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An analysis of the Wi-Ni Carbide Alloy Diffusion Bonding technique in its application for DME Engine Fuel Pump

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Abstract

Dimethyl Ether(DME) engine use a highly efficient alternative fuel having a great quantity of oxygen and has a advantage no polluting PM gas. The existing DME fuel cam 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 piston shoe 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 hardness of specimen and bonding rate were measured using ultrasound equipment. The bonding state of each condition was excellent, and the thickness of mid-layer, temperature and maintaining time were measured. The mid-layer thickness according to bonding temperature and maintaining time were observed with optical microscope. We analyzed the micro-structural analysis, formation of bonding specimen, wafer fabrication and fuel cam abrasion test. Throughout this study, we confirmed that the fuel cam for DME engine which demands high durability against velocity and pressure is excellent.

Keywords: *DBM(Diffusion Bonding Method), DME(Dimethyl Ether), WC-Ni carbide alloy, carbide wafer, fuel cam.*

1. INTRODUCTION

DME(Dimethyl Ether) engine has a higher cetane number than that of diesel engine, therefore it is a highly efficient alternative fuel having a great quantity of oxygen(34.8 wt %) and has a advantage no polluting PM gas which is a toxic material of a diesel engine[1]. DME is an ether compound which is combined with one oxygen molecule and two methyl molecules. DME has a high cetane number and 70% of diesel calorific value. Also it is oxygenated alternative fuel having a great quantity oxygen. DME is non-toxic material to human, non-corrosiveness, room temperature transparent likewise LPG, and liquefied at approximately 5 bar pressure [2,3]. But DME fuel, having high compressibility number, changes density and modulus of elasticity considerably according to the change of pressure and temperature, so it is difficult not only to take the amount of fuel injection rate but also to control the fuel injection rate according to operating condition.

The fuel cam is main part of DME fuel pump. The sliding speed between piston shoe and fuel cam is average of 4.67m/sec(2,000~3000 rpm) and pressure is 8.01MPa(80bar, 0.8㎏f/㎟). The fuel cam shoe contact area, demanding high pressure and rotation speed, needs non-corrosiveness, therefore carbide alloy having a high characteristics of non-corrosiveness adopted as a shoe contact material. The existing DME fuel cam material

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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 piston shoe and contact area demanding high characteristics is needed.

The diffusion bonding process is as belows. The development of optimal bonding process of WC-Ni base carbide alloy bonding and basic material. The selection and development of optimal liquid binder contents by bonding experiment depending on the change of Ni addition [4]. The development of optimal bonding work condition of WC-Ni base carbide alloy bonding and steel base material. By using WC-Ni-Si-B4C base composition which was developed in the first stage, the minimal usage technique of carbide alloy was developed through the solid state diffusion bonding technique with steel base material as shown in figure 2 of mimetic diagram [5].

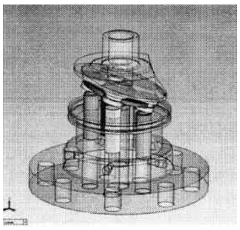


Figure 1. DME Fuel Cam

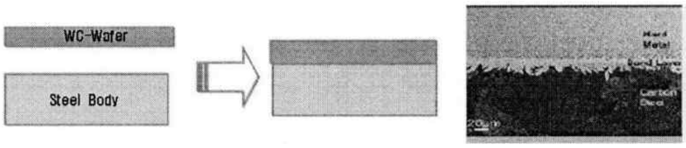


Figure 2. The Development of DME Fuel Pump Fuel Cam using Diffusion Bonding Technique

2. Test of WC-Ni base Carbide Alloy and Steel Bonding Technique

2.1 The Development of WC-Ni base Carbide Alloy and Steel Bonding Technique

The development of WC-Ni base carbide alloy optimal bonding composition technique was accomplished. To check out the influence of bonding temperature and time, bonding characteristics of sintering temperature was experimented as shown Table 1. The test condition was that the bonding temperature of 1010~1120℃ with 20℃ temperature interval and maintaining time-to-live of 30 minutes [6].

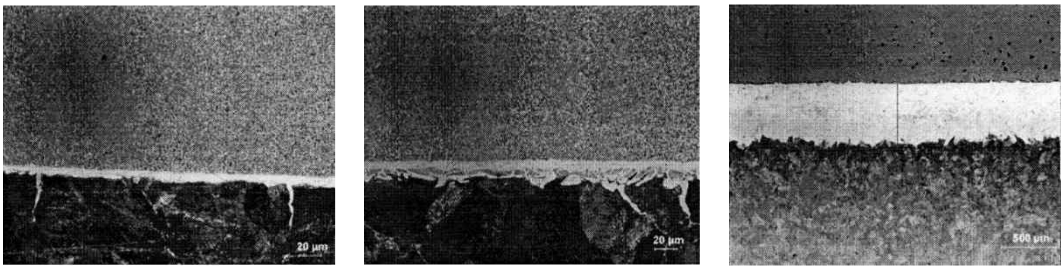
The bonding was done using vacuum furnace. After furnace cooling, gas quenching was accomplished. The hardness of specimen and bonding rate were measured using ultrasound equipment. The results of bonding rate at 1010℃ and 1070℃ using ultrasonic equipment are represented.

Table 1. Test result of bonding temperature and maintaining time

No.	Bonding temperature(℃)	Maintaining time(min)	Hardness HRA	Observation of formation	
				Bonding rate(%)	Mid-layer thickness(μm)
A	1010	30	87.1	91	10
B	1030	30	87.8	100	15
C	1050	30	87.7	100	18
D	1070	30	87.3	100	20
E	1090	30	87.9	100	25
F	1110	30	87.9	100	100
G	1120	30	87.4	100	500

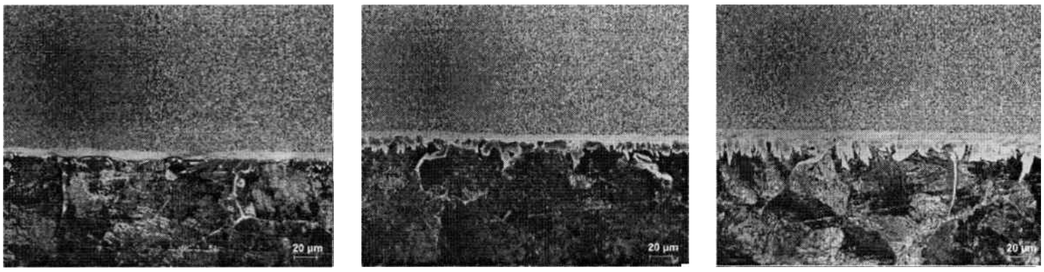
After bonding process, HRA(load 60kg) of specimen were measured, and bonding state and thickness of mid-layer were observed with optical microscope throughout the formation observation of each specimen. The bonding state of each conditions was excellent, and the thickness of mid-layer, temperature and maintaining time were measured as shown in Table 1. As a test result, thickness of bonding layer was 18~25㎛ at 1050~1090°C bonding temperature.

The mid-layer thickness according to bonding temperature and maintaining time were observed with optical microscope as shown in figure 3 and figure 4.



(a) 1030℃ (b) 1070℃ (c) 1120℃

Figure 3. Thickness change of bonding layer according to bonding temperature (30min)



(a) 30 min (b) 60 min (c) 90 min

Figure 4. Thickness change of bonding layer according to bonding maintaining time (℃)

2.2 Evaluation of bonding characteristics in WC-Ni base carbide alloy and steel bonding

The FE-SEM SEM image and COMPO image of bonding products which were sintered at 1060°C for 30 minutes with WC-25.6 wt% Ni-1.5 wt% Si-1.1 wt% B4C formation were represented in Fig. 5. The upper part of COMPO image is WC-Ni base sintered products and lower part of that is S45C steel. The boundary layer, that meets sintered products and steel is bonding layer. We confirmed that wedge having same color with bonding layer moves to the direction of steel area. The analysis of wedge formation is needed because it is confirmed that the wedge parts improve the bonding characteristics

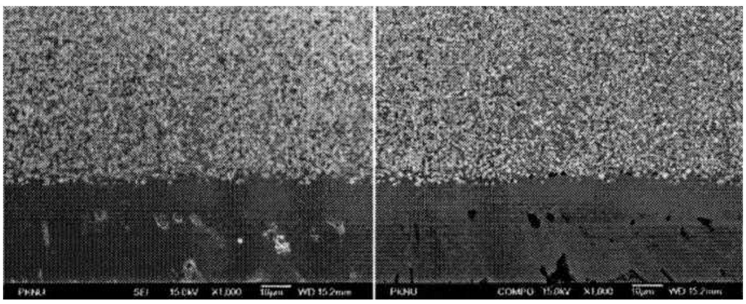


Fig. 5 The microstructure of WC-Ni / steel bonding area

The result of FE-SEM EDS bonding products which were sintered at 1060℃ for 30 minutes with WC-25.6 wt% Ni-1.5 wt% Si-1.1 wt% B4C formation were represented in Fig. 6. In the point 1 location, the formation was analyzed in 65.75wt%W, 34.24wt%Ni. In the point 2 location the formation was analyzed in 51.15wt%W, 6.05wt%C, 30.62wt%Ni, 10.06wt%Fe. Therefore, we confirmed that Fe spread from steel to sintered products near bonding area. In the bonding area at point 3 location, the formation was 6.55wt%C, 49.01%Ni, 39.02wt%Fe, 2.61wt%Si and the phase was mainly Ni-Fe-Si.

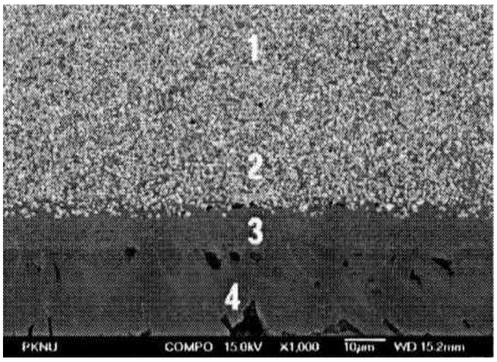


Figure 6. The result of EDS analysis of WC-Ni / steel bonding products

The EPMA analysis result of bonding products which were sintered at 1060℃ for 30 minutes with WC-25.6wt% Ni-1.5wt% Si-1.1wt% B4C formation was represented in Fig. 7. The lower part is WC-Ni base carbide alloy and upper part is steel area. We confirmed that Ni and Si diffuse into steel part with Ni, Fe and Si phase, and boron with Ni diffuse into steel part in wedge shape. The formation of bonding products are shown as Table 2.

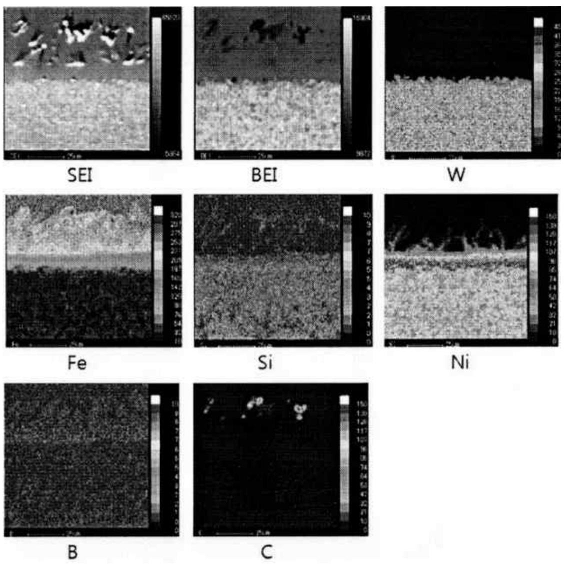


Figure 7. The EPMA analysis result of WC-Ni/steel bonding area

Table 2. The formation of bonding products

Element	1(wt%)	2(wt%)	3(wt%)	4(wt%)
W M	65.76	51.25	-	-
C K	-	6.05	6.55	5.18
Ni K	34.24	30.62	49.01	6.70
Fe K	-	10.06	39.02	86.08
Si K	-	-	2.61	-
O K	-	2.10	2.80	2.04

3. Results of the fuel cam abrasion test

The abrasion test of DME diesel engine fuel cam was accomplished. The DME engine fuel pump test equipment and monitoring system are shown in Fig. 8. The test conditions are 10MPa of pressure, 2500rpm of revolution speed, 5 m/sec of sliding velocity and 5,000 hours of time elapsed.

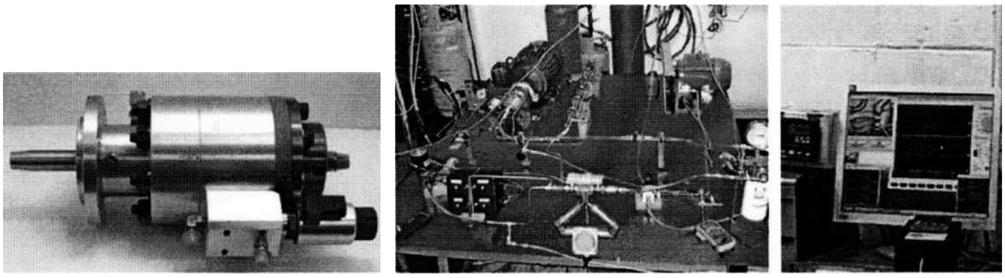


Figure 8. The DME engine fuel pump test system

In Fig. 9, abrasion test result of fuel cam for 5,000 hours was represented. The abrasion depth is 10.03μm, which meets the quantitative goal of this test. The sliding velocity and pressure of diesel engine fuel cam between counterpart and fuel cam is average of 4.67m/sec and 8.01MPa, respectively.

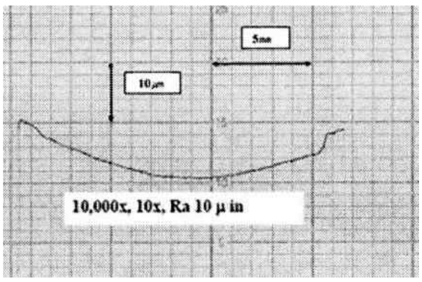


Figure 9. The fuel cam abrasion test result (5,000 hours)

4. Conclusions

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 status of this test specimen was excellent and the thickness of bonding layer was 18~25㎛ at 1050~1090℃ bonding temperature.

The hardness of specimen and bonding rate were measured using ultrasound equipment. The bonding state of each condition was excellent, and the thickness of mid-layer, temperature and maintaining time were measured. The mid-layer thickness according to bonding temperature and maintaining time were observed with optical microscope. We analyzed the micro-structural analysis, formation of bonding specimen, wafer fabrication and fuel cam abrasion test. We confirmed that the fuel cam for DME diesel engine which demands high durability against velocity and pressure is excellent.

The abrasion depth is 10.03μm, which meets the quantitative purpose goal of this test. The sliding velocity and pressure of diesel engine fuel cam between counterpart and fuel cam is average 4.67m/sec and 8.01MPa, respectively. Throughout abrasion test, we confirmed that the durability of fuel abrasion cam which demands high durability against velocity and pressure is excellent.

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