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The dependence of the contiguity of WC on Co content and its independence from WC grain size in WC–Co alloys

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Abstract

This paper reports the results of a systematic investigation which has confirmed that the contiguity of the carbide phase in WC–Co alloys is only a function of cobalt content. The investigation, which was based on a wide range of WC–Co alloys varying in cobalt content as well as grain size, has also shown that the contiguity of the carbide phase has an approximately constant value (≈0.25) at cobalt volume fractions $V_{Co} > \cong 0.20$ (but $\neq 1$). This result is consistent with the observed tendency of WC grains to coalesce into groups of two or more at high cobalt contents, with the formation of WC/WC boundaries of energy lower than twice the energy of WC/Co interfaces.

Keywords: WC–Co; Contiguity

1. Introduction

Contiguity was defined by Gurland in 1966 [1] as "the fraction of the total internal surface area of a phase that is shared by particles of the same phase". Therefore, by definition, the contiguity can vary between 0 and 1. In WC–Co the contiguity of the carbide phase has been assumed to tend to zero when the cobalt volume fraction tends to one and to tend to one when the cobalt volume fraction tends to zero. Measured values of contiguity have confirmed that the contiguity of WC in WC–Co decreases with increasing Co content (e.g. Ref. [2]) but have not shown conclusively whether the contiguity depends on WC grain size, mostly because results from contiguity measurements have always shown large scatter [3,4]. For example, Lee and Gurland's results [2] suggest that (for equal cobalt content) the larger the WC grain size the larger is the contiguity of the carbide phase, while Sigl and Fischmeister's results [5], which have been plotted in Fig. 1, suggest the opposite.

The present investigation aimed at verifying that the contiguity of the WC phase depends on cobalt content but not on grain size. The basis of the hypothesis that the contiguity of WC does not depend on grain size is that micrographs of two WC–Co grades of equal cobalt content and grain size "x" and "ax", at magnifications of "ay" and "y" respectively, would appear identical, since the two grades of equal composition would appear to have the same grain size and the same mean free path in the binder. Since contiguity measurements do not depend on the magnification of the micrographs used for the measurements [1], the two grades would have the same contiguity.

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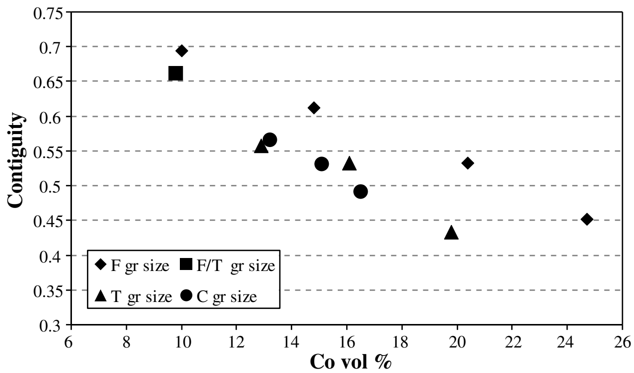

Fig. 1. Plot of Sigl and Fischmester's contiguity results vs the cobalt volume fraction of their samples, from one of their papers [5]. F, F/T, T and C are symbols used by Sigl and Fischmeister to designate fine, fine/medium, medium and coarse grain sizes.

2. Method

This investigation was based on a wide range of WC–Co grades varying in cobalt content from 5 to 64 vol% and in grain size from about 0.7 to 5 μm (see Table 1). These grades were produced by O'Quigley [6] for an investigation on the dependence of some mechanical properties of WC–Co on composition and microstructure [7,8]. The cobalt content and the microstructural parameters were measured by O'Quigley [6] by linear analysis [9] and the processing conditions were optimized for each grade, so that larger grain sizes were not obtained by processes that would affect the contiguity, such as longer sintering times [10]. The grain size of the grades listed in Table 1 can be divided into the four groups in Table 2.

The contiguity values were obtained from high magnification micrographs, using the following formula [1]:

$$C = \frac{2N_{\alpha\alpha}}{2N_{\alpha\alpha} + N_{\alpha\beta}} \tag{1}$$

Table 2
The groups into which the samples in Table 1 were divided on the basis of their mean WC grain size, for the purpose of plotting results versus Co content at constant grain size

Groups of grades	Mean WC grain size (μm)
UF (ultra fine)	0.6 ± 0.04
F (fine)	1.1 ± 0.18
T (medium)	3.0 ± 0.37
C (coarse)	5.1 ± 0.44

where C is the contiguity of the carbide phase and $N_{\alpha\alpha}$ and $N_{\alpha\beta}$ are the average number of intercepts of a random line of unit length with traces of carbide–carbide interfaces and carbide–cobalt interfaces respectively [1].

The results from the contiguity measurements were plotted by O'Quigley [6] against cobalt content for each of the four grain sizes, as shown in Fig. 2. The results exhibit a large scatter, except in the case of the ±5 μm grades. The large scatter in these contiguity results is in agreement with the results of other investigators [3,4] and has been claimed to be due to variations in grain size distribution [3].

This investigation consisted of verifying that the contiguity of WC in WC–Co can be expressed as a function of only one variable: the cobalt content. This was done by two methods:

(i) *First method*: It was investigated if Lee and Gurland's definition of contiguity [2]

$$C = 1 - \frac{V_{Co}}{(1 - V_{Co})\lambda/d}, \tag{2}$$

where d = WC grain size, λ = mean free path in Co, V_{Co} = Co volume fraction, could be reduced to a relationship between C and V_{Co} only.

(ii) *Second method*: It was investigated if an analytical expression of the type $C = f(V_{Co})$ existed, which would fit the experimental results in Fig. 2.

Table 1
Summary of the grades used in this investigation, their cobalt content and their measured microstructural parameters

	Grain size (μm)	MFP (μm)	Contiguity		Grain size (μm)	MFP (μm)	Contiguity	Co vol fraction		Grain size (μm)	MFP (μm)	Contiguity		Grain size (μm)	MFP (μm)	Contiguity
								0.05					**C3**	5.30	0.74	0.61
				F4	1.30	0.19	0.51	**0.07**					**C4**	5.10	0.76	0.50
				F6	1.27	0.27	0.47	**0.10**	**T6**	2.66	0.50	0.41	**C6**	5.32	1.12	0.46
								0.13	**T8**	2.65	0.66	0.38	**C8**	5.21	1.18	0.32
UF10	0.60	0.20	0.41	**F10**	1.07	0.30	0.30	**0.16**	**T10**	2.60	0.86	0.41	**C10**	4.77	1.40	0.33
UF12	0.62	0.25	0.40	**F12**				**0.19**	**T12**	2.97	1.18	0.39	**C12**	4.89	1.62	0.27
UF14	0.59	0.26	0.35	**F14**	1.17	0.55	0.39	**0.22**					**C14**	5.88	2.32	0.27
UF16	0.65	0.28	0.21					**0.25**					**C16**	5.10	2.19	0.22
								0.28	**T18**	3.47	1.69	0.21	**C18**	5.65	2.72	0.20
UF20	0.56	0.37	0.33	**F20**	0.96	0.60	0.29	**0.31**					**C20**	5.08	2.91	0.23
UF30	0.66	0.67	0.25	**F30**	0.84	1.05	0.39	**0.43**					**C30**	4.86	5.04	0.27
UF40	0.61	0.96	0.25	**F40**	0.86	1.41	0.29	**0.54**	**T40**	3.34	5.25	0.25	**C40**	4.13	6.26	0.22
UF50	0.56	1.22	0.19	**F50**	0.96	2.35	0.28	**0.64**	**T50**	3.27	7.37	0.22	**C50**	4.71	10.75	0.23