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The effect of thermal shock on the abrasive wear of WC-12wt%Co

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5. GENERAL DISCUSSION AND CONCLUSIONS

The results presented in this investigation prove that varying thermal shock temperature affect the wear rate of WC-12wt%Co alloys; refer to Figure 4.4. The wear rate of WC-12wt%Co after thermal shock was found to be initially high compared to samples without thermal shock. This initial wear rate was influenced by the heating temperature in that as the temperature increased from 600°C to 1000°C higher initial wear rates were recorded. No such effects were observed with respect to increasing thermal shock cycles; refer to Figure 4.6. As the wear tests progressed, the rate of mass loss under all test conductions converged, implying that the specimens have only been damaged down to a certain depth. Time required for the wear rates to converge increased with increasing temperature and thermal shock cycles.

The highest measured wear rate was after ~7.0 seconds of abrasive wear. In this study the thickness of the layer removed after ~7.0 sec of abrasive wear on a sample subjected to thermal shock of 60 cycles at 1000°C was approximated to be 13.3 µm (see Table 4.4). These thicknesses appear to be higher because of the hard abrasive material (SiC) used in this study. These thicknesses are based on theoretical extrapolation, however these calculations will not be valid as the wear rate reaches steady state because they are based on the assumption that the volume of the material lost increases with cycles. Assuming that this thickness is removed after every cycle which would simulate rock drilling in mining industries; after 10 cycles of abrasive wear a thickness of ~133 µm would be removed. After 60 cycles a thickness of ~796 µm will be removed and so on. This is a considerable thickness considering that the initial high mass loss response observed in this study is repeated possibly hundreds of times during rock drilling and that drill bits are subjected to severer conditions than

those used here. If the drill bits are exposed to thermal shock during rock drilling increased damage will happen when drilling for long time periods or for many cycles. A study by Ishihara et.al [24] observed thermal stresses at thermal shock temperatures as low as 500K. These temperatures are lower than the temperatures used in this investigation and therefore thermal stresses must have been induced during the tests, but this was not investigated here.

The focus of the project was the investigations of the effect of thermal shock on the abrasive wear of WC-Co alloys. Factors that could have contributed are: depleted cobalt on and below the surface, oxidation, decarburization of WC and calcium particles on the surface. Other authors, as reviewed in the literature observed surface cracks forming as a result of thermal shock, but this was not the only case in this investigation.

WC-12wt%Co undergoes considerably high shape changes and forms an oxide when exposed to a temperature of 800°C for a long time (5 minutes). Water alone does not facilitate the removal of Co from WC-Co alloys or decarburization of WC. It only slightly etches the surface, see Section 4.4. Therefore it appears that voids between WC grains and depleted cobalt below the surface maybe a result of thermal shock.

Comparing wear scars of samples before and after thermal shock did not show any obvious differences after 180 seconds of abrasive wear (see Section 4.2.3). This confirms the graphs of mass loss/time versus cumulative time where the wear rate was the same after 180 seconds for all the tests done. See Section 4.21 and 4.22.

5.1 Depleted Co on and below the surface

The following sections explains the formation of voids between WC grains, decarburized WC, oxidation, depleted surface layer and calcium observed after thermal shock and how they may possibly affect the high wear rate as observed during approximately 40 seconds of abrasive wear.

The voids (see Figures 4.18, 4.25 and 4.26(a)) were observed between the WC grains on and below the surface after thermal shock. These voids were found to be random. Differences in thermal expansion/contraction between the interior and the surface of the material or different thermal expansion/contraction between the WC and the Co during thermal shock could have possibly forced the Co to drift to the surface. The drifting of Co to the surface was confirmed by microprobe analysis of cross-sections where high peaks of Co were observed on the surface (refer to Figure 5.1 which is the same as Figure 4.62).

Co depletion changes the surface properties of the WC-Co alloys with respect to the core, hence a high wear rate at the beginning of the wear tests was observed. During abrasive wear Co drifted to the surface will be removed easily. With less binder phase in the surface, cracking of carbide grains occurs during abrasive wear due to the load applied by the abrasive particles. It is stated in the literature that during sintering of WC-Co alloys, on cooling the Co contracts more than the WC which puts the WC in compression and decreases the possibility of cracks formation [15]. Although microprobe analysis depicted possible Co movement on some samples, the evidence is not conclusive of general Co drift during thermal shock.

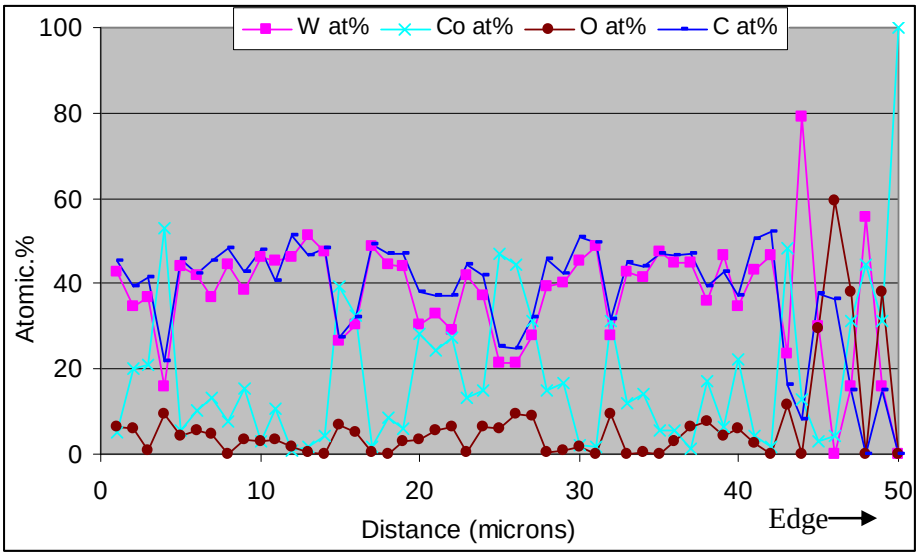


Figure 5.1: Line-scan element atomic percent after 60 cycles of thermal shock at 600°C. The W and the C stop going together from about 5 microns from the edge while there is high peak of Co which could mean that the Co has drifted to the surface.

5.2 Decarburization of WC

The possibility of WC decarburization to W_2C on and below the surface was shown by microprobe spectra where the W:C atomic ratio was no longer the same near surface such as in Figure 5.1. The line scan in Figure 5.2 shows the W and C being parallel up to about 5 µm from the edge. Decarburization may result from subjecting the WC-12wt%Co sample to high temperatures in the presence of oxygen. This was observed only in a few of the line-scans done, which suggests that the decarburization may have been random.

From the line-scan in Figure 5.1 results decarburization may have occurred within 5µm from the surface. This thickness is less than the thickness removed after ~7.0

seconds of abrasive wear (see Table 4.4), which implies that the decarburized layer may have contributed to the initial high mass loss rate because it was removed in the first cycle of abrasive wear. The decarburized layer is known to be porous thus could have resulted in high wear rate during the first ~7.0 seconds of abrasive wear [10].

Attempts were also made using XRD to confirm the decarburization of WC, but unfortunately the formation of W_2C could not be confirmed.

5.3 Oxidation of WC-12wt%Co

The change of surface colour observed when WC-12wt%Co was subjected to high temperature can be a sign of oxidation. Stereo microscope and SEM investigations of the surface revealed a layer which limited the visibility of the microstructure. This layer which was called “stain” in Chapter 4 can contain oxides since EDS analysis and some of the line scans revealed oxygen on the surface after thermal shock (see Figure 4.39 of a spectrum analysis of sample after 60 cycles of thermal shock at 1000°C).

The staining increased in intensity as the temperature increased (see Section 4.3.1.1). As mentioned in Section 4.3.2.1, the oxygen peak in the EDS spectra was lower than the Co peak next to it after 60 cycles at 600ºC and 800ºC but became higher than the Co peak after 80 and 100 cycles at 800ºC and 60 cycles at 1000ºC. These observations suggest that the oxidation increased as both thermal shock cycles and thermal shock temperature increased.

The XRD analysis shown in Appendix C confirmed the formation of WO_3 after 60 thermal shock cycles at 1000°C. This observation agrees with other the authors who observed the same oxides when subjecting WC-Co alloys to high temperatures

[30,31]. These observations point to the “stain” layer as oxides. These oxides are known to be brittle and porous as explained in the literature survey. Their porousness contributed to the initially high wear rate observed after thermal shock and evidently increased with increasing temperature.

5.4 Calcium compound formation

It was interesting to observe after thermal shock a calcium compound on the surface of the samples which increased in number with the heating temperature as explained in section 4.3.2.1. The calcium compound was found to be Ca_2C by using the XRD (see Appendix C). The calcium peaks did not show differences when varying thermal shock cycles which imply that the density of the calcium compound on the surface is dependent on the heating temperature as shown by the calcium peaks when varying thermal shock cycles (see Section 4.3.2.1).

During drilling in mining different temperatures can be achieved and water that is used to flush away crushed rocks can contain different compounds. These compounds on the surface can buildup only when heating and quenching without abrasive wear. But during rock drilling this layer will not build up because thermal shock and wear occur simultaneously. Therefore it is doubtful that the formation of the calcium compound has a significant effect on wear.