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# Wear behavior of WC-Co carbides with addition of $Cr_3C_2$ and Ni

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**Abstract.** Cemented carbides present some characteristics that ensure high performances for cutting and wear-resistant tools. The aim of the work is to evaluate the influence of Chromium Carbide and Nickel on the properties (wear and friction) of a cemented carbide constituted by a hard phase of tungsten carbide and a binder phase of cobalt. Different tests were carried out by varying the percentage of $Cr_3C_2$ and, for one only case, also Nickel was added. The tests were carried out by a pin-on-disk apparatus and diamond abrasive sheet. The experimental campaign provided tests for different values of load and relative velocity. Friction coefficient was directly evaluated by the apparatus and data on the wear were obtained by measuring the loss of weight of the samples (parallelepipeds with hemispherical head). The tests allowed to determine the percentage of $Cr_3C_2$ that ensure an improvement of the aforementioned properties and to highlight the irrelevance of Nickel.

## Introduction

Wear [1-2] is a major cause of machines performance reduction, so any reduction of this phenomenon is advantageous. Wear is also the main aspect considered in the case of cutter, for example drill bit, used to machine different materials for various industrial applications. Rubbing and the energy dissipation (friction) are the essential causes of wear phenomenon, therefore improving the control of them it results a big advantage. Although the wear occurs on the top surface, which is the same side of the corresponding friction phenomena, the two phenomena, friction and wear, are not correlated in a simple way [3]. There are several cases where a low friction does not necessarily mean low wear [4] instead, as for certain materials combinations, it is possible to reach a situation in which the wear rate (volume of removed material / apparent contact area per unit of sliding distance) increases and the friction decreases in time domain. The study of new materials is therefore of considerable relevance in all fields of application in which there are contact conditions between bodies in relative motion. Sintered carbides WC-Co [5] are used to manufacture cutter for chip removal industrial processes [6] (turning, milling, drilling) or to any other process in which it is required an high hardness material [7] (cutting, crushing, etc.). Tools made of hard metal have an higher hardness than those made of stainless steel (1500 HV compared to 1000 HV), they resist to higher cutting temperatures (1000 °C compared to 600 °C) and have a good wear behavior [8]. These mechanical characteristics allow highest machining speed and a definitely highest tool life. The object of this work, performed in collaboration with the 'Nashira Hard Metals' company, consists in the study of wear behavior of sintered carbides (WC-Co) used, for example, to manufacture dies for bricks production by extrusion technique. An excessive wear during the process causes a loss of products calibration and an excessive increase in costs for raw materials caused by the enlargement of the extrusion section. To overcome this problem it is thought that the addition of an additive to the mixture WC-5Co, in particular the Chromium Carbide, could improve the wear behavior. The presence of Chromium should reduce the friction coefficient and increase the hardness by acting as an inhibitor of grains growth of tungsten [9]. Consequently the final compound, after the sintering process, would be characterized by a greater wear resistance. The material characteristics of WC–Co alloys [10] are directly related to their chemical composition and microstructure. Accordingly, their final mechanical properties can be tuned as a function of specific applications by varying their cobalt content, grain size and carbide additives such as $Cr_3C_2$ or VC [11–15]. Abrasive wear tests were carried out in order to analyze if and how effectively the addition of Chromium Carbide ($Cr_3C_2$) and Nickel (Ni) improve the wear behavior of the tungsten carbide specimens.

**Materials and Methods**

The tests were carried out on a set of specimens made by Nashira Hard Metals S.a.S. The samples consist of defined weight percentages of tungsten carbide (WC) and cobalt (Co). Moreover, some of them have an addition of additives, in particular the $Cr_3C_2$ and Ni. The purpose of the tests is to detect the influence of additives on the wear behavior of these materials. The tested materials composition and the grain size of the same is given in Table 1.

**Table 1: Chemical composition of the samples**

| Sample Code | WC [%] | Co [%] | Ni [%] | $Cr_3C_2$ [%] | grain size [μm] |
|---|---|---|---|---|---|
| A | 90 | 10 | | | 5 |
| B | 89.5 | 10 | | 0.5 | 5 |
| C | 89 | 10 | | 1 | 5 |
| D | 88.5 | 10 | | 1.5 | 5 |
| E | 88.5 | 9.5 | 0.5 | 1.5 | 5 |
| F | 88 | 10 | | 2 | 5 |

The experimental campaign provides the hardness evaluation, the wear characterization and the determination of the friction coefficient for each hard metal mixture. Hardness is a very important parameter about the choice of material for the extrusion die used to manufacture bricks. The instrument, used to perform the Rockwell method test, is a durometer that provides directly the hardness index (HRA). For wear testing was used a *pin-on-disk* machine and the manner of carrying out the tests follows the ASTM G99-95a reference.
For the tests was used as an abrasive paper a diamond. Each specimen, shown in Figure 1a, has a prismatic shape with two hemispherical end heads. This structure provides a continuous contact between the pin, made of carbide, and the diamond paper during the test (Figure 1b).
Following the tests specifications:

- Normal loads of the pin contact on the disk: 5 N, 10N, 15N
- Tangential sliding speeds: 0.094 m/s (r = 45 mm), 0.14 m/s (r = 67.5 mm), 0.188 m/s (r = 90mm)
- Test duration: two minutes
- Angular velocity of the fixed machine: 20 rpm

Nine tests were performed for each specimen (6 types) considering the different combinations of speeds (3 values) and normal loads (3 values). A total of 54 tests were carried out. As wear parameter it was considered the weight loss of material at the end of each test. In order to avoid the clogging of the test track, the abraded material was sucked during the test. As regards the friction coefficient, it is determined directly by *pin-on-disk software*. The choice of operating parameters, not too high, lies to simulate the real phenomenon conditions. The operating condition of WC-Co die is characterized by low speed advances with low loads.

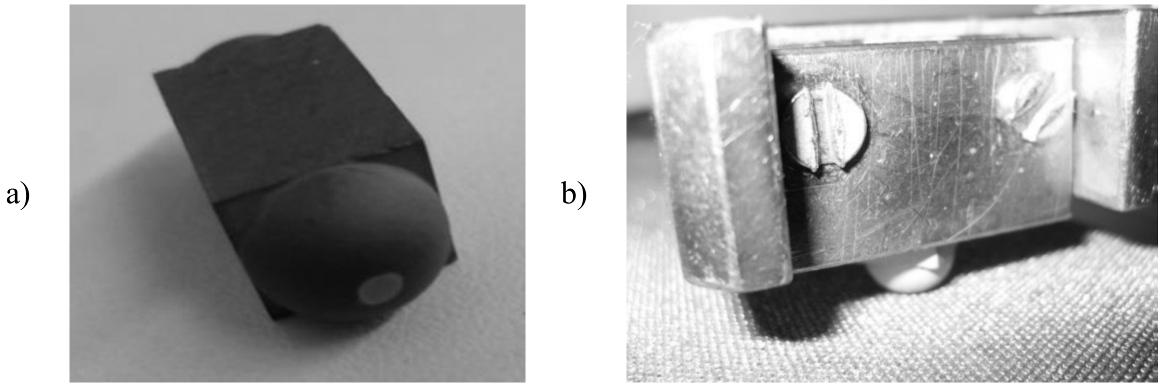


Figure 1: Sample a) free b) assembled in the pin-on-disk apparatus

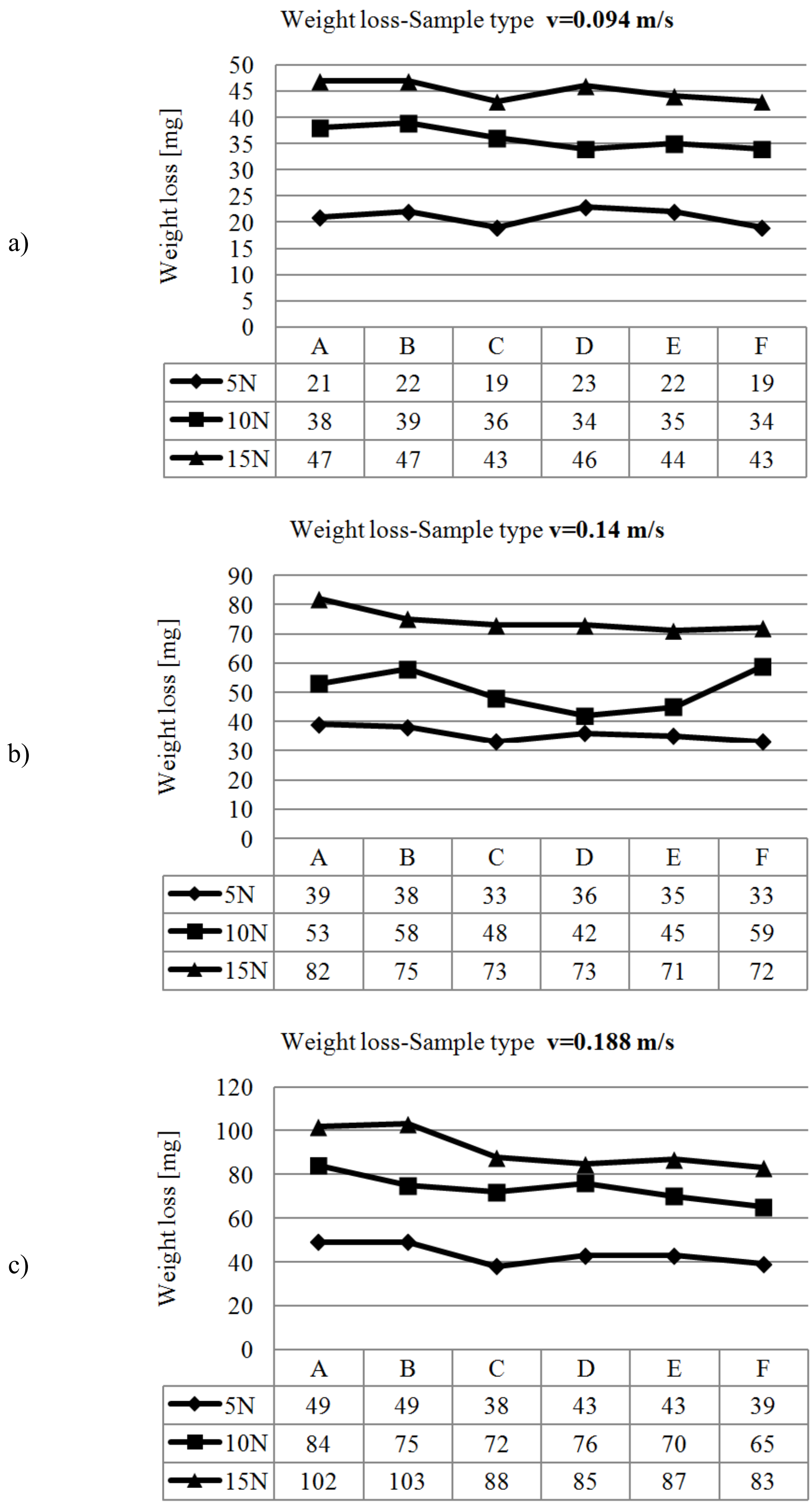
**Results**

Table 2 shows the hardness values of each samples. By literature [16] it was observed that WC-Co compounds with high hardness have a best wear behavior. For our tests, the hardness values are very similar and it does not allow to draw results on wear behavior. Then, in order to evaluate the effect of the addition of carbide grains inhibitors on the samples wear, it is decided to evaluate the friction coefficient trend in each test condition and the weight loss recorded during each test. It is established the optimal percentage of $Cr_3C_2$ that improves wear behavior of WC-Co. Figures 2 illustrate the samples weight variations (expressed in milligrams) at the end of each test for the three tested speeds and varying the normal load.

**Table 2: Rockwell A hardness values for the specimens**

| code | Hardness (HRA+/-0.2) |
|---|---|
| A | 88.6 |
| B | 88.4 |
| C | 88.4 |
| D | 89.1 |
| E | 88.9 |
| F | 88.9 |

In order to evaluate the results it is necessary to specify that a lower weight loss during the *pin-on-disk* test shows a greater wear resistance of the tested material. By the achieved results it is clear that the C specimen presents the best wear behavior because as a whole has a small weight loss. The E specimen, which has the 0.5 wt.% of Ni and more than 1 wt.% of $CR_3C_2$, doesn't shows significant differences in behavior compared to the D sample, characterized by the same value of Chromium Carbide but without Nickel adding. Then, it seems to not exist an influence on the wear behavior adding Nickel in the WC-Co compound, but it certainly presents an evolution on the corrosion phenomenon [17]. It has been also evaluated the friction coefficient for each specimen in each test condition. After studying the friction force trend, it has been calculated the friction coefficient as the ratio between the tangential force and the normal load. By way of example, in Figure 3 is shown the coefficient trend during the D sample test. The peaks are due to the contact between the aspirator and the diamond paper during the tests. The aspirator is used to clean the test track throughout tests duration.




a) v=0.094 m/s

| | A | B | C | D | E | F |
|---|---|---|---|---|---|---|
| 5N | 21 | 22 | 19 | 23 | 22 | 19 |
| 10N | 38 | 39 | 36 | 34 | 35 | 34 |
| 15N | 47 | 47 | 43 | 46 | 44 | 43 |

b) v=0.14 m/s

| | A | B | C | D | E | F |
|---|---|---|---|---|---|---|
| 5N | 39 | 38 | 33 | 36 | 35 | 33 |
| 10N | 53 | 58 | 48 | 42 | 45 | 59 |
| 15N | 82 | 75 | 73 | 73 | 71 | 72 |

c) v=0.188 m/s

| | A | B | C | D | E | F |
|---|---|---|---|---|---|---|
| 5N | 49 | 49 | 38 | 43 | 43 | 39 |
| 10N | 84 | 75 | 72 | 76 | 70 | 65 |
| 15N | 102 | 103 | 88 | 85 | 87 | 83 |

**Figure 2: Weight loss for each specimen; tests carried out at speeds of a) 0.094 m/s b) 0.14 m/s c) 0.188 m/s and variable load**

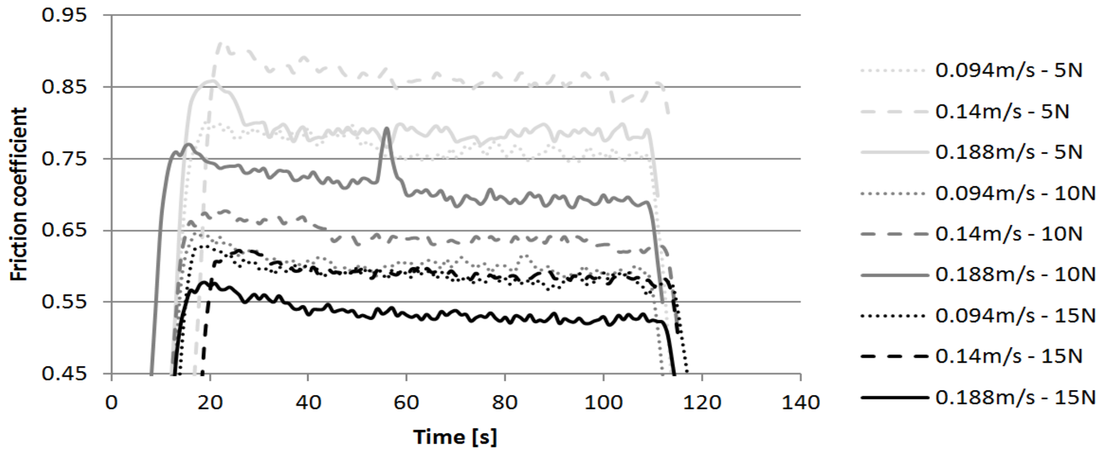
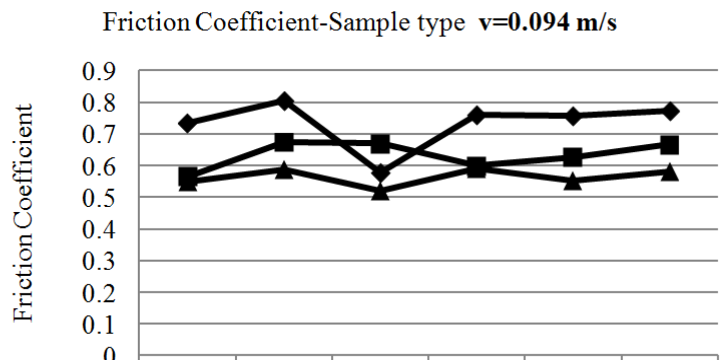



**Figure 3: Friction coefficient trend for D sample test**

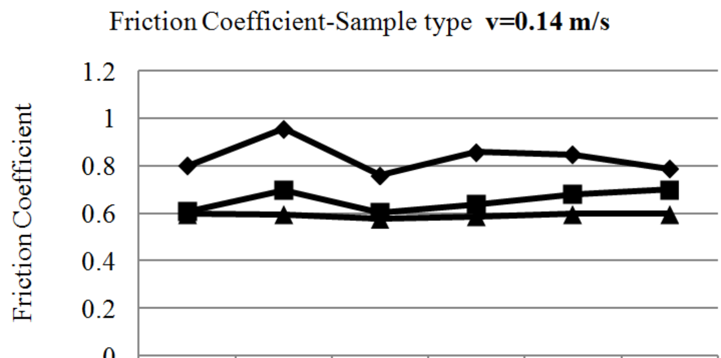
By the friction coefficient analysis it is observed the speed irrelevance in the tests results, while it is noted that the coefficients are lowered when the normal load increases. Instead, when the wear increases, it arises a larger contact surface and therefore it is effected a lower pressure. Likely the lower pressure causes a lower friction coefficient. By the obtained data it was carried out a values rearrangement. The Figures 4 show the approximate values of the friction coefficient after each test.

a)



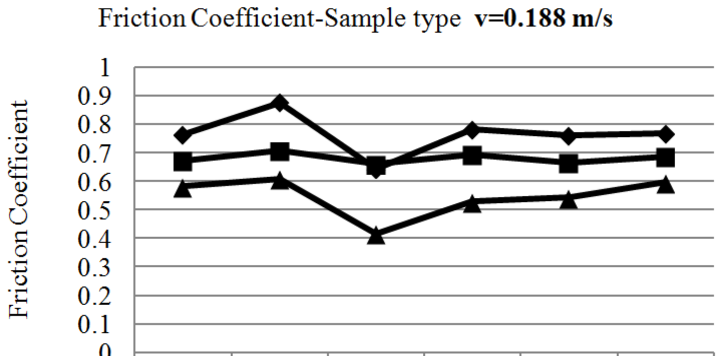

| | A | B | C | D | E | F |
|---|---|---|---|---|---|---|
| 5N | 0.734 | 0.804 | 0.577 | 0.761 | 0.756 | 0.772 |
| 10N | 0.566 | 0.674 | 0.67 | 0.6 | 0.626 | 0.666 |
| 15N | 0.548 | 0.587 | 0.52 | 0.589 | 0.551 | 0.58 |

b)




| | A | B | C | D | E | F |
|---|---|---|---|---|---|---|
| 5N | 0.801 | 0.958 | 0.76 | 0.859 | 0.847 | 0.788 |
| 10N | 0.607 | 0.697 | 0.603 | 0.637 | 0.681 | 0.699 |
| 15N | 0.598 | 0.595 | 0.575 | 0.586 | 0.598 | 0.598 |

c)




| | A | B | C | D | E | F |
|---|---|---|---|---|---|---|
| 5N | 0.763 | 0.876 | 0.643 | 0.782 | 0.762 | 0.769 |
| 10N | 0.672 | 0.706 | 0.659 | 0.693 | 0.666 | 0.685 |
| 15N | 0.582 | 0.607 | 0.415 | 0.528 | 0.542 | 0.596 |

**Figure 4: Friction coefficient for each specimen; tests carried out at speeds of a) 0.094 m/s b) 0.14 m/s c) 0.188 m/s and variable load**

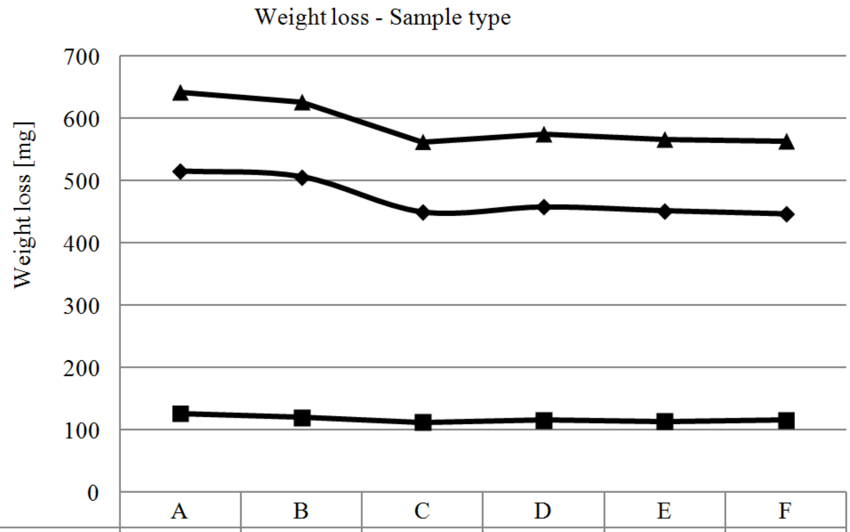
It was calculated the average value for the nine tests obtained on each compound and moreover the average value of all the average values (Table 3). These results that show the lowest value of the coefficient is equal to 0.61 for C sample, i.e. the one with the 1 wt.% of Chromium Carbide. Then follows the value 0.65 for the A specimen. The highest value was found for B sample even if it has 0.5 wt.% of $Cr_3C_2$, while D, E and F samples have values fairly similar. By the results analysis it appears a lack of correspondence between the wear values and friction ones, which should have a similar trend. In fact, the B sample frictions coefficient is greater than that of A sample, instead the weight loss for the B specimen is definitely higher than that of the A specimen. The same observation is also valid for D and E specimens which have a frictions coefficient greater than that of A specimen, but D and E specimens are definitely harder. By this considerations it discerns that hardness aspect is more important than that friction one.

**Table 3: Average value of the friction coefficient for each specimen**

| Specimen | Average friction coefficient |
|---|---|
| A | 0.652 |
| B | 0.723 |
| C | 0.616 |
| D | 0.669 |
| E | 0.670 |
| F | 0.684 |

The only correspondence between the wear and friction values is found for C specimen. The tests carried out on this specimen not only shows a lower friction coefficient but, being characterized by lower weight loss, it certainly has a lower wear tendency.

In the end it is decided to carry out a single test at speeds of 0.178 m/s with a load of 15 N and a duration of three minutes on each sample type. The tests were carried out on the specimens which already presented a wear trace. This test is used to verify the results obtained in other conditions. In Figure 5 are shown respectively: the weight variations that undergo the specimens after this additional test, the sums for each sample of all weight changes recorded in the different tests, and finally the variation of the total weight considering also the final test.




| | A | B | C | D | E | F |
|---|---|---|---|---|---|---|
| Sum of weight loss of all tests | 515 | 506 | 450 | 458 | 452 | 447 |
| Weight loss v=0.178 m/s | 126 | 120 | 112 | 116 | 114 | 116 |
| Total weight loss | 641 | 626 | 562 | 574 | 566 | 563 |

**Figure 5: Weight loss trend @ v=0.178 m/s, Sum of weight loss trend, and total weight loss trend for each specimen after the carried out tests**

Also these last analyses confirmed what it shown earlier, i.e. the best sample for the proposed target is C. After reaching 1 wt.% of $Cr_3C_2$ in the WC-Co mixture the compound is affected by the positive effect of Chromium, the improvement in terms of wear starts to appear for a 0.5 wt.%. Indeed the B specimen hasn't a good friction behavior, then the addition of Chromium improves the wear in terms of weight loss, but not of friction coefficient. Finally, the Nickel addition surely does not affect the improvement of the wear behavior of materials, but improves the corrosion behavior as demonstrated by bibliographic studies [17].

## Conclusions

It was analyzed how $Cr_3C_2$ and Ni addition to the WC-Co mixture influences the friction and wear behavior of the sintered samples. The tests revealed the following:

- A lack of correspondence between the wear values (measured as weight loss of the samples during the tests) and friction coefficients, which should have a similar trend as analyzed by literature;
- The wear improvement in the WC-Co compound is already presented by the addition of 0.5 wt.% of the $Cr_3C_2$ up to a maximum value of 1 wt.%. More than 1 wt.% of $Cr_3C_2$ to the WC-Co compound it denotes a lowering in terms of wear behavior;
- The tests carried out on C specimen, in which is present the 1 wt.% of $Cr_3C_2$, not only shows a lower friction coefficient, being characterized by a lower weight loss, but it certainly have a lower tendency to wear out;
- The Nickel addition (0.5 wt.% in the WC-Co compound) does not affect the wear behavior of the materials.

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