Carbon and Cobalt Diffusion in Liquid Phase Sintering of WC-Co with Gradient Composition

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Abstract

In this study, the diffusion behaviors of C and Co in liquid phase sintering of WC-Co system were investigated whether these two components diffused in the same direction in case of having opposite gradient each other with not being η phase. The green compacts with controlled compositions in not being of η phase and gradient composition which one is WC-5Co-1.2%C, the other is WC-XCo-0.2%C (where X = 5, 10, 15, 20, 25) were sintered at 1350℃ and 1400℃ and then the diffusion behaviors of C and Co were investigated by analyses of compositional change, also determined for microstructure and microhardness. Also, same testing was carried out on the specimens with dual layers sintered in upright and reverse positions to evaluate the effect of gravity on the diffusion in liquid Co.
From the results of this study, we can find the fact that the direction of diffusion for C and Co in WC-Co system during liquid phase sintering was different and the effect of gravity for the liquid was insignificant. Also other physical properties were changed on the diffusion of elements.

Keywords : Diffusion, WC-Co system, Dual phase, Gradient, Hard metal

1. Introduction

It was well known theoretically on the liquid phase sintering mechanism of WC-Co system using in widely as the material for mold and tool because of high wear resistance and TRS.[1] And in same system the effect of carbon on the carbide formation, carbide shape, and microstructure also were well studied by many researcher.[2]

At the these aspect, some studies were carried out to make the ideal combination using composition gradient material with comprised in surface layer with a very high hardness and inner layer with a high TRS[3].

By the way, it has been proved that the movement of atomic C and Co during sintering in WC-Co has the same directions regardless of differences in Co content. According to the previous works, this phenomenon was only occurred under the condition of existence both a compositional gradient of C and η phase, meaning lower C than its stoichiometric content, at a part of lower C content.[4] They discussed in same works that the diffusion of atomic C and Co has the same directions regardless of the compositional gradient of Co since the reaction between η phase and C diffused from a part of higher C content provides more liquid Co, just like the formula of $(W_3Co_3)C+2C \rightarrow 3WC + 3Co$. And the liquid Co diffuse to the region of lower C content because of corresponding distribution of the volume fraction of the liquid phase [4].

This study was carried out to verify the discussions of previous works for the diffusion directions of C and Co in WC-Co during sintering process under the condition of inexistence both η phase and a reverse compositional gradient of C and Co. Also the effect of gravity on the diffusion of liquid phase was investigated.

2. Experimental procedure

In this study, WC powder (0.5㎛, DaeguTec), Co powder (NCo 600, 5㎛, Changsung) and C powder (3.3㎛) were used as the starting materials. The each powder was mixed as follow table 1. In order to inhibition of the η phase, excess carbon of 0.2wt% was more added

Table 1. The Symbol and Composition for specimen having gradient

Symbol	First Composition	2nd Composition
0205-1205	0.2C-5Co	1.2C-5Co
0210-1205	0.2C-10Co	
0215-1205	0.2C-15Co	
0220-1205	0.2C-20Co	
0225-1205	0.2C-25Co	

The powder compaction was compressed with dual layer and sintered at 1350 and 1400℃ for 1hour using a vacuum furnace. Dimension, hardness and density were checked. And then specimens was cut and polished to observe optical

microstructure. The content of C and Co was analyzed by a scanning electron microscopy (SEM), and an energy dispersive X-ray analysis (EDX) as regular intervals for determination of diffusion distance.

3. Results

The micrographs of vertical cross section were shown at Fig. 1. SEM-EDX results on moving of Co and C after sintering are shown Fig. 1, 2 with metallograph for the cross-section. The η phase is not appeared in any composition and condition. Co and Carbon did not diffuse in same direction.

In case of (a) of Fig. 1, which had same content of 5%Co, but carbon content differ, carbon diffused to opposite direction(left on Figure) during sintering and then size of it, free carbon, reduced. Diffusing area was widening and carbon content becomes a flat.

In case of (b) ~ (d), similar diffusions by moving of liquid to lower liquid area on the "pore filling effect" were found. Carbon also moved by solving and diffusing in liquid Co to the lower area. But the case of (e), which had 25% Co content, a non - diffused area remained in one side because of slow diffusivity of Co

The size of free carbon of excess carbon area was increased with cobalt content increasing because carbon melts rapidly in much liquid. In low Co content, its size was smaller than it's of higher Co content. It may occurred by uniform solving of carbon in liquid. The η phase was not founded in whole specimen. The carbide shape were triangle or trapezoid because of sufficient carbon.[5]

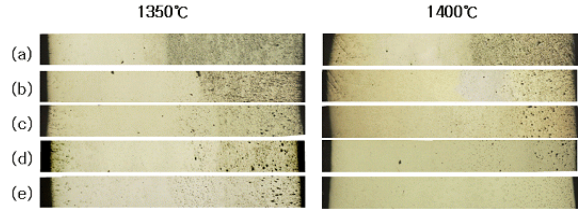

Fig. 1. Macro metallography at each composition after 1350℃ and 1400℃ sintering during 1 hr. Right side is 1205 area. (a) 0205-1205 (b) 0210-1205 (c) 0215-1205 (d) 0220-1205 (e) 0225-1205.

SEM and EDX were used in analyzing of content for W, Co and carbon.. EDX were detected to 5 points at 14 sectional areas of each specimen.

Fig. 2, 3 are showed the combination of microphotograph and SEM-EDX results. Fig. 2 showed same Co content (5%) but different carbon content(0205-1205) after sinetring at 1350℃for 1hr. Carbon was diffused to opposite side. There is interface and small change in carbon content. Fig. 1 represented the case of different carbon and cobalt content at an opposite gradient (0225-1205). Carbon and cobalt diffused to opposite side independently and respectively. It means carbon and cobalt diffuse to low potential area without interruption. there is a high cobalt area as above mentioned.

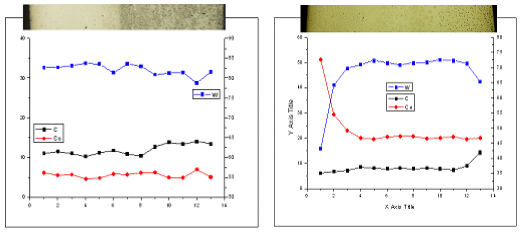

Fig. 2. Composition for specimen sintered at 1350℃. (left) 0205, (right) 1205. Fig. 3 Composition for specimen sintered at 1350℃. (left) 0225, (right) 1205.

Testing for hardness and density were measured (Fig. 4). Hardness in high carbon area was lower than low carbon area because of free carbon. Measured density range is 98-99%.

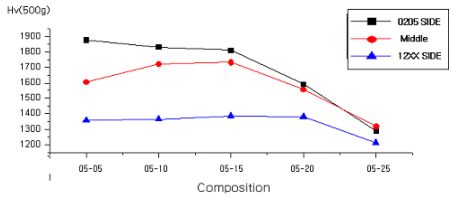

Fig. 4. Hardness of specimen as gradient composition.

4. Conclusions

Conclusions from this study are as follows;

1. Diffusion direction of Co atom was opposite to that of carbon atom after liquid phase sintering in WC-Co system not being η phase consisted of material pair which carbon and cobalt has an opposite gradient of content respectively. The fact is no doubtable that this phenomenon was occurred by diffusion.
2. The diffusion of carbon and cobalt were diffused independently and respectively. In case of pair of 25% Co-0.2C and 5%Co-1.2C, however, there is the less diffused zone in part of the higher cobalt side.
3. The size of residue free carbon was increased with increasing cobalt content.

5. Acknowledgments

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6. References

[1] Encycl. of Chem. tech. Sup. vol. 2nd ed. JW&S (1971) 278-293
[2] Abelin H, Gidlund J and Neretnieks I, (1982): Migration in a Single Fracture, Lutze W(ed), Elsevier Sci Pub Co, 529-538
[3] Alexander WR, Scott RD, MacKenzie AB and McMinley IG (1988) Radiochimica Acta, 44/45 283-289
[4] Fang Z. Scripta Materialia 52(2005) 785-791
[5] Han SH, Park JK and Huh MY, J KPMI 6;4 (1999) 307-313