Journal of the Korean Ceramic Society
Vol. 30, No. 6, PP. 429~432, 1993

# Toughening of Ni Bonded $Cr_3C_2$ by Mo Particulates

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(Received March 22, 1993)

# Mo 입자에 의한 Ni 결합 $Cr_3C_2$의 고인성화

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(1993년 3월 22일 접수)

**ABSTRACT**

$Cr_3C_2$ material is characterized by high chemical stability and poor sinterability with low strength [50~150 MPa]. In his study, low melting temperature nickel powder was used to improve sinterability as well as strength. In addition, molydenum particles were added to the Ni-bonded $Cr_3C_2$ cermet pseudomatrix to increase resistance to fracture. The specimens made by hot-pressing under vacuum and strength was measured by 4-point bending. Indentation cracking and fractographic examination were conducted to study the interaction of the indentation cracks with the reinforcing particles. Toughening mechanisms and failure will be discussed in terms of crack/particle interactions and compared with previous works.

**요 약**

$Cr_3C_2$는 높은 화학적 안정성을 가진 반면 미약한 소결성으로 일반적으로 낮은 강도[50~150 MPa]를 가지는 재료로 알려져 있다. 본 연구에서는 저융점의 금속 Ni을 첨가하여 소결성 및 상온강도를 증진시켰으며, 금속결합 세라믹 복합체에 Mo 입자를 첨가하여 파괴 저항성을 향상시켰다. 시편은 진공 가압 소결로 제작하였으며, 4점곡강도 방법으로 상온강도를 측정하였다. 압흔방법 및 파단면 관찰로 입자와 균열 상호간의 관계를 실험적으로 알아보았으며 복합체의 고인성화 기구를 본 연구 및 기존 연구 발표와 비교해 보았다.

## 1. Introduction

In recent years, several toughening mechanisms have been suggested for improving the properties of brittle materials, especially fracture toughness[1,2]. The first mechanism is the use of crack-impeding second phases. The 2nd phase particles disturb the advancing crack, which can lead to changes in the shape, size, and direction of crack propagation[3-6]. In a ductile dispersoid-brittle matrix composite has been shown that advancing crack front passes through the interface or is blunted when it encounters the ductile dispersoids, resulting in plastic deformation of the metal particles[7-9].

Crack deflection or multiplication produces tilting and twisting of the advanced crack front and can be another toughening mechanism. The deflection mechanism originates in the presence of a stress field surrounding second phase particles along the matrix-particle interface, in which the stress is caused by property mismatches. The particle-crack interactions result in a reduction of the stress-intensity in resultant sets of crack and in mixed mode failure[10,11].

The crack surface bridging by ductile phases is broadly accepted to be one of primary toughening mechanisms in ductile-brittle composites. If a crack in the matrix propagates through the metal inclusions, the cracks will be bridged by intact particles. The second phase dispersoids could act as a bridge between the opposing faces of the crack, avoiding further crack opening and reducing the energy for more crack pro-

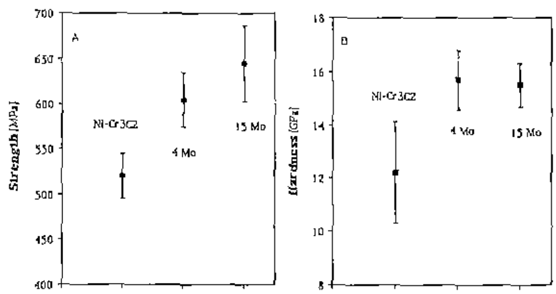


**Fig. 1.** Plots flexural strength (A) and hardness (B) of cerments.

pagation[12-15].

The toughening of the brittle matrix by the dispersion of ductile phases has been previously studied[11-17]. In general, the results indicate that the trends toward an increase in resistance to fracture [$\Delta K_c$] with increase *in size* [$R$] *and volume fraction* [$F$] *of metal* particles;

$$\Delta K_c \propto \sqrt{RF} \tag{1}$$

The influence of metal reinforcements was more conveniently analysed using Eq. 1 instead of crack length and geometric constant. A simple expression for toughening of composites can be described as following;[15]

$$K_c = A\sigma_{y,m}\sqrt{RF} \tag{2}$$

where A is the contant and $\sigma_{y,m}$ is the yield strength of metal particles.

## 2. Experimental Procedures

*Molybdenum* particles* (5~10 μm) were dispersed in Ni* (15 wt%)-$Cr_3C_2$* pseudo matrix and the mixtures were hot-pressed at 1300℃, 20 MPa under vacuum condition. The specimens were cut and machined into rectangular bars with dimension of 3×4×40 mm. 4-point *flexural test (10 mm inner & 30 mm outer span* length) was used strength and indentation method was adopted for hardness and the fracture toughness measurements.

The fracture toughness was calculated by eq. (3);[18]

$$K_c = 0.016\sqrt{\frac{E}{H}}\,PC^{-3/2}$$

*Mo, Ni, $Cr_3C_2$ powder: Hermann C. Starck

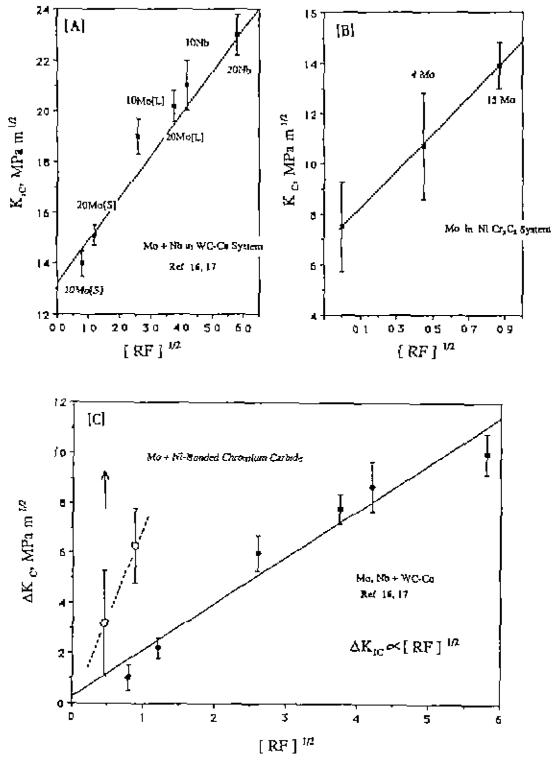


**Fig. 2.** *Plots of fracture toughness (A, B) and increase* in toughness (c).

where P is the indentation load and C is the crack length. The indentation was repeated 3 times for each *load (50N, 100N, 200N). The trace of the indentation*-produced crack was used to infer particle-crack interaction and fracture surface analysis was also used to find failure sources and pattern.

## 3. *Result and Discussions*

The Fig. 1 and 2 summarize the mechanical properties of the hot-pressed $Cr_3C_2$ cermets. Hot-pressing at 1300℃ with 20 MPa pressure densified the composites to within 97~98% of theoretical densities. The strength (Fig. 1(A)) of composites increases with the content of Mo second phases (4 vol%=5 wt%, 15 vol%=20 *wt%). Fig. 1(B) shows that the addition of Mo increa*ses the hardness of the composites, compared to that of 15 wt% Ni-85 wt% $Cr_3C_2$, even though hardness generally decreases with increase in metallic phase in metal-ceramic composites. However, there is no obvious difference between 4 vol% and 15 vol%.

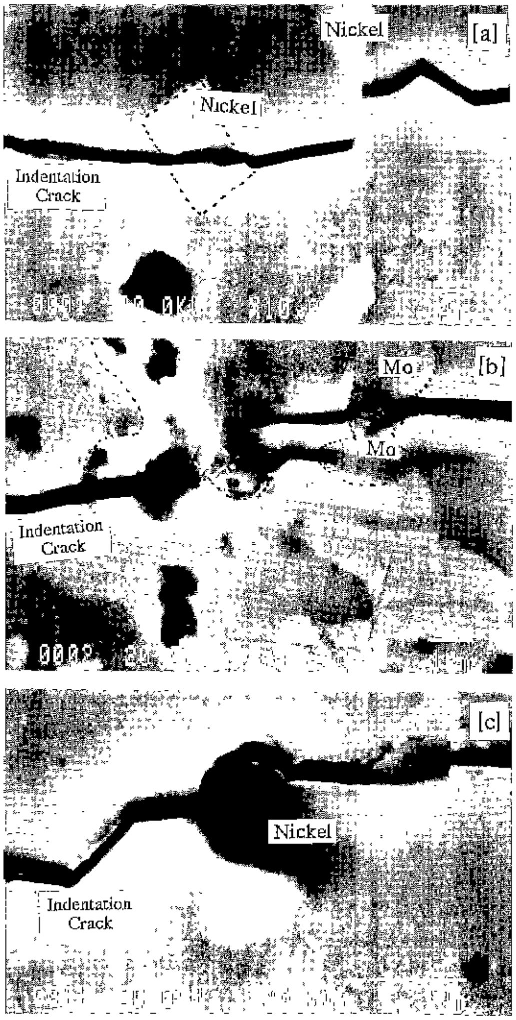


**Fig. 3.** Scanning electron photographs illustrating the interaction of crack with metal phases; (a) crack penetration and deflection, (b) crack brdging, and (c) crack deflection.

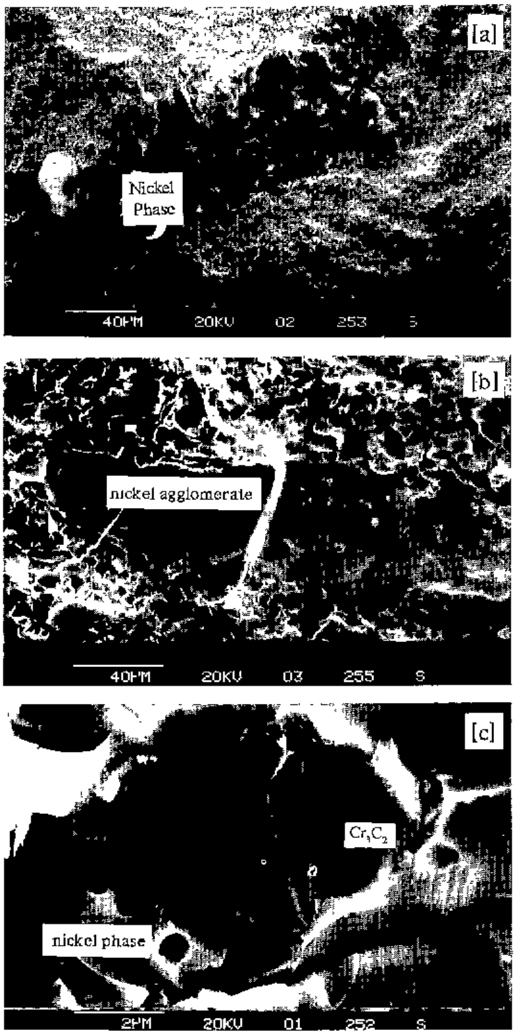


**Fig. 4.** Scanning electron photographs showing failure-initiating sources.

Fig. 2 shows the relation of racture toughness as a function of size and volume fraction of dispersoids. The data in this study are compared to those of Han and Mecholskys' work[16,17]. The metallic phase in both WC-Co and $Cr_3C_2$-Ni system increases the fracture toughness. The figure clearly illustrates that volume fraction and particle size are important toughening factors in ductile particles-brittle matrix composites (Eq. 1, 2).

As seen in Fig. 3, the metallic particles disturb the crack propagation. Indentation crack penetrates nickel particle, which did not completely melt during densification, and deflects around methal particle (Fig. 3(a), (c)). In addition, crack bridging behavior by Mo dispersoids can be seen in Fig 3(b). The interactions of ductile phase with crack mentioned above might account for increase in fracture toughness of Ni bonded $Cr_3C_2$ composites.

Fractographic examination of fractured bars reveals that the failure sources are inhomogenieties of microstructure, mainly the excessively dispersed nickel phase in certain region due to improper mixing, and pores due to shrinkage of metal binder during cooling stage. The improvement in manufacturing process might increase the strength of composites. Both intergranular and transgranular fractures were observed in $Cr_3C_2$ matric composites.

## 4. Conclusions

The strength of $Cr_3C_2$ can be increased by low-temperature melting nickel phase and the fracture toughness of cermets can be improved by dispersion of metallic particles. This study shows that the size and volume fraction of ductile particles are major factors in controlling crack propagation. The toughning mechanisms involved in the toughnening of Mo reinforced Ni-$Cr_3C_2$ are generally crack deflection and crack bridging. Fracture surface analysis shows that the failure-initiating sources are associated with microstructural defects, e.g., pores and binder clusters.

In addition to the investigation of toughening mechanism, this study also suggests that $Cr_3C_2$ can be not only coating material but also structural material if proper additives be used.

## REFERENCES


1. J.A. Cornie, Y.M. Chiang, D.R. Vhlmann, A. Mortensen and J.M. Collins, "Processing of Metal and Ceramic Composites," *Ceram. Bull.*, **65**(2), 293-304 (1986).
2. R.w. Rice, "Mechanisms of Toughening in Ceramic Matrix Composites," *Ceram Sci & Eng. Proceeding*, **2**(7-12), 661-701 (1981).
3. D.J. Green and P.S. Nicholson, "Fracture of Brittle Particulate Composites," in Fracture Mechanics, Vol. IV, ed. by R.C. Bradt, A.G. Evans, D.P.H Hasselman, and F.F Lange, 945-960, Plenum Press. New York, 1973.
4. F.F. Lange, "The Interaction of a Crack Front with a Second-Phase Dispersion," *Phil Mag.*, **22**, 983-992 (1970).
5. A.G. Evans, "The Strength of Brittle Materials Containing Second Phase Dispersiona," *ibid.*, **26**, 1327-1344 (1972).
6. R.W. Davidge and T.J. Green, "The Strength of Two-Phase Ceramic/Glass Material," *J Mater. Sci*, **3**, 629-634 (1968)
7. C.O. Mchugh, T.J. Whalen, and M. Humenik, Jr., "Dispersion-Strengthed Alumina Oxide," *J. Am. Ceram. Soc.*, **49**(9), 486-491 (1966).
8. D.T. Rankin, J.J. Stiglich, D.R. Petrak and R. Ruh, "Hot-pressing and Mechanical Properties of $Al_2O_3$ with an Mo-Dispersed Phase, *ibid*, **54**(6), 277-281 (1971)
9. V.V. Kirstic, P.S. Nicholson and R.G. Hoagland, "Toughening of Glass by Metallic Particles," *ibid*, **64**(9), 499-504 (1981).
10. K.T. Faber and A.G. Evans, "Crack Deflection Process—I. Theory," *Acta Metall*, **31**(4), 565-576 (1983).
11. K.T. Faber and A.G. Evans, "Crack Deflection Process—II. Experiment," *ibid.*, **31**(4), 577-584 (1983).
12. F. Erdogan and P.F. Joseph, "Toughening of Ceramics thorugh Crack Bridging by Ductile Particles," *J. Am. Ceram Soc*, **72**(2), 262-270 (1989).
13. F. Erdogan, "The Interaction between Inclusions and Crack," in Fracture Mechanics, Vol I, edited. by R.C. Bradt, A.G. Evans, D.P.H. Hasselman, and F.F. Lange, 245-267. Plenum Press. New York, 1973.
14. L.S. Sigl, P.A. Mataga, B.J. Dalgleish, R.M. McMeeking and A.G. Evans, "On the Toughness of Brittle Materials Reinforced with a Ductile Phase," *Acta Metall.*, **36**(4), 945-953 (1988).
15. A.G. Evans and R.M. McMeeking, "On the Toughening of Ceramic by Strong Reinforcements," *ibid.*, **34**(12), 2435-2441 (1986).
16. Dongbin Han, Ph.D. Thesis. The Pennsylvaniak State University. 1990.
17. Dongbin Han and Jack J. Mecholsky, "Fracture Behavior of Metal Particulate-Reinforced WC-Co Composites," *Mater. Sci & Eng*, 293-302 (1991).
18. G.R. Antis, P. Chantikul, B.R. Lawn and D.B. Marshall, "A Critical Evaluation of Indentation Techniques for Measuring Fracture Toughness· I Direct Crack Measurements," *J. Am. Ceram. Soc.*, **64**(9), 533-538 (1981)