Effect of Manganese on the Microstructure of Cemented Carbides

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Abstract

The plastic deformation behavior of cemented carbides is related to the WC grain boundary strength. Ab initio calculations predict that Co and Mn segregate to WC/WC grain boundaries. To experimentally study the effect of Mn, a WC-Co-Mn material was manufactured and compared to a WC-Co material. The microstructure was studied using scanning electron microscopy (SEM), including electron backscatter diffraction (EBSD). Special attention was paid to the WC grain size and the frequency of special low-energy grain boundaries. Mn was found to have negligible effect on both the WC grain growth and the fraction of Σ2 WC/WC boundaries in the as-sintered material.

Keywords : **WC-Co, Mn, EBSD, grain boundary segregation**

1. Introduction

The plastic deformation behavior of cemented carbides during operation is related to the WC grain boundary strength. Recent *ab initio* calculations by Christensen and Wahnström[1] predict that Co and Mn will segregate to WC/WC grain boundaries. These calculations also suggest that the presence of Co and Mn at WC/WC interfaces increases their work of separation, hence strengthening the grain boundaries. It has been experimentally verified that Co segregates to the WC/WC grain boundaries[2].

To investigate these predictions, Mn was added to a cemented carbide alloy.

2. Experimental and Results

The WC-Co-Mn was produced using conventional powder metallurgical routes. This includes mixing by milling for 8 h, drying, compaction and sintering. The sintering was performed at 1410 °C for 1 h in vacuum. As Mn-source pure Mn powder was used (Koch-Light Lab Ltd. Mn powder 99.9w%). Special precautions were taken to minimize the amount of sulphur to prevent the formation of MnS. The chemical composition of the materials is given in Table 1 and the physical properties of the materials are given in Table 2. The microstructure of the materials is shown in Figs. 1 and 2.

To study the impact of Mn on the WC grain size EBSD was used. The EBSD system was also used to measure the fraction of low energy Σ2 WC/WC boundaries in the materials (Table 3). The Σ2 WC/WC boundaries exist where the grains have a rotation of 90 degrees about the [10-10] axis. Brandon's criterion [3] is used for level of acceptance of deviation from the CSL; *i.e.* 10.6 degrees. The results of the EBSD investigations are given in Table 3.

Table 1. Chemical analysis of the as-sintered Mn material and reference in mass%.

Compositions	W*	C	Co	Mn
WC-Co-Mn	84.26	5.44	9.90	0.17
WC-Co	84.80	5.41	9.89	0.00

* W by difference

Table 2. As-sintered properties of Mn material and reference.

	HC* (kA/m)	S**	Dens. (g/cm^3)	Porosity (ISO4505)	HV3
WC-Co-Mn	13.2	0.87	14.55	A01B00 C00	1390
WC-Co	14.1	0.87	14.58	A00B00 C00	1397

* Coercivity ** Relative magnetic saturation to Co (by weight)

In order to detect any Mn segregation to WC/WC grain boundaries, a transmission electron microscopy (TEM) specimen was produced. The specimen was studied using a Philips CM200 FEG-TEM equipped with a Link Isis energy-dispersive X-ray spectrometry (EDS) system. Four WC/WC grain boundaries were investigated with EDS. No Mn was detected. The result from a typical boundary is shown in Fig. 3. The non-zero signal from the Co in the WC is a specimen preparation artifact.

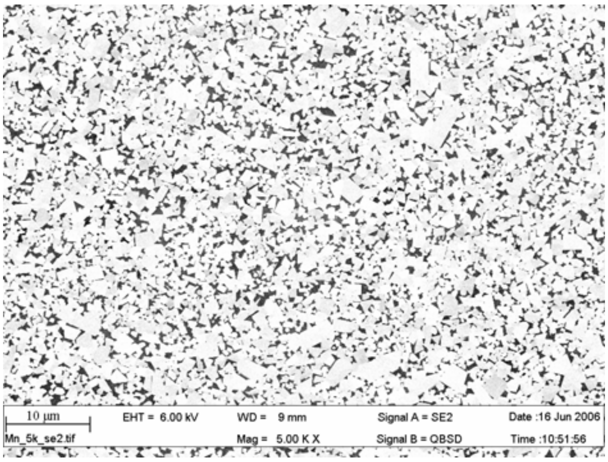

Fig. 1. SEM image of the WC-Co-Mn material.

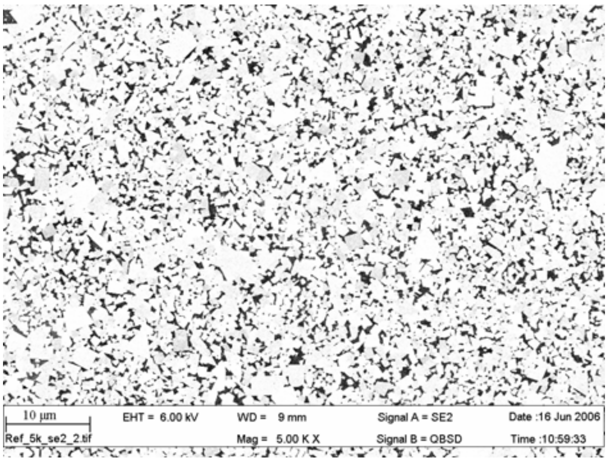

Fig. 2. SEM image of the WC-Co material.

Table 3. Grain size measurements from EBSD (equivalent circle diameter) and fraction of Σ2 WC/WC boundaries (length of Σ2 boundaries / total high angle boundary length).

	Mean grain size (µm)	Std dev. of grain size distribution	Fraction of Σ2 WC/WC boundaries
WC-Co-Mn	0.69	0.41	0.177
WC-Co	0.71	0.41	0.175

Two grain boundaries in the Mn material were analyzed with an energy compensated tomographic atom probe (EcoTAP) produced by CAMECA. Both grain boundaries contained approximately half a monolayer of Co. No Mn atoms could be detected. The reconstruction of one of these analyses is shown in Fig. 4.

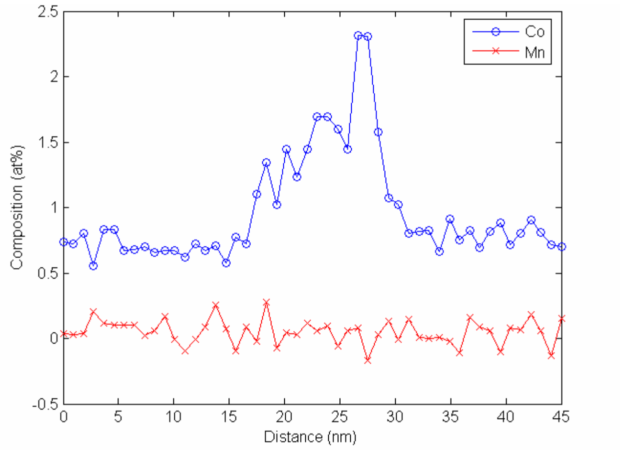

Fig. 3. EDS analysis across a WC/WC grain boundary.

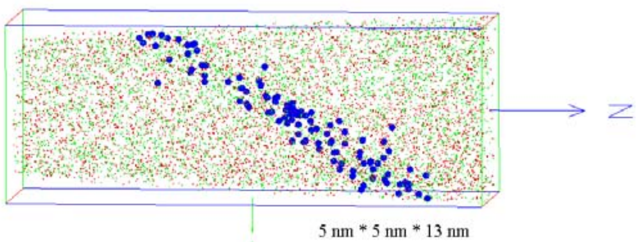

Fig. 4. EcoTAP analysis of WC-Co-Mn material. Co atoms are magnified.

3. Summary and conclusions

According to the present investigation Mn was found to have negligible effects on the WC grain growth and the fraction of Σ2 WC/WC boundaries in the as-sintered material by means of EBSD. However, there is a difference in the coercivity value. The reason for this needs further investigations.

In the manufactured material, no Mn was detected at the WC/WC grain boundaries by means of TEM/EDS and atom probe.

4. References

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