A R C H I V E S O F M E T A L L U R G Y A N D M A T E R I A L S
Volume 60 2015 Issue 2
DOI: 10.1515/amm-2015-0157

D.-K. KIM*, I.-J. SHON**, J. SONG*, W.-J. RYU*, H.-CH. SHIN*, E.-Y. KWON*, H. SHIN*, S.-J. KANG***,♯

A STUDY ON THE METAL CARBIDE COMPOSITE DIFFUSION BONDING FOR MECHANICAL SEAL

BADANIE ŁĄCZENIA DYFUZYJNEGO KOMPOZYTU METAL WĘGLIK NA MECHANICZNE USZCZELNIENIE

Mechanical Seal use highly efficient alternative water having a great quantity of an aqueous solution and has an advantage no corrosion brine. Metal Carbide composites have been investigated as potential materials for high temperature structural applications and for application in the processing industry. The existing Mechanical seal material is a highly expensive carbide alloy, and it is difficult to take a price advantage. Therefore the study of replacing body area with inexpensive steel material excluding O-ring and contact area which demands high characteristics is needed.

The development of WC-Ni base carbide alloy optimal bonding composition technique was accomplished in this study. To check out the influence of bonding temperature and time, bonding characteristics of sintering temperature was experimented. The bonding statuses of this test specimen were excellent. The hardness of specimen and bonding rate were measured using ultrasound equipment.

In this work, Powder of WC (involved VC, Cr), Co and Mo_2C mixed by attrition milling for 24hours. Nanostructured WC-27.6wt.%Ni-1.5wt.%Si-0.11wt.%VC-1.1wt.%B_4C composite were fabricated at 1190°C by high temperature vacuum furnace. To check out the influence of bonding temperature and time, bonding characteristics of sintering temperature was experimented. Its relative density was about 99.7%. The mechanical properties (hardness and fracture toughness) were 87.2 HRA and 4.2 M·Pam$^{1/2}$, respectively. The bonding status of this test specimen was excellent and the thickness of bonding layer was 20 ~30§ at 1050 and 1060°C bonding temperature.

Keywords: diffusion bonding, nanostructures, mechanical seal, hard metal, mechanical properties

1. Introduction

A mechanical seal is a device designed to help join mechanisms or systems together by containing pressure or preventing leakage. The existing Mechanical seal material is a highly expensive carbide alloy and usually use Co as a liquid phase binder. However, cobalt is not economically attractive and the resultant cemented carbide has low corrosion resistance [1]. This has prompted considerable efforts to find a satisfactory alternative binder [2-4]. The focus on Ni as a binder has been motivated by results showing higher corrosion and oxidation resistance [5]. And also, in order to take a price advantage, it is required to replace body area with inexpensive steel material excluding O-ring and contact area which demands high characteristics.

WC hard materials are widely used for a variety of machining, cutting, drilling, and other applications. Morphologically, they consist of a high volume fraction of hard hexagonal WC phase embedded within a soft and tough Co or Ni binder phase [6]. WC-Co and WC-Ni hard materials are formed by sintering WC powders with a binder (typically Co or Ni) at a temperature near the melting point of the metal and the mechanical properties of these materials depend on their composition and microstructure (especially on the grain size of the carbide phase [7]. In general, decreasing WC particle size enhances the composites' mechanical properties such as hardness, wear resistance, and transverse rupture strength [8]. Increasing the volume fraction of binder increases the fracture toughness at the expense of hardness and wear resistance [9, 10].

Nanocrystalline materials, as advanced engineering materials, have received much attention due to their improved physical and mechanical properties. It is one of main keys to control grain growth during sintering from nanosized powder because The grain size in sintered materials becomes much larger than that in pre-sintered powders due to a fast grain growth. In this regard, the roles of binders such as Ni, Si and B_4C which can make dense WC materials to be consolidated at the temperature of 1190°C were investigated.

Diffusion bonding is a promising approach for high temperature joints [11, 12]. And diffusion bonding, a solid-state bonding process that allows the contact surfaces to be joined

* TECHNOLOGY RESEARCH DIVISION, KOREA INSTITUTE CARBON CONVERGENCE TECHNOLOGY, 110-11, BANRYONG, JEONJU, 561-844, REPUBLIC OF KOREA
** DIVISION OF ADVANCED MATERIALS ENGINEERING, RESEARCH CENTER OF ADVANCED MATERIALS DEVELOPMENT, CHONBUK NATIONAL UNIVERSITY, 664-14 DEOKJIN-DONG 1-GA, DEOKJIN-GU, JEONJU, JEONBUK 561-756, REPUBLIC OF KOREA
*** MECHANICAL DESIGN ENGINEERING, CHONBUK NATIONAL UNIVERSITY, JEONJU, KOREA
♯ Corresponding author: kangsj@jbnu.ac.kr

under pressure and at elevated temperatures with minimum macroscopic deformation, has been used for the bonding of almost all the metallic materials with incompatible chemical and metallurgical properties, whose bonding is not appropriate by classical welding methods [13]. This bonding process does not introduce the formation of unexpected phases at the bond interface that may occur in some advanced materials, and the usual defects in fusion welding processes such as crack, hole, and segregation can be avoided [14, 15].

2. Experimental process

2.1. The fabrication of WC-27.6wt.%Ni-1.5wt.%Si-0.11wt.%VC-1.1wt.%B_4C composite

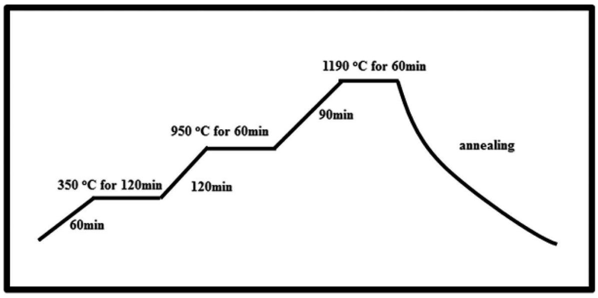

Fig. 1. The sintering pattern of WC composites used in this study

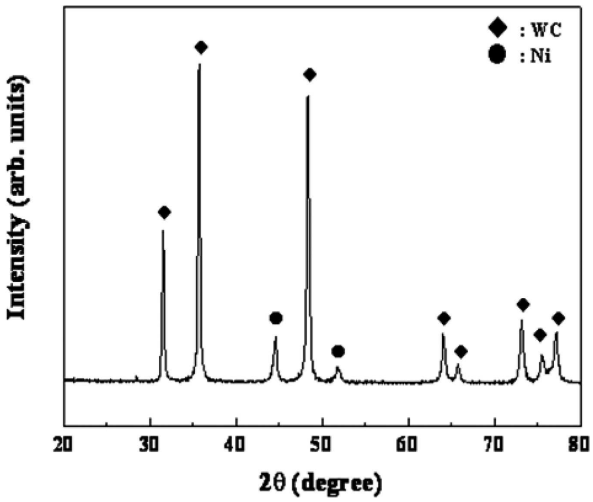

Fig. 2. X-ray diffraction of WC-27.6wt.%Ni-1.5wt.%Si-0.11wt.% VC-1.1wt.%B_4C composite sintered at 1190°C

WC and Ni powders were used as raw materials. The composition of WC-27.6wt.%Ni-1.5wt.%Si-0.11wt.%VC-1.1 wt.%B_4C powder were milled by attrition ball milling method for 24h. After milling process, milled powder was sintered up to 1190°C by high temperature vacuum furnace. Fig. 1 indicates the sintering pattern of WC-27.6 wt.%Ni-1.5wt.%Si-0.11wt.%VC-1.1wt.%B_4C composite. The process was carried out under a vacuum of 0.03 torr. The relative density of the WC-27.6wt.%Ni-1.5 wt.%Si-0.11wt.%VC-1.1wt.%B_4C composite was measured by Archimedes' method and was about 99.7%. In order to analyze compositional and microstructural information, X-ray diffraction (XRD) and field emission scanning electron microscope (FE-SEM) were used. XRD patterns of sintered sample are shown in Fig. 2. In the Fig. 2, only WC and Ni peaks were observed, as marked. Fig. 3 shows the FE-SEM image of the sintered composite. Well-dispersed fine grains of WC in the Fig. 3 were observed and the average grain size of WC was about 300 nm. The composition of WC was developed through below steps.

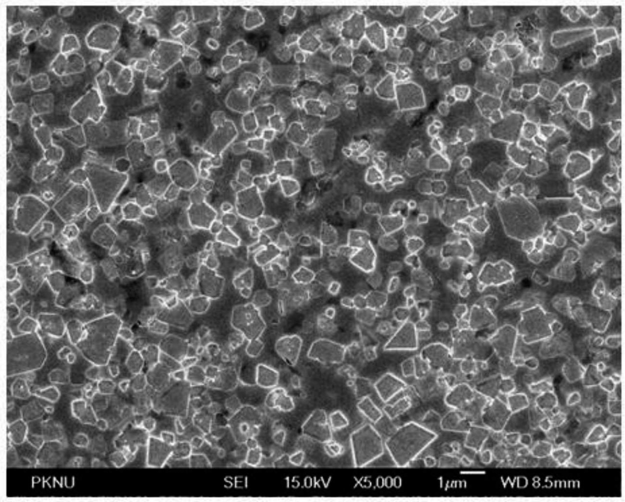

Fig. 3. FE-SEM image of WC-27.6wt.%Ni-1.5wt.%Si-0.11wt.% VC-1.1wt.%B_4C composite sintered at 1190°C

2.1.1. The fabrication of WC-Ni composite.

Based on the theory of the liquid phase sintering, the quantity of liquid phase sintering binder has a significant role in fabricating dense WC. In this study, Ni was used for WC sintering binder and the proper quantity of Ni binder on WC were experimented with 21.6, 23.6, 25.6 and 27.6wt.%Ni as shown Table. 1. Fig.4 indicates optical images of the WC-Ni composites according to the quantity of Ni binder. In the Fig. 4(d), the WC composite with 27.6wt.%Ni was a proper composition to fabricate a dense structure.

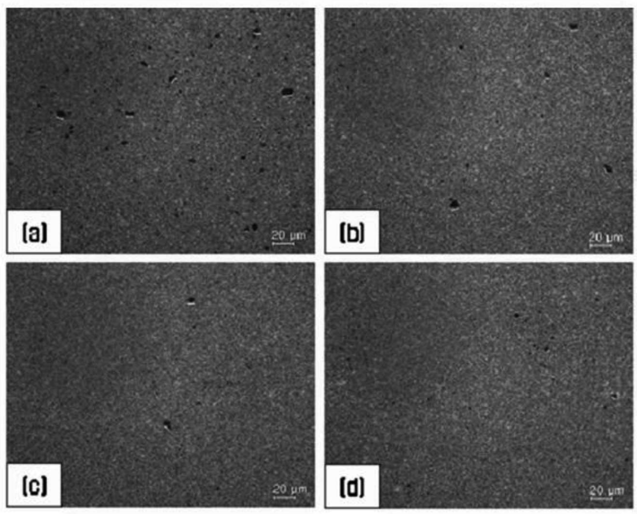

Fig. 4. Optical microscope image of WC-Xwt.%Ni composite. (X = (a) 21.6, (b) 23.6, (c) 25.6 and (d) 27.6wt.%Ni)

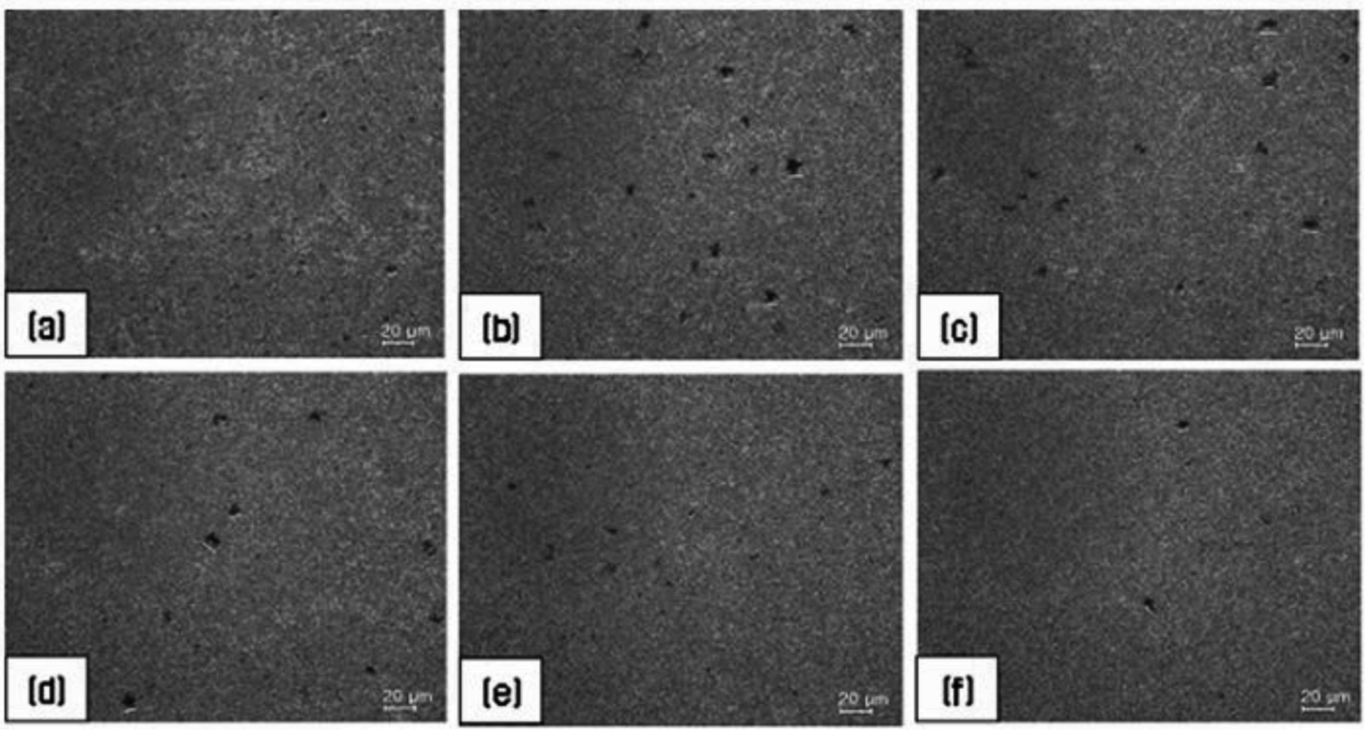

Fig. 5. Optical microscope image of WC-27.6wt.%Ni composite with Xwt.%Si. (X = (a) 0, (b) 0.3, (c) 0.6, (d) 0.9, (e) 1.2 and (f) 1.5wt.%Si)

TABLE 1
The composition of WC-Xwt.%Ni composite

No.	Composition
(a)	WC-21.6wt.%Ni
(b)	WC-23.6wt.%Ni
(c)	WC-25.6wt.%Ni
(d)	WC-27.6wt.%Ni

2.1.2. The fabrication of WC-Ni-Si composite

Liquid-phase binders were required to sinter the WC which generally could not be consolidated at the 1190°C. As above mentioned that Ni was used to sinter WC, Ni used as liquid-phase binder cannot be useful material for sintering WC because the melting point of Ni is higher than 1190°C. In this regard, Si is a proper material to decrease the melting point of Ni. Table. 2 represent the composition of WC-Ni composite with 0, 0.3, 0.6, 0.9, 1.2 and 1.5 wt.%Si. Fig. 5 indicates optical microscope of the above composition samples sintered at 1190°C. In the Fig. 5(f), a number of pores are removed and even the size of pores tend to be smaller than the others. Fig. 6 indicates the shrinkage rate of sintered samples according to Xwt.%Si (X = 0 ~1.5). Based on the results, dense WC-27.6 wt.% Ni-1.5 wt.%Si composite is one of the most dense and proper structure.

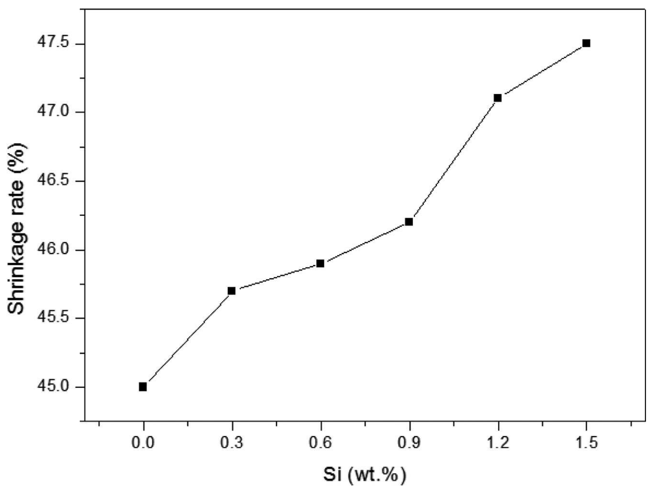

Fig. 6. The results of shrinkage rate of WC-27.6wt.%Ni composite with Xwt.%Si. (X = 0, 0.3, 0.6, 0.9, 1.2 and 1.5wt.%Si)

TABLE 2
The composition of WC-27.6wt.%Ni composite with Xwt.%Si

No.	Composition
(a)	WC-27.6wt.%Ni
(b)	WC-27.6wt.%Ni-0.3wt.%Si
(c)	WC-27.6wt.%Ni-0.6wt.%Si
(d)	WC-27.6wt.%Ni-0.9wt.%Si
(e)	WC-27.6wt.%Ni-1.2wt.%Si
(f)	WC-27.6wt.%Ni-1.5wt.%Si

2.1.3. The fabrication of WC-Ni-Siu-B_4C composite

Zener pinning is the influence of a dispersion of fine particles near grain boundary in the polycrystalline [16]. Small particles act to prevent the motion of such boundaries by exerting a pinning pressure which counteracts the driving force pushing the boundaries. Thus, we thought that B_4C function to interrupt grain growth as shown Fig. 7. Fine and uniform grains existed in the Fig. 7(d) and therefore, WC-27.6 wt.% Ni-1.5 wt.%Si –1.1wt% B_4C is a suitable for diffusion bonding material due to its dense microstructure.

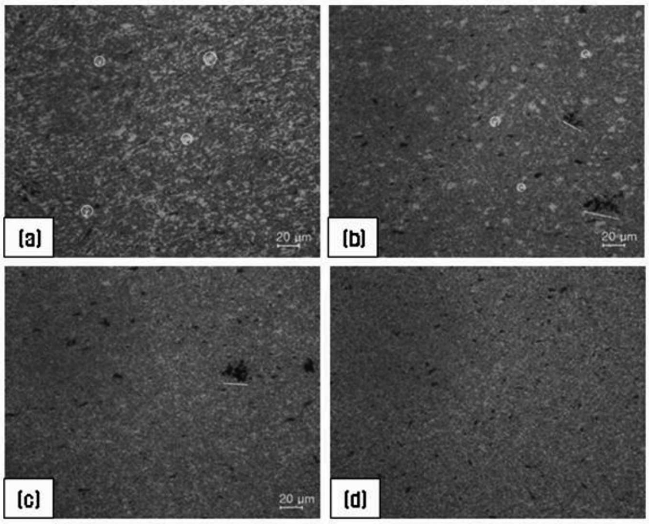

Fig. 7. Optical microscope image of WC-27.6wt.%Ni-1.5wt.%Si composite with Xwt.%B_4C. (X = (a) 0.3, (b) 0.6, (c) 0.9 and (d) 1.1wt.%B_4C)

2.2. The development of bonding technique on the WC-27.6 wt.% Ni-1.5 wt.%Si-1.1wt.% B_4C composite and a steel material

The diffusion bonding tests of the WC-27.6wt%Ni-1.5wt% Si-0.11wt%VC-1.1wt%B_4C composite and a steel material were conducted in high temperature vacuum furnace as shown Fig. 8 and the change of bonding process pattern is shown Fig. 9. Having a significant role in bonding process, bonding temperature and holding time in the bonding tests were choosen as independent variables and the conditions is shown in Table 3. All of bonding tests were processed at the bonding temperature of 1050 ~1060°C with 10°C temperature interval and holding time of 30, 60 and 90minutes.

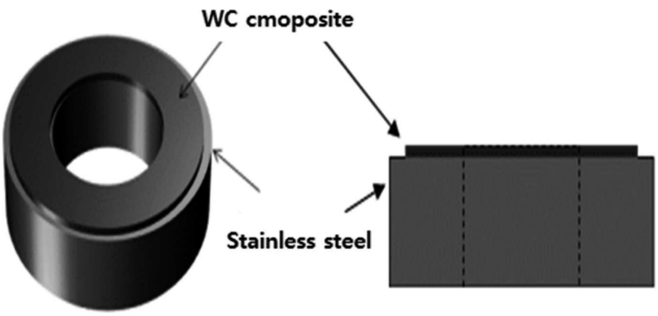

Fig. 8. Schematic diagram of WC-27.6wt.%Ni-1.5wt.%Si-0.11wt.% VC-1.1wt.%B_4C composite and stainless steel for diffusion bonding

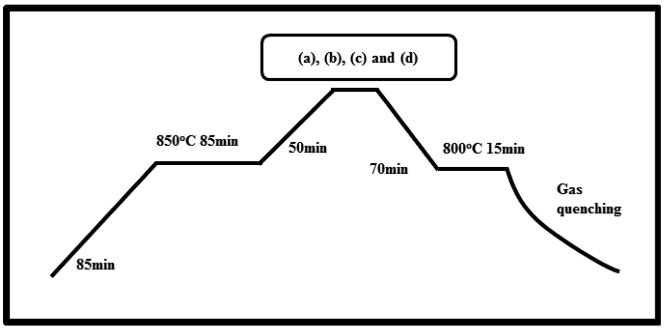

Fig. 9. Diffusion bonding patterns of WC-27.6wt.%Ni-1.5wt.%Si-0.11 wt.%VC-1.1wt.%B_4C composite and stainless steel

TABLE 3

The conditions of diffusion bonding between WC-27.6wt.%Ni-1.5wt.%Si-0.11wt.%VC-1.1wt.%B_4C composite and stainless steel

No.	Condition
(a)	At the temperature of 1050°C for 30 min
(b)	At the temperature of 1050°C for 60 min
(c)	At the temperature of 1050°C for 90 min
(d)	At the temperature of 1060°C for 30 min

3. Results and discussion

The diffusion bonding of WC-27.6wt%Ni-1.5wt%Si-0.11 wt%VC-1.1wt%B_4C composite and a steel material were conducted in high temperature vacuum furnace. The thickness changes in interlayer between WC-27.6wt.%Ni-1.5wt.%Si-0.11wt.%VC-1.1wt.%B_4C composite and a steel material according to temperatures and holding times were shown in the Fig. 10 which shows the optical microscope image of the joints bonded interlayer. Interlayer of WC-27.6wt.%Ni-1.5wt.%Si-0.11wt.%VC-1.1wt.%B_4C composite and a steel material were bonded at 1050°C and 1060°C for different holding time. The more the bonding temperature and holding time increase, the more the thickness of the interlayer was thickened. The thickness of bonding layers was 20 ~30§ at the bonding temperature of 1050 ~1060°C. The thickness differences caused by bonding temperature and holding time exert influence on the mechanical properties of interlayer as shown Fig. 11. The Rockwell hardness of interlayer of WC-27.6wt.%Ni-1.5wt.%Si-0.11wt.%VC-1.1wt.%B_4C composite and a steel material were similar to that of WC-27.6wt.%Ni-1.5wt.%Si-0.11wt.%VC-1.1wt.%B_4C composite and higher than that of the steel material. By considering the Rockwell hardness results of the interlayer, it is possible for mechanical seals to be fabricated by diffusion bonding using WC and a steel material. This production process could result in a lot of advantage such as cost reduction, weight lightening and ease of machining.

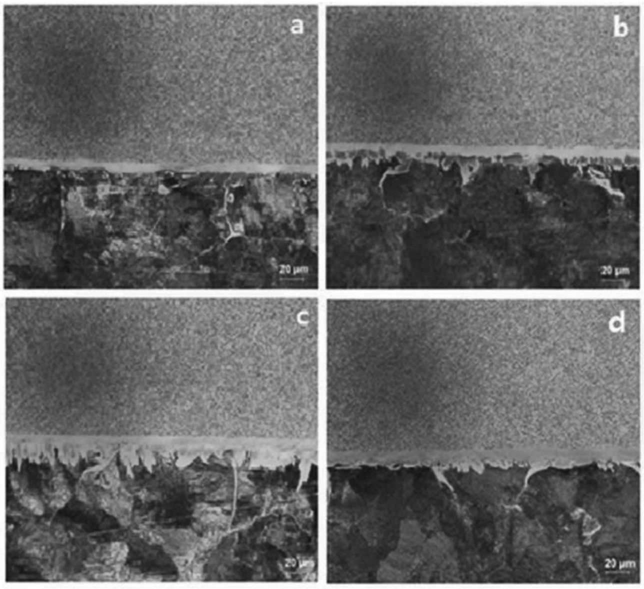

Fig. 10. Optical microscope image of bonding area between WC-27.6wt.%Ni-1.5wt.%Si-1.1wt.%B_4C composite and stainless steel

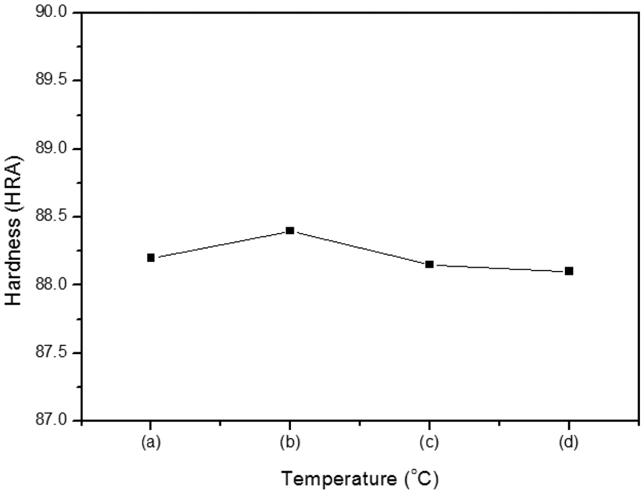

Fig. 11. The hardness results of bonding area between WC-27.6wt.%Ni-1.5wt.%Si-1.1wt.%B_4C composite and stainless steel

4. Conclusions

The fabrication of hard metal, WC-27.6wt.%Ni-1.5wt.%Si-0.11wt.%VC-1.1wt.%B_4C, was accomplished at 1190°C in high temperature vacuum furnace. The temperature sintered in this study was generally lower than that of WC composite thanks to the binder of Ni, Si and B_4C. The appropriate amount of Ni, Si, B_4C binder for sintering WC was investigated. The micro-structural information of WC-27.6wt.%Ni-1.5wt.%Si-0.11wt.%VC-1.1wt.%B_4C was investigated by FE-SEM and the average grain size of WC in the composite was about 300 nm. The WC-27.6wt.%Ni-1.5wt.%Si-0.11wt.%VC-1.1wt.%B_4C composite was successfully bonded with a steel material at 1050 ~1060°C for 30, 60 and 90 holding time. The bonding thicknesses of interlayer between WC-27.6wt.%Ni-1.5wt.%Si-0.11wt.%VC-1.1wt.%B_4C and steel are from 20 to 30 and then Rockwell hardnesses of the area are also from 88.2 to 88.4. Based on high mechanical properties, mechanical seals designed by diffusion bonding between WC-27.6wt.%Ni-1.5wt.%Si-0.11wt.%VC-1.1wt.%B_4C and the steel material can result in positive effect on cost reduction, weight lightening and ease of machining.

Received: 20 November 2014.

REFERENCES

[1] S. Imasato, K. Tokumoto, T. Kitada, S. Sakaguchi, Int. J. Refract. Met. Hard Mater. **13**, 305 (1995).

[2] E.A. Almond, B. Roebuck, Mat. Sci. Eng. A **105**, 237 (1988).

[3] G. Gille, J. Bredthauer, B. Gries, B. Mende, and W. Heinrich, Int. J. Refract. Met. Hard Mater. **18**, 87 (2000).

[4] P. Goeuriot and F. Thevenot, Ceram. Int. **13**, 99 (1987).

[5] S.H. Choi, S.D. Kang, Y.S. Kwon, S.G. Lim, K.K. Cho, I.S. Ahn, Res. Chem. Intermed. **36**, **7**43 (2010).

[6] Hirata, H. Zheng, M. Yoshikawa, Diamond and Related Mater. **7**, 1669 (1998).

[7] M. Sherif El-Eskandarany, J. Alloys and Compounds **305**, 225 (2000).

[8] M. George, J. Iniguuze, L. Bellaiche, Nature **413**, 54 (2001).

[9] S.G. Shin, Metal and Materials **6**, 195 (2000).

[10] M.J. Ledoux, C.H. Pham, J. Guille, H. Dunlop, J. Catalysis **134**, 383 (1992).

[11] S.Q. Ding, S.M. Zhu, Y.P. Zeng, D.L. Jiang, Ceram. Int. **32**, 461 (2006).

[12] V. Cockeram, J. Am. Ceram. Soc. **88**, 1892 (2005).

[13] S. Chen, F. Ke, M. Zhou, Y. Bai, Acta Metall. **55-9**, 3169 (2007).

[14] P. He, D. Liu, Mater. Sci. Eng. A **437-2**, 430 (2006).

[15] Y. Li, P. Liu, J. Wang, Vacuum **82-1**, 15 (2008).

[16] J. Gao, R.G. Thompson, B.R. Patterson, Acta Mater. **45**, 3653 (1997).