Controlling Mechanical Properties of Ultra-fine WC-10%Co Cemented Carbides for Precision Molds

精密金型用超微粒 WC-10%Co 超硬合金の機械特性制御

Kenji FUJIMOTO

藤本　賢二

Key words ; Hardness, transverse rupture strength, fracture toughness, inhibitor, grain growth
キーワード ; 硬さ，　抗折力 , 破壊靭性 , 抑制剤 , 粒成長

Abstract

Mechanical properties of ultra-fine cemented carbides for precision molds are affected by VC and Cr_3C_2 which are added to as grain-growth inhibitors. Therefore, the addition effects of VC and Cr_3C_2 on ultra-fine WC-10%Co cemented carbides were investigated. It was confirmed that on the basis of hardness, the grain growth-inhibiting effect score of Cr_3C_2 is 0.38 with a score of 1 representing VC. We also confirmed the influence of Cr_3C_2 on the transverse rupture strength and the fracture toughness is smaller than that of VC.

精密金型用超微粒超硬合金の機械的性質は粒成長抑制剤として添加される VC と Cr_3C_2 に大きく影響を受ける。そこで WC-10%Co 超微粒超硬合金における VC と Cr_3C_2 の添加の影響を調査した。硬さを基準に VC の粒成長抑制効果を 1 とした場合、C_3C_2 の粒成長抑制効果は 0.38 であることが確認された。また、抗折力や破壊靭性値に及ぼす Cr_3C_2 の影響は VC より小さいことを確認した。

1.Introduction

With respect to WC of WC-Co cemented carbide, the smaller raw powder of WC is, the more the grains tend to grow during the sintering. Therefore, to get less than 1 μm of grain size, some kind of carbides are usually added as a grain-growth inhibitor. VC and Cr_3C_2 are widely known as the most effective inhibitors for WC-Co cemented carbide and many studies on them had been performed[1)2)], but the influence of them is still not clear. Therefore, we investigated the influence of VC and Cr_3C_2 on the mechanical properties of ultrafine WC-10%Co cemented carbide in this paper.

2.Experimental

Commercial cobalt, tungsten carbide, vanadium carbide and chromium carbide powders were used as raw powders. Details are shown in Table 1.

Table 1 Properties of raw powders

powder	size[μm]	Total Carbon [%]
WC(a)	0.44	6.09
WC(b)	0.70	6.17
Co	1.5	-
VC	0.8	17.52
Cr_3C_2	1.6	13.39

VC and Cr_3C_2 in the range 0.05-0.60% were added to WC-10% Co (mass %). The mixing was done for 96hrs with methanol solvent in a ball mill. The slurry after mixing was dried and green compacts (5×10×30 mm) were prepared under a pressure of 98 MPa. These were finally sintered for 1.5hrs at 1673K in vacuum atmosphere and HIP treatment was also applied for 0.7hr at 1613K under a pressure of 40MPa N_2.

Table 2 Composition of the specimens

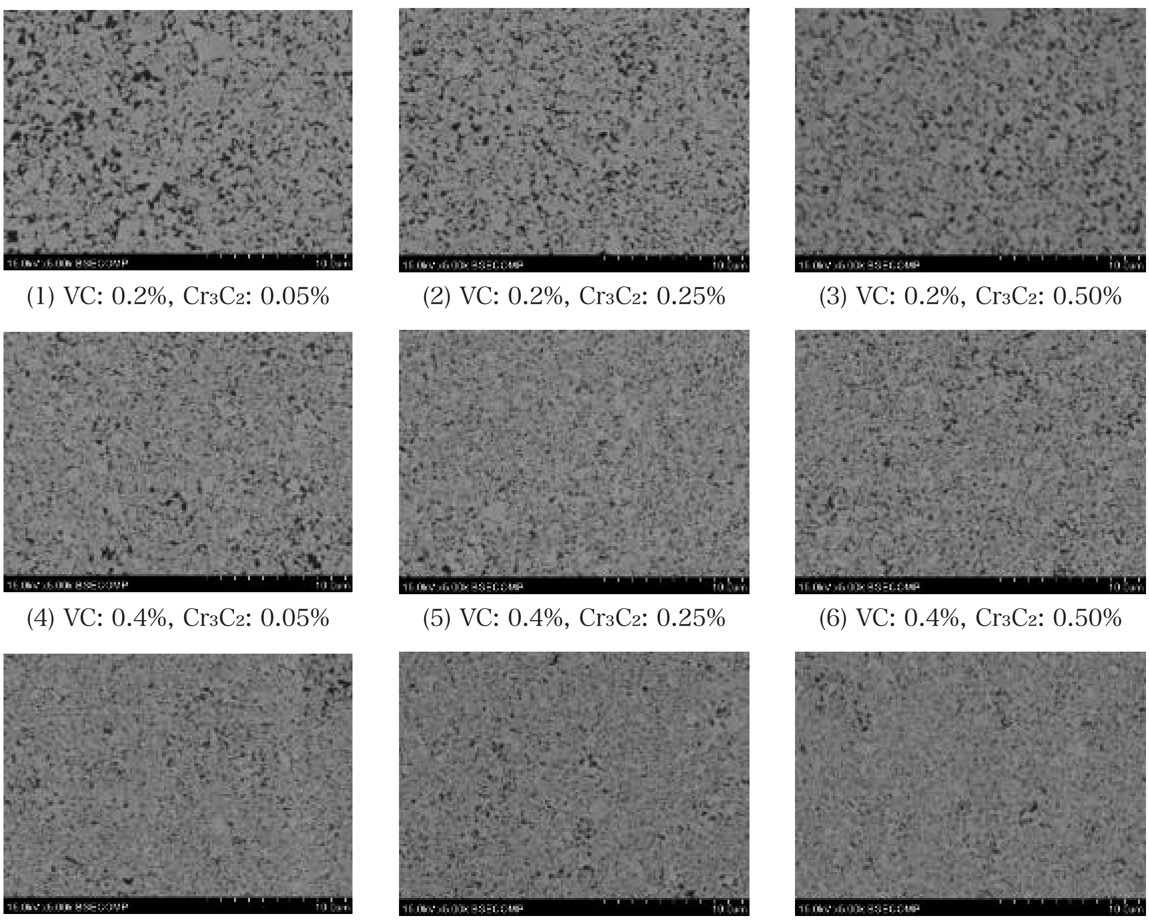
WC[%]		Co	VC	Cr_3C_2	sum	C(th)	SG(th)
WC(a)	WC(b)	[%]	[%]	[%]	[%]	[%]	[-]
Bal.	17.90	10.0	0.20	0.05	100.0	5.55	14.49
				0.25		5.56	14.45
				0.50		5.58	14.41
			0.40	0.05		5.57	14.43
				0.25		5.59	14.40
				0.50		5.60	14.35
			0.60	0.05		5.60	14.38
				0.25		5.61	14.35
				0.50		5.63	14.30

Sintered specimens were evaluated by specific gravity (SG), relative density (RD), hardness by HRA and HV30, transverse rupture strength (TRS) and fracture toughness by K1C.

3.Results and Discussion

3.1 Microstructure

Each of microstructures is shown in Fig.1. WC grain size can be measured by these pictures and becomes smaller as the additive amount of VC and Cr_3C_2 increases, indicating that VC and Cr_3C_2 inhibit the grain growth of WC in WC-Co cemented carbide as reported. In addition, these photographs also show that the addition effect of VC is larger than that of Cr_3C_2.



(1) VC: 0.2%, Cr_3C_2: 0.05%
(2) VC: 0.2%, Cr_3C_2: 0.25%
(3) VC: 0.2%, Cr_3C_2: 0.50%
(4) VC: 0.4%, Cr_3C_2: 0.05%
(5) VC: 0.4%, Cr_3C_2: 0.25%
(6) VC: 0.4%, Cr_3C_2: 0.50%
(7) VC: 0.6%, Cr_3C_2: 0.05%
(8) VC: 0.6%, Cr_3C_2: 0.25%
(9) VC: 0.6%, Cr_3C_2: 0.50%

Fig.1 Microstructures of WC-10% Co cemented carbide with various additive amounts of VC and Cr_3C_2

3.2 Effect on hardness

Although it is well known that the effect of VC as a grain-growth inhibitor is larger than that of Cr_3C_2, we tried to compare them in detail here in order to grasp the difference quantitatively. We usually measure a grain size of WC with its microstructure, but the grain boundary is not clear due to its ultrafine size and the resolution limit of a scanning electric microscope. In this study, therefore, we decided not to use the grain size for evaluation but tried to evaluate the grain-growth inhibiting effect by hardness of the cemented carbide which is strongly correlated with the grain size.

Figs. 2 and 3 show addition effects of VC and Cr_3C_2 on Rockwell hardness of the cemented carbide, respectively. In both cases, the hardness increases as the additive amount increases, and the effect of VC is larger.

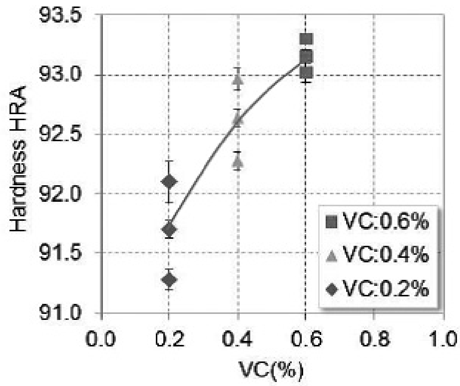


Fig. 2 Effect of VC on Hardness

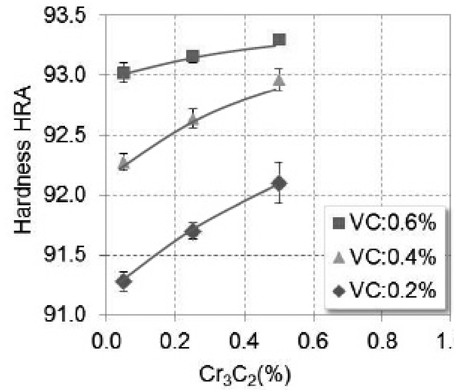


Fig. 3 Effect of Cr_3C_2 on Hardness

In order to estimate the addition effects of VC and Cr_3C_2 quantitatively, we defined a value of Z as follows at first:

Z=x×(additive amount of VC) + y × (additive amount of Cr_3C_2), x and y are arbitrary units.

Then, we prepared a graph representing hardness on the vertical axis and Z on the horizontal axis when x=1 (i.e., standardized with the additive amount of VC) and performed a regression analysis changing the value of y. Finally, we estimated the effect score of Cr_3C_2 with a score of 1 representing the grain growth-inhibiting effect of VC by calculating a value of y where the squared value of R is the highest.

Fig.4 shows a relation between the grain-growth inhibiting effect of Cr_3C_2 (y) and the squared value of R from the regression analysis of Z (x=1, y) and hardness. The value of y in HRA hardness is 0.37 and that in HV30 hardness is 0.39 where the squared value of R is the highest. Therefore, the grain-growth inhibiting effect of Cr_3C_2 is considered to be the average, 0.38.

Fig.5 shows a relation between Z (=VC (%) +0.38Cr_3C_2 (%)) and HRA hardness when y=0.38.

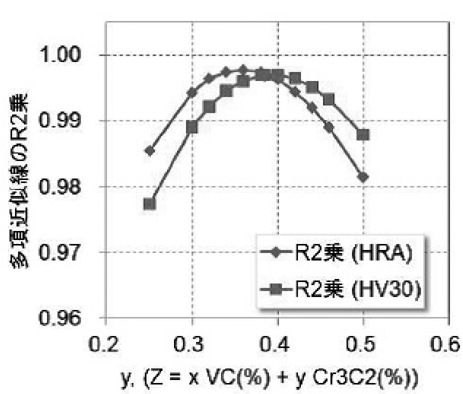


Fig. 4 Effect of VC on Hardness

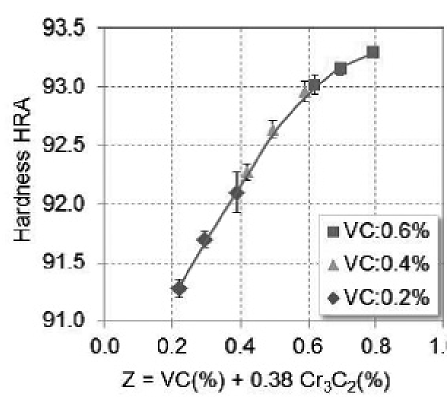


Fig. 5 Relation between Z (=VC (%) +0.38Cr_3C_2 (%)) and HRA hardness when y=0.38

3.3 Effects on Transverse Rupture Strength (TRS)

We converted the addition effects of VC and Cr_3C_2 on TRS to the grain growth-inhibiting effect score ($Z=$ VC (%) $+0.38Cr_3C_2$ (%)) using the results in Section 3.2 and prepared a graph.

The TRS slightly decreases and the deviation (the error bar shows a standard deviation, n=5) becomes smaller as Z increases. The reason why the deviation is larger when Z is 0.5 or less is probably because the grain growth-inhibiting effect is weak and the microstructure of cemented carbide is inhomogeneous.

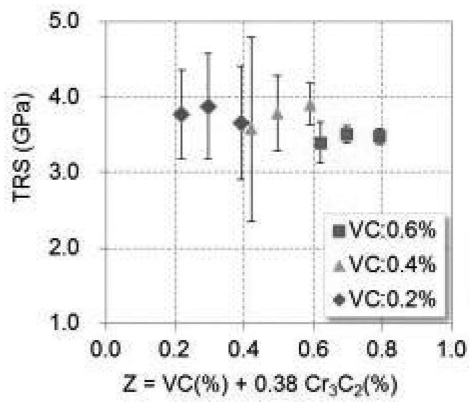


Fig. 6 Relation of Z ($VC+0.38Cr_3C_2$) and TRS (Average)

3.4 Fracture Toughness

Fig.7 is a graph showing the addition effects of VC and Cr_3C_2 on the fracture toughness (Indentation fracture method with a load of 30kgf, calculated from Evans's equation) which are converted to the grain growth-inhibiting effect scores. In general, fracture toughness is inversely proportional to hardness, but in this graph showing the hardness as the grain growth-inhibiting effect, the data of 0.20% VC and is greatly different from 0.40%, suggesting that the addition effect of VC is greater than the grain-growth inhibiting effect.

To separate the effects of VC and Cr_3C_2, we prepared graphs representing addition effects of VC and Cr_3C_2 on the horizontal axis, respectively, as shown in Fig. 8 and 9. In Fig. 8, the fracture toughness decreases as the additive amount of VC increases. On the other hand, the additive amount of Cr_3C_2 doesn't affect the fracture toughness in Fig.9, thus Cr_3C_2 is deemed to have little influence on the fracture toughness.

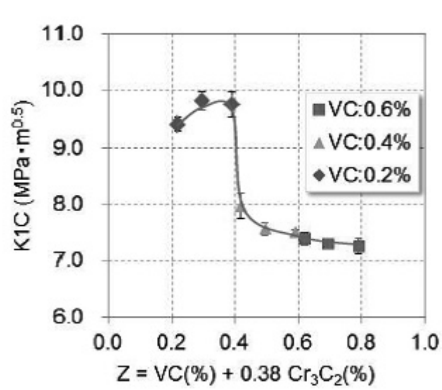


Fig.7 Relation of Z ($VC+0.38Cr_3C_2$) and Fracture Toughness (K1C)

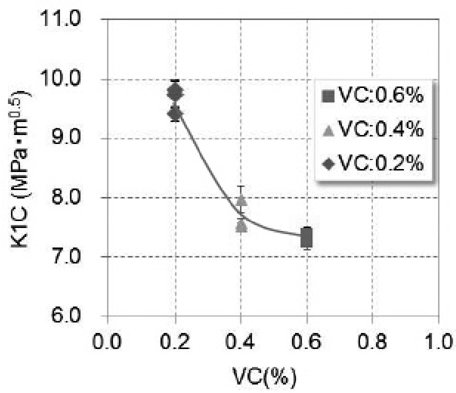


Fig.8 Relation of VC and Fracture Toughness (K1C)

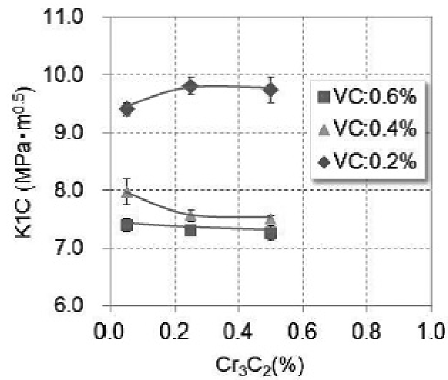


Fig.9 Relation of Cr_3C_2 and Fracture Toughness (K1C)

4.Conclusions

Addition effects of VC and Cr_3C_2 on mechanical properties of ultrafine WC-10% Co cemented carbide were investigated.

It was confirmed that on the basis of hardness, the grain growth-inhibiting effect score of Cr_3C_2 is 0.38 with a score of 1 representing VC. We also confirmed the influence of Cr_3C_2 on the transverse rupture strength and the fracture toughness is smaller than that of VC.

5.References

[1] Hayashi, Suzuki, et al.: Powder and Powder Metallurgy, 19 (1972), 67-71

[2] Hayashi, Suzuki, et al.: Powder and Powder Metallurgy, 19 (1972), 106-112