyquist plots. Figure 4 shows typical impedance response of the different surfaces of the cutting tool (figure 1). The high impedance magnitude for the coating (figure 4(a)) is attributed to high charge-transfer resistance of TiAlN, due to its protective ability [5]. On the other hand, the slope at high frequencies in figure 4(b) is characteristic of the porosity of the WC–Co [6] on the worn surface (vertex of the tool). Indeed, a higher magnification than figure 3 it can be observed the presence of pores on WC–Co surface exposed (centre of figure 5). These results showed how EIS analysis can be an alternative technique to study structure and defects of thin layers as reported elsewhere [7].

Figure 4. Nyquist diagrams of the pristine TiAlN coating (a), and the worn surface (b), of the studied cutting tool measured in 3.0% NaCl aqueous solution in the frequency range $10^5$ to 0.1 Hz.

Figure 5. SEM images of the worn out cutting tool at different magnifications: a) x150 and b) x2000.

4. Conclusions
In this work an evaluation of the premature wear of a cutting tool using physical characterization together with an electrochemical analysis was carried out. Physical and chemical characterization allowed verifying that cutting tool was constituted of a WC-Co substrate with a TiAlN coating, which is an advanced material with high wear resistance. Worn surfaces analysis showed that a severe wear mechanism, such as adhesion, which acts on the interface between tool and machined element
surfaces. Hence, a poor performance of the cutting tool as reported by the manufacturing company was confirmed. In addition, EIS analysis of the coating suggested the existence of some porosity in the coating, which could explain the unexpected performance of the cutting tool. Additional analyses are necessary to assess this hypothesis. This work shows how the use of the electrochemical techniques can contribute to carry out tribological failure analysis of mechanical components of industry.

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