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# Obtaining and characterizing of WC-Co coatings obtained from thermal spray by flame

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**Abstract.** Tungsten carbide is used in the production of cutting tools for steel and as protection against wear due to its extremely high hardness. High speed oxygen fuel spraying process has been widely used to deposit WC-Co coatings. However, the decomposition and oxidation of WC-Co has been reported during the process, where carbon and tungsten are released, resulting in the formation of an amorphous matrix with the cobalt of the compound. This is attributed to the high heating and cooling rates suffered by the raw material. An alternative method is the thermal spray by flame, which allows controlling the working temperature and the residence time of the particles in the hot flame, avoiding the decomposition of tungsten carbide, on the other hand, it is a versatile and a low cost method. In this study projection parameters of a WC-18Co coating sprayed with a thermal flame spraying process from a commercial feedstock powder were determined to decide the conditions under which compact coatings are obtained with low porosity, avoiding dissociation of the tungsten carbide. The composition of the powders and substrates was determined by X-ray fluorescence microscopy and optical emission, respectively, X-ray diffraction studies were performed to characterize compositions and microstructures the coatings sprayed; the morphology was by scanning electron microscope. It was found that the best condition for this type of coatings is a neutral flame at a projection distance of 12 cm.

## 1. Introduction

Tungsten-Cobalt Carbide (WC-Co) alloys are used in a wide range of wear-resistant applications in a variety of conditions including wear, abrasion and erosion. The erosion resistance of such compounds is well studied both in sintered bulk samples and in coatings obtained with high-speed oxygen (HVOF) [1].

HVOF has been widely used to deposit WC-Co coatings. In this process, the fuel and oxygen are injected into a combustion chamber where they ignite and generate heat to melt and propel the particles to the substrate, the temperature reached in the process is up to 3000 K and the speed of the particles is up to 800 m/s [2].

It has been shown that for thermally sprayed coatings, WC decarburization occurs during the spraying process which affects the microstructure with a concomitant decrease in hardness and wear resistance of materials [1-6].

This phenomenon depends on the deposition conditions characterized by a high temperature, a generally oxidizing atmosphere and high cooling rates, so that the pulverized material undergoes complex physical and chemical transformations.



In particular, several studies have revealed that during the spraying of WC-Co, a part of WC is transformed into  $WC_{1-x}$ ,  $W_2C$  and metallic tungsten, while carbon and dissociated tungsten dissolve in the amorphous cobalt matrix, which has been demonstrated by studies based on X-ray diffraction (DRX), differential thermal analysis (DTA) and transmission electron microscopy (TEM).

The extent of these transformations depends on the spray method, the projection parameters [7] and the dust characteristics [1-6].

Other processes, such as flame spray (FM), can retain a larger fraction of WC in the coating. FM is a technique which consists of projecting small particles melts thanks to the energy released in the reaction of an oxidant (oxygen) and the fuel that is commonly acetylene, a flow of molten or semi-molten particles is conducted to the substrate, previously prepared for ensure good adhesion of the coating. They collide and suffer a plastic deformation, forming splashes in the form of discs (pancakes) or (flower), depending on the physical and thermal conditions with which they impact, so they accumulate and form coatings [7-10]. However, the previously mentioned transformations still happen, but to a certain extent, since this technique allows to control the working temperature and the residence time of the particles in the hot flame, avoiding the decomposition of tungsten carbide.

In this study projection parameters of a WC-18Co coating sprayed with a FM process from a commercial feedstock powder was determined and establishes the conditions under which compact coatings are obtained with low porosity, avoiding dissociation of the tungsten carbide. Coatings were manufactured with four different process conditions, where the type of flame and working distance were varied.

The structural characterization of both raw materials and coatings was analyzed by X-ray diffraction (XRD), the morphology by scanning electron microscopy (SEM), and the elemental composition by energy dispersion spectra (EDS).

## 2. Metodology

The powder used to obtain the coatings is a commercial reference Metco® 76F-NS tungsten carbide cobalt powder. It is a sintered tungsten carbide - 18 wt % cobalt powder. Particle size ( $53 \pm 10$  micron) was developed to maximize coating density without sacrificing coating thickness or finish. In addition, carbon chemistry was adjusted to compensate for decarburization losses and carbide size was optimized for proper combustion.

The coatings were made on AISI 1020 substrates, commonly used in structures and pipes subjected to wear environments, which consisted of cylinders of 2.5 cm in diameter and 0.5 cm in height, they were prepared with an abrasive blast of corundum to give an average roughness of  $5.3 \pm 0.2 \mu\text{m}$ , then, they were bathed in alcohol with ultrasound to eliminate the corundum and the remaining dirt.

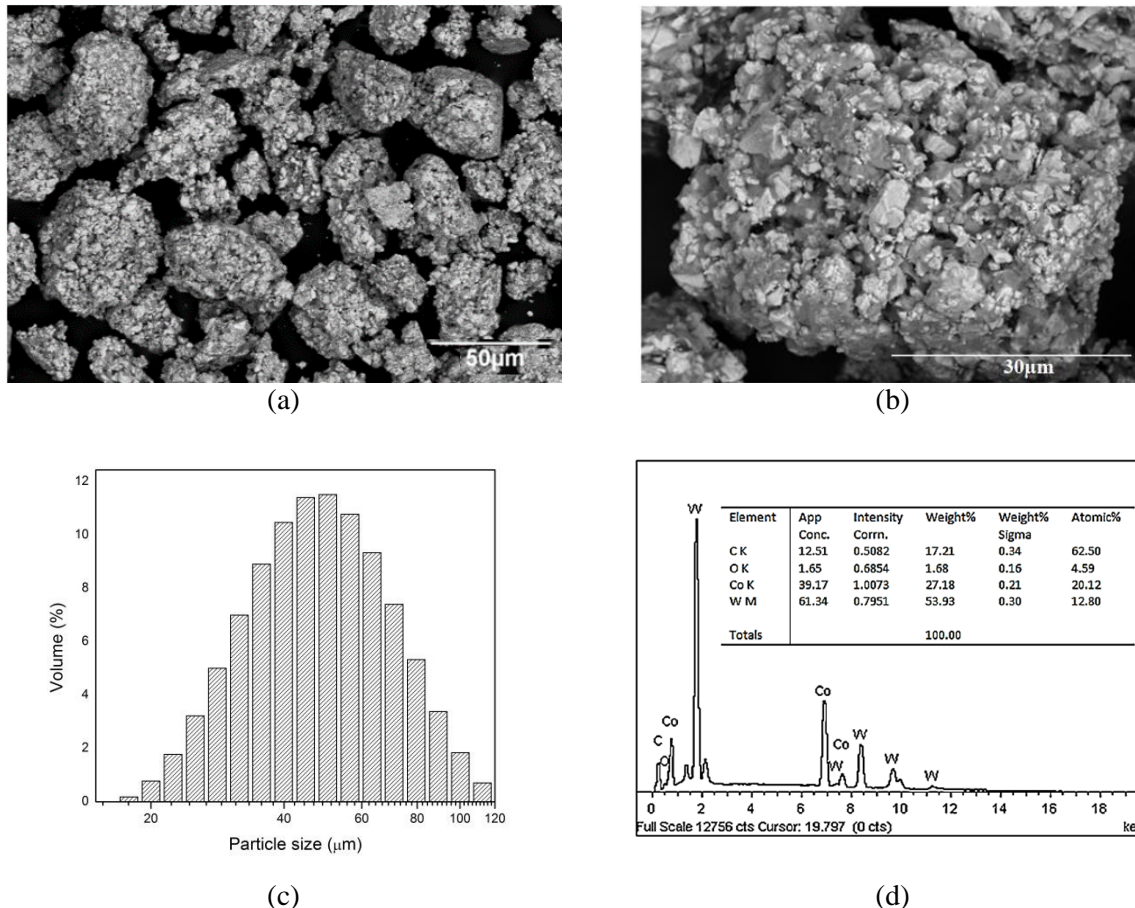
The technique used was FS with oxyacetylene, using a modified Eutalloy® Terodyn 2000 torch. The spray parameters were determined according to the manufacturer's recommendations and the experience of the researchers. Four different conditions were made to obtain the coatings that are named as: WCCo1, WCCo2, WCCo3, y WCCo4, where the letters refer to the powder used and the numbers identify the four conditions under which the coatings were obtained.

## 3. Analysis of results

The shape of the powders, their size and composition by EDS, appears in Figure 1. The powders have an irregular angular shape, are porous and have a narrow distribution width and an average of  $50 \mu\text{m}$ , as illustrated in Figure 1, parts (a) and (c). They consist mainly of tungsten (W), followed by cobalt (Co), and carbon (C), as indicated by the results of the EDS analysis, present in part d) of Figure 1.

The diffraction analysis of R-X, is shown in Figure 2, where the phases of  $W_1C_1$  and  $C_o$ , present in the dust are identified. Table 1 summarizes the parameters used to obtain the coatings named as WCCo1, WCCo2, WCCo3, and WCCo4, where two oxidizing and neutral flames were used, and two projection distances, which allowed working with two atmospheres with different oxygen concentrations and two flame temperatures [11].

It is important to bear in mind that, under conditions 2 and 3, the powder flow varied during the spraying process, started with the value marked with a \* and ended with the marked with \*\*, this is because the shape of the dust does not allow a constant flow rate. In addition, the variations in the current do not allow to maintain a constant vibration in the powder feeder, as shown below, this influences the morphology of the coatings.



**Figure 1.** Microstructure of a feedstock powder particle (a) low magnification, (b) high-magnification granulometric distribution (c) and (d) chemical composition by EDS.

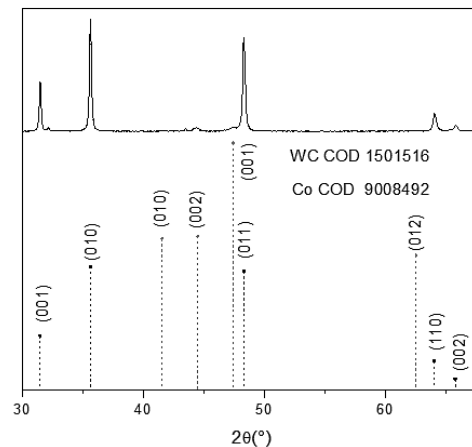
**Table 1.** Spray parameters used to obtain the coatings

Sample	WCC <sub>0</sub> 1	WCC <sub>0</sub> 2	WCC <sub>0</sub> 3	WCC <sub>0</sub> 4
Flame (C <sub>2</sub> H <sub>2</sub> : O <sub>2</sub> )	1: 3.2	1: 3.2	1: 1.7	1: 1.7
Stand-off distance (cm)	12.0	7.5	12.0	7.5
Powder flow gr/min	6.6	5.4 * 7.2 **	7.2 * 25.8 **	7.8
Preheating passes	3	3	3	3
Spray passes	8.0	12.0	12.0	12.0

\* Powder flow started with this value \*\* Powder flow ended with this value.

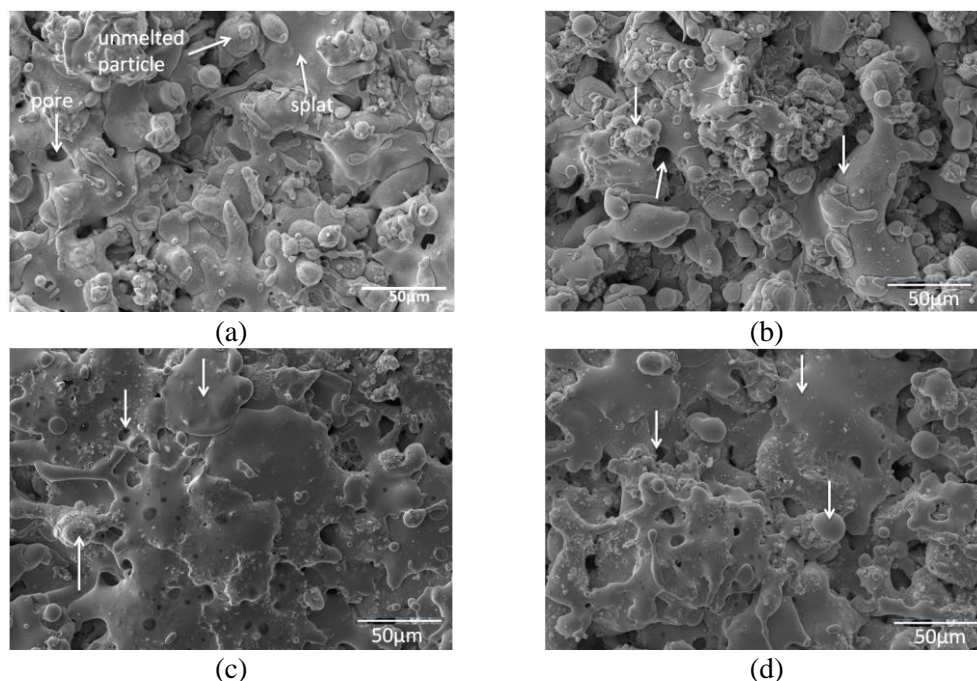
In Figure 3, the morphology of the coatings in the four developed conditions is shown. It is observed that under conditions 1 and 2, shown in Figure 3 as (a) and (b), in which the type of oxidant flame was kept constant and the spray distance was varied, coatings with particles without melted and semi-melted in the surface were obtained, this allows to say that the energy supplied in the reaction was enough to melt the Co particles. The cobalt was heated until it reached its evaporation temperature, forming bubbles that give rise to the formation of spherical porosity, (See Figure 3, parts (a) and (b)). The opposite occurs in conditions 3 and 4, indicated in Figure 3 as (c) and (d) where the

particles melt completely, and form a splat without splashing and without reaching the evaporation temperature. There are some particles, almost complete, in which the Co is semi melted. In this case, the spray distance was varied equally, but a neutral flame remained constant, although it has a short hot zone, its temperature is slightly higher than the oxidant, and the residence time of the particles in the flame is smaller, allowing Co to reach its melting temperature, but not its evaporation. This is in agreement with that reported by other authors [12].



**Figure 2.** X-ray diffraction patterns of the WCCo powders and the present phases.

The morphology of the coatings in their cross-sectional area is shown in Figure 4. It is evident that the type of flame has a marked influence on the morphology of the coatings. The WCCo3 and WCCo4 coatings, (see parts (c) and (d)) clearly contains a much higher concentration of tungsten monocarbide crystals (WC), as distinguished by the higher proportion of dark gray phase than the WCCo1) and WCCo2 coatings (see parts (a) and (b)).



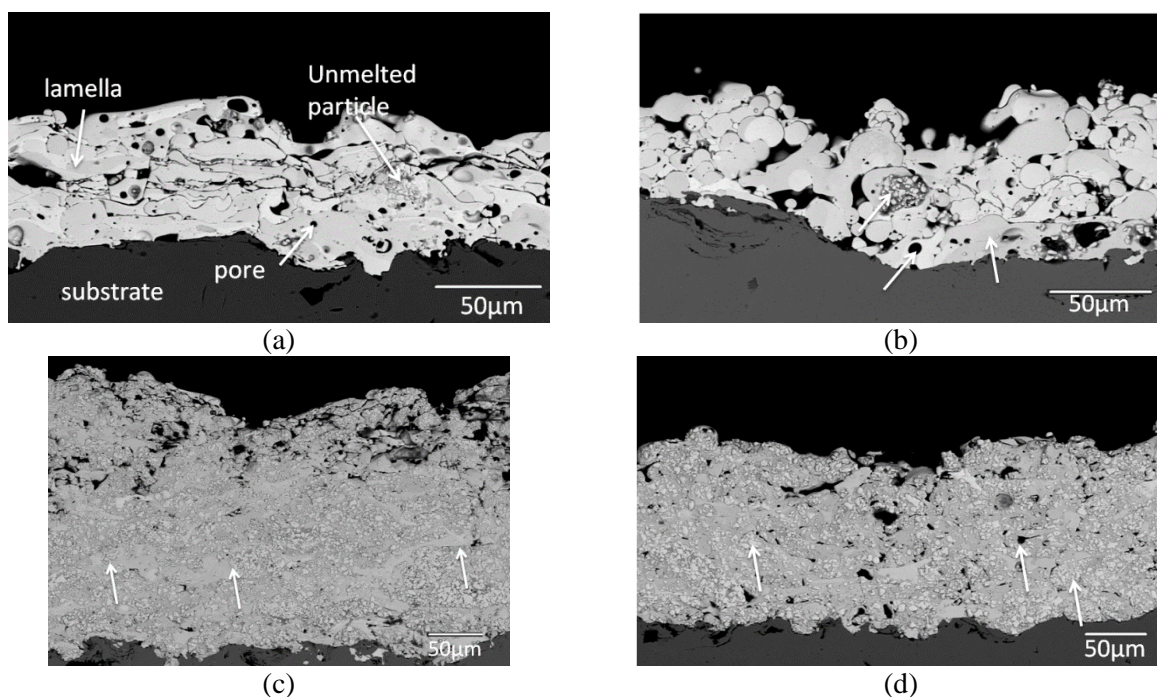
**Figure 3.** Morphology of the coatings in their transversal area. a) WCCo1, b)



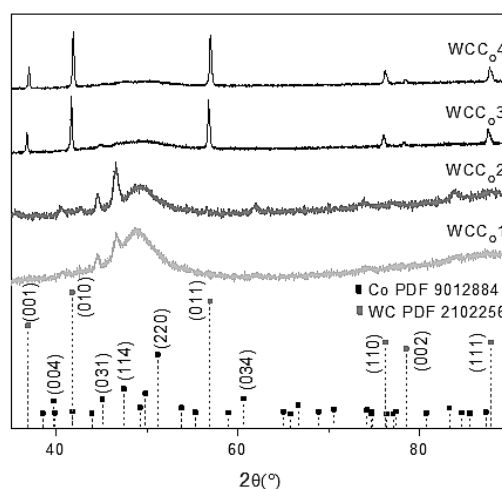
WCCo2, c) WCCo3, d) WCCo4.

The X-ray diffraction patterns of the coatings are shown in Figure 5; they indicate that a substantial amount of amorphous matrix material was created during the thermal spray process. Carbon and tungsten, liberated through the dissociation of the WC, combine with cobalt present in the starting powder to form amorphous material on solidification, this was also found in coatings by HVOF by J. Nerz 1992 [6]. XDR analysis confirmed the presence of a larger percentage of WC in the WCCo3 and WCCo4 vs WCCo1 and WCCo2 coatings.

This result was expected due to the short residence time of the particles in the neutral flame, which has the shortest hot zone and the low oxygen concentration, which would limit the decomposition process.



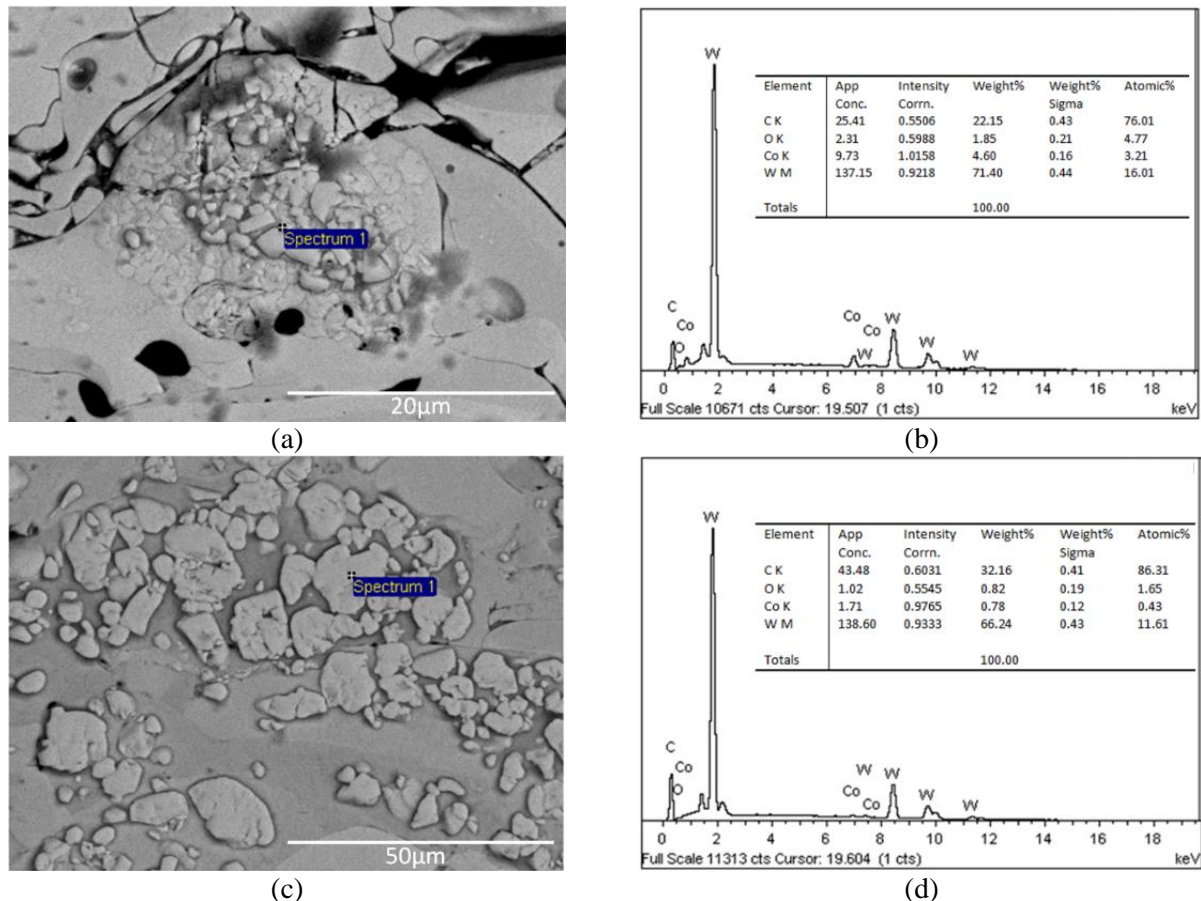
**Figure 4.** Low-magnification micrograph (SE mode) of the coatings in their transversal area.( a) WCCo1,( b) WCCo2, (c) WCCo3, (d) WCCo4.



**Figure 5.** X- ray diffraction patterns for

### WCCo1, WCCo2, WCCo3 and WCCo4 coatings

The chemical composition by EDS of the conditions WCCo1 and WCCo3 is shown, in Figure 6, parts (b) and (d) respectively, a carbon loss is observed as expected due to oxidation during spraying, presenting a greater loss in the coatings obtained with an oxidizing flame (WCCo1 and WCCo2), due to a greater presence of oxygen. The high resolution SEM micrograph of Figure 6, parts (a) and (b) shows the cobalt-agglutinated WC particles.



**Figure 6.** Chemical composition by EDS of conditions 1 and 3. (a) and (b) WCCo1, (c) and (d) WCCo3.

### 4. Conclusions

The thermal spray by flame allows to obtain homogeneous coatings of WCCo and to maintain the tungsten carbide phase. A neutral flame and a projection distance between 7.5 and 12 cm are the conditions under which coatings with low degradation of tungsten carbide are obtained.

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