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Effect of CrC-Ni on the tribological behaviour of WC cemented carbide.

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Abstract. Tungsten carbide (WC) is extensively used in industrial processing as cutting tools, wear resistant components and drilling tools owing to the good combination of phenomenal properties. The binder phase of WC is usually cobalt (Co) as a result of good wetting behaviour and excellent solubility with regards to WC particles. However, degradation of WC-Co components when subjected to harsh environmental conditions often results in premature failures during application. In this study, the effect of CrC-Ni on the microstructure, mechanical and tribological properties of WC based cermet produced by spark plasma sintering was investigated. Sintered samples were then analysed and characterized by SEM and EDS. Macro hardness of the sintered compacts were evaluated using Rockwell hardness machine at 150kg load. Subsequently, comparative studies on the tribological behaviour of the experimental samples were performed using a reciprocating wear set up at 200°C. The area of the wear track cross-section was measured using optical profiler and the wear rate in terms of volume loss was calculated. Results showed improved mechanical and tribological properties on WC-20CrC-7Ni sample as compared to WC-Co cemented carbide sample.

1. Introduction

The growing technological developments demand systems capable of operating at high temperatures. Recently, critical industrial applications require materials that are resistant to wear and corrosion especially under severe operating environments. Friction and wear are known to be the two important hard metal parameters that affect the effective work of machine parts subjected to harsh working conditions such as machining under high temperatures and pressures. Cemented carbides are metal-ceramic composites materials consisting of a ceramic phase, tungsten carbide, and a metal binder, usually cobalt. WC-Co cemented carbides are extensively used in various industries such as machining, metal cutting/forming, mining, construction and oil-and-gas drilling, due to their high hardness, resistance to wear, and their toughness and strength. [1,2]. Nowadays, WC-Co have proved to be important materials in material processing necessary for commercial and industrials purposes and metals such as Co is used as binder phase to improve their fracture toughness. However, hard metals with Co have some limitations preventing the wider usage of the material. Such limitations involve high density, poor oxidation and corrosion resistance. [2–4]. To overcome these deficiencies, attempts have been made by various researchers to replace Co with other matrix materials due to factors that Co is relatively scarce, costly and its lower corrosion resistance. [7]. Effort was made to substitute Co with Ni and Fe binders and it was reported that WC-Ni resolve the issue of low corrosion resistance resulting in cemented carbide with better resistance in corrosion and oxidation as compared to WC-Co and WC-Fe. However, WC-Ni possesses low mechanical properties than WC-Co. Furthermore, WC-Fe has less oxidation and corrosion resistance when compared to WC-CO and WC-

Ni. [2, 5, 7]. Improved cemented carbide is achievable by appropriate modification of microstructure (WC grain size) and microchemistry (composition of the binder phase). Chromium carbide is known to improve wear behaviour, reduce friction and increase hardness by acting as a grain growth inhibitor for tungsten carbide. Hard metals with chromium as the binder are reported to have higher hardness, work hardening rate and marked improvement in abrasion resistance. [5, 6, 8]. The purpose of this study is to evaluate the influence of CrC-Ni on the microstructure, mechanical and tribological properties of WC based cemented carbide processed by powder metallurgy.

2. Methodology

2.1. Materials and characterization

Commercially available WC-12Co and WC-20CrC-7Ni powders with particle sizes of –45 +11µm and -45+15µm were used as staring powders. The powders were then consolidated to disks of 40 mm in diameter using spark plasm sintering system model HHPD25, FCT Germany. The pressure of the furnace was maintained at 1 mbar during consolidation while the uni-axial compression was done throughout the sintering process with 50 MPa. Sintering was performed with a holding time of 5 min, at temperature 1200 ˚C and heating rate of 100 ˚C / min. Scanning electron microscope was used to reveal the microstructures of the sintered samples. Rockwell hardness (Galleo Durezze) was used to determine the hardness at the load of 150kg.

2.2. Tribological experiments

A reciprocating wear test procedure using ball on flat geometry was employed. A steel ball of 6mm diameter with embedded diamond particles was used as the counterpart sliding against sintered samples (WC-Co and WC-CrC-Ni) in a reciprocating motion at 200 ˚C. The samples were ground to 220 µm and polished to 1 µm using diamond suspension, thereafter thoroughly cleaned and rinsed in an ultrasonic bath of acetone and dried in air. The wear tests had a fixed stroke of 4mm while the oscillating frequency of 4Hz was used. The applied load was 6.37 N and 20000 cycles were completed for each test. Subsequent to wear testing, samples were assessed using confocal profilometer (Smart proof 5, Zeiss) to observe the general wear track features in 3D, but more importantly to determine the volume of the material removed. The wear loss was then used to calculate the specific wear rate, K, based on Lancaster relationship [9].

$$k = \frac{V}{PD} \tag{1}$$

Where V is the volume loss in mm^3 , P is the applied load in N and D is the sliding distance in m.

3. Results and discussion

The scanning electron microscopy images of the sintered samples are shown in Figure 1. The presence of WC and the binder additives (Ni, CrC and Co based metallic binder) can be clearly identified. The microstructure indicates the presence of two distinct phases in WC-12Co cermet (Fig. 1 a), while three distinct phases are present in WC-20CrC-7Ni based cermets containing tungsten carbide with nickel and chromium (Fig. 1 b). The WC-12Co cermet in Figure 1a confirms that the white phase is the tungsten carbide phase while the dark phase is rich in the metallic binder which is Co. In the case of the WC-20CrC-7Ni based cermet presented by Figure 1 b, the white phase is the tungsten carbide phase while the grey phase dispersed within the dark phase is rich in the metallic binder Ni and CrC and the dark phase contains tungsten carbide. It is also observed that the proportion of tungsten carbide (dark phase) increases with an increase in the wt.% of tungsten carbide in the composite

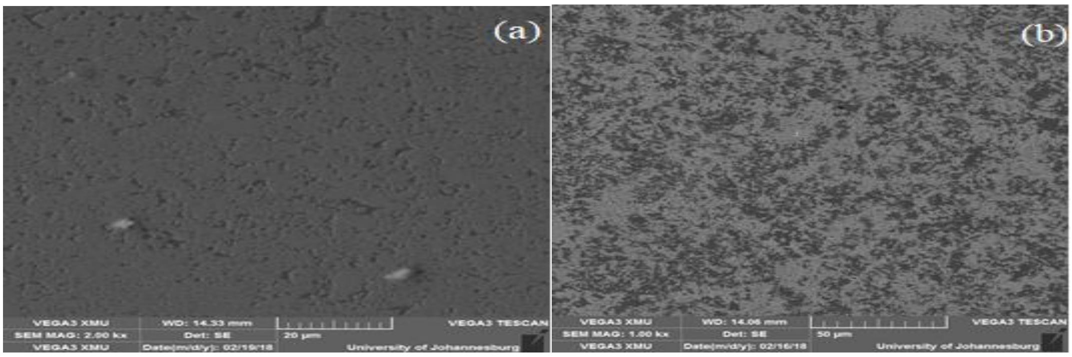

Figure 1. FE - SEM images of sintered samples: (a). WC-12Co composite without chromium and Nickel, (b). WC-20CrC-7Ni based composite containing 20% chromium with 7%Nickel

The hardness values of the sintered samples are presented in Figure 2. It was observed that WC-20CrC-7Ni cermet showed improved hardness as compared to the WC-12Co cermet. This could be as a result of chromium carbide incorporation into the cermet. Chromium carbide improves the hardness of the obtained sintered compacts. Furthermore, CrC is a refractory compound known to retain its strength and hardness at high temperature [6].

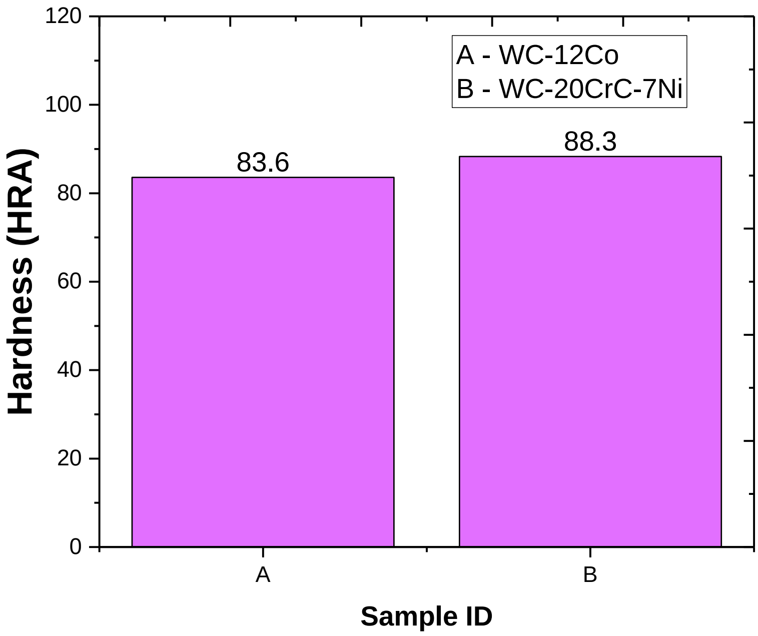

Figure 2. Hardness results of the sintered samples

The evolution of coefficient of friction during the reciprocating wear tests at 200°C is shown in Fig. 3. It is apparent that the COF of the WC-12Co cermet is higher than the one of the WC-20CrC-7Ni

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cermet under the same contact load. Because chromium carbide is known as a grain growth inhibitor, it was observed that the cermet containing CrC showed reduced COF as compared to the cermet without CrC. This is due to the fact that CrC being extremely a hard and corrosion resistant material is able to impact its properties on to the overall properties of the cermet.

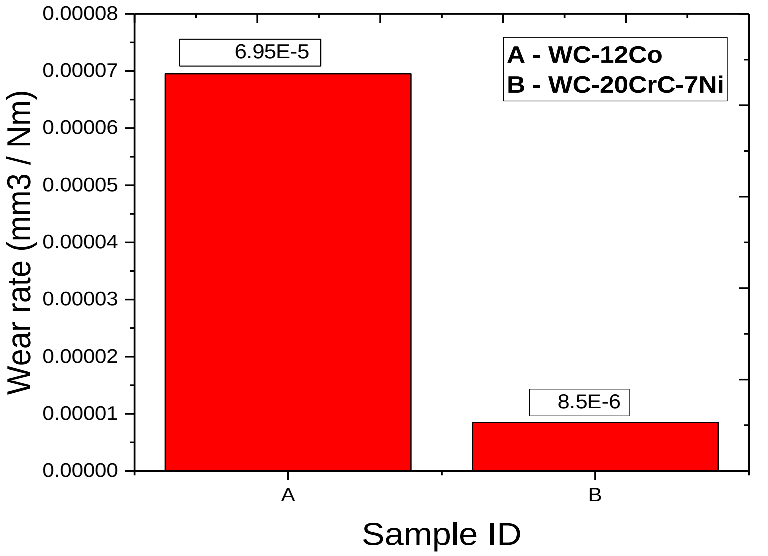

Figure 3. Coefficient of friction against time for WC-12Co and WC-20CrC-7Ni worn at 6.37 N.

The volumetric wear rates of the cemented carbides after reciprocating wear experiments using 6.37 N contact load at 200 °C are reported in Fig 4. It was observed that WC-12Co cermet showed increase in wear rate while the WC-20CrC-7Ni cermet showed reduced value of the wear rate. This is due to the fact that chromium carbide has excellent protection against abrasion and erosive wear. Furthermore it can be noticed that there is a remarkable reduction in the wear rate of WC-20CrC-7Ni caused by CrC.

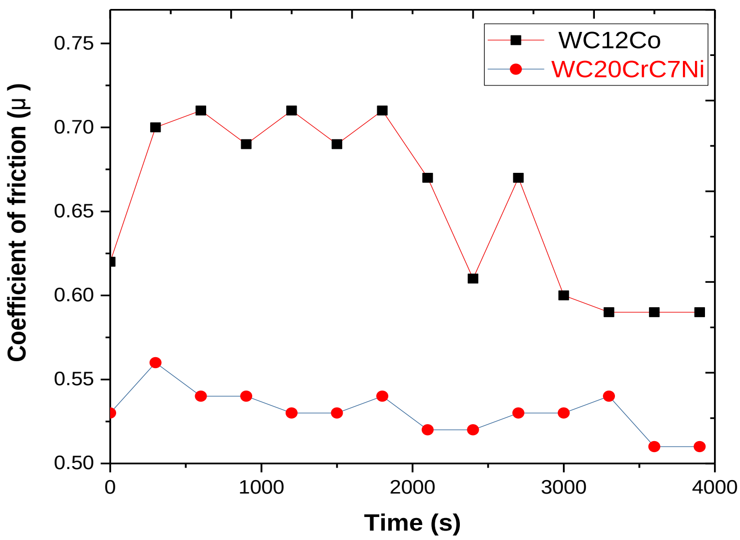

Figure 4. Wear rate of the sintered samples

4. Conclusion

Dry reciprocating sliding experiments on WC-12Co and WC-20CrC-7Ni cermets were successfully investigated. Based on the results obtained, the following conclusions are made:

- The addition of the inhibitor CrC makes a noticeable contribution to the properties of the cermet.
- A cermet with CrC-Ni showed improved mechanical and tribological properties as compared to the WC-12Co cermet.
- Exceptional reduction in the wear rate proved that the presence of the inhibitor improves wear rate of the cermet.

5. Acknowledgements

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