Development of laser brazing system with precise temperature control

Kotaro Matsu and Kangdao Shi from Tokyo Braze Co., Ltd.
3-23-10 Minamikarasuyama Setagaya-ku Tokyo 157-0062 JAPAN
Phone 03-3300-1141 Fax 03-3300-1145
email: kotaro@tokyobraze.co.jp and ishi@tokyobraze.co.jp

Yoshihisa Sechi from Kagoshima Prefectural Institute of Industrial Technology
1445-1 Oda Hayato-cho Kirishima-city 899-5105 Kagoshima JAPAN
Phone 0995-43-5111 Fax 0995-64-2111
email: sechi@kagoshima-it.go.jp

Abstract

Among the heating process of brazing, laser heating has excellent characteristics such as high-speed heating in local area. The laser brazing technology has been successfully applied to aluminum to steel joint of car body. However, this laser brazing method controls only power output and scanning velocity but not brazing temperature. If brazing temperature can be controlled by measuring actual temperature during heating, it can be control forming intermetallic compounds at the joint and this will be big benefit for brazing dissimilar metals. In this study, laser brazing system with precise temperature control was developed. Actual temperature was measured during heating by infrared thermometer and feedback to the pulse generation system to control heating temperature. In tool industry, market demand of high performance cutting tools which are combination of diamond to carbides has been increased and they are all brazed. Current brazing method is by induction heating or in the furnace. These heating methods have tendency to graphitization of diamond in a long brazing time at high temperature. Laser brazing method is suitable for brazing of diamond to carbides in short brazing time with controlled temperature. PCD and WC was brazed by developed laser brazing system in this study. Mechanical properties were evaluated by shear strength test and compared with furnace brazing parts. Cross section of the brazed joint was observed by optical microscope and SEM. Elemental distribution was analyzed by EPMA. Sound brazing joints were obtained with higher joint strength than furnace brazing parts. Minimum forming of intermetallic compound at the joint was observed in short brazing time.

Introduction

Brazing is known as joining process with heating so that it is impossible to avoid from heat affecting for mechanical properties of joint. Therefore, controlling brazing temperature and holding time is very important but it was not done in any of current brazing processes. Particularly, short brazing time and precise brazing temperature is very difficult to control. To solve this difficult problem, it is understood that laser heating can be the one of good solutions.

There are many types of lasers; YAG laser as solid-state laser, CO_2 laser as gas laser, liquid laser, semiconductor laser, fiber laser and others. Those lasers are used in various fields and applications. With the spread of its applications, prices of laser systems have gradually declined, so further expansion of its application is expected.

As well as in brazing field, laser brazing technology has already been put to practical use in the automobile industry. They have successfully brazed dissimilar metals with less distortion by controlling the heat input to the joint by locally heating in short brazing time. However, the application of laser brazing is hardly found other than the automobile industry. Furthermore, heating time and temperature control of laser brazing are only adjusted by the laser output and the moving speed of robot. To perform the best characteristics of laser brazing, it is necessary to control the heating temperature and time more accurately to make brazing joint properly. Then, we have developed a laser brazing system which is capable with precise temperature control by feedback from measured temperature value of base metal.

Developed laser brazing system

Appearance of the developed laser brazing system is shown in Photo. 1. The developed laser brazing system is equipped a radiation thermometer which is a non-contact thermometer, and the temperature measurement data of the base metal is input to the main unit control unit. The brazing temperature is controlled by controlling the pulse output of the laser with the function generator (pulse generator) via the control PC. In order to enable stable temperature control in this system, it is necessary to get fast enough response speed of the radiation thermometer and the laser oscillator, and sufficient speed of the sequencer calculation of the main control unit. The specifications of this system allow operation at all speeds within few msec.

Vacuum chamber is installed for making different condition of brazing atmosphere as vacuum, vacuum + Ar gas or Ar gas only. Appearance of the vacuum chamber is shown in Photo.

2. The laser is irradiated from directly above the sample. Irradiation of any figures is possible by Galvanometer scanner.

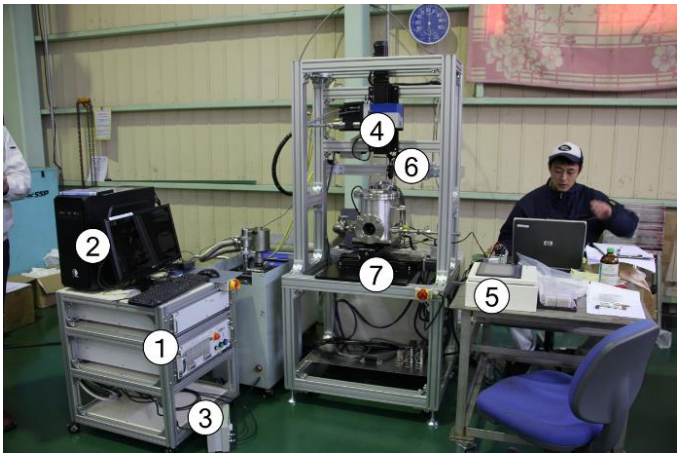


Photo. 1 Appearance of the developed laser brazing system

1. Fiber laser oscillator: Power and optical unit
2. Control PC
3. Function generator (Pulse generator)
4. Galvanometer scanner
5. Main control unit
6. Radiation thermometer
7. X-Y stage

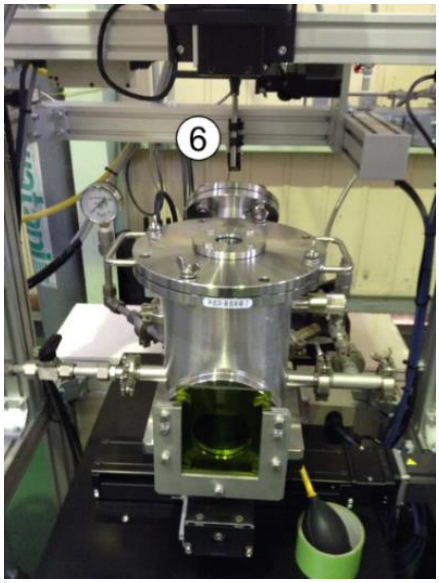


Photo. 2 Appearance of the vacuum chamber

Experimental procedure and materials

Cemented carbide (ISO class K10) and PCD (polycrystalline diamond) were selected as the specimens. This material combination is applied to high performance cutting tools. Actual products are brazed with active brazing alloy in vacuum or Ar gas. However, the diamond can be carbonized depending on the brazing conditions so that there is a problem that not only the joint quality is affected but also the original performance of diamond becomes insufficient as high performance cutting tool. In evaluating this developed laser brazing system, brazing of the cemented carbide and PCD was done in varied brazing conditions and brazing joints were investigated.

Schematic diagram of specimen is shown in Fig.1 The specimen is used the actual product, so it is a near net shape of the cutting tool. Cemented carbide backed PCD chips are commonly used and brazing surface is always carbide to carbide. But, PCD chip surface was brazing surface to make the specimens. The specimens were degreased and cleaned with acetone before brazing. Appearance of brazed specimens are shown in Photo. 3.

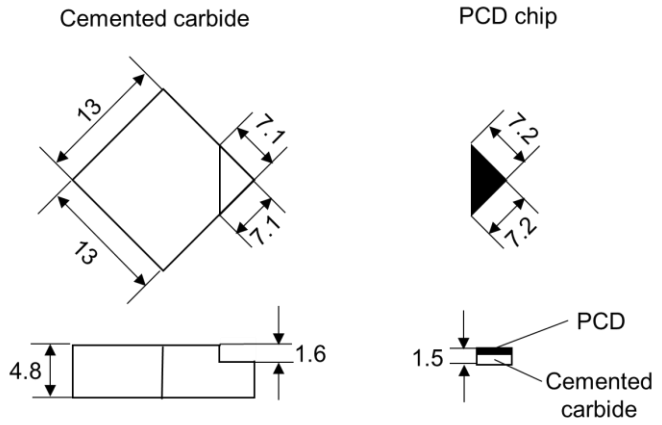


Fig. 1 Schematic diagram of specimen

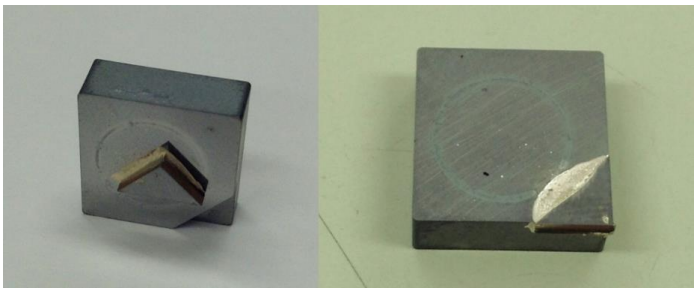


Photo. 3. Appearance of brazed specimens
Left: For shear test and cross-section
Right: Actual product shape

Paste form of TB-629T was used as brazing alloy. Chemical compositions and melting range of TB-629T is shown in Table 1. A certain amount of brazing alloy was applied to the whole surface of the chip side, then set to carbide. Brazing paste was dried sufficiently at 150 degrees C.

Table 1 Chemical compositions and melting range of TB-629T

Type	Chemical compositions (mass%)				Melting range (℃)
	Ag	Cu	In	Ti	
TB-629T	60	24	14	2	620 ～ 720

Brazing was carried out after inside of the chamber was vacuumed to 1.5 Pa, then Ar gas was introduced while vacuum was continued. Laser irradiation was started with the pressure inside the chamber controlled at 1.5 x 10^3 Pa. Brazing temperature was fixed at 780 degrees C and the brazing time

was varied as 5, 30 and 60 sec. Accuracy of temperature control at brazing temperature was within ±10 degrees C.
Laser irradiation position and measurement point of the radiation thermometer by the guide laser, and PCD chip position was shown in Photo. 4. Laser irradiation position was circular by Galvanometer scanner and it was moved at a speed of 500 mm/sec.

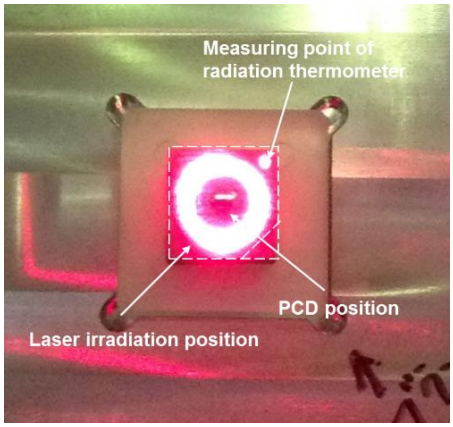


Photo. 4 Laser irradiation position and measurement point of the radiation thermometer by the guide laser, and PCD chip position

For comparison with making specimens by laser brazing, specimens by vacuum furnace was prepared. Vacuum brazing was carried out that vacuum pressure was reached to 1.0×10^{-1} Pa, then Ar gas was introduced while vacuum continued, and vacuum pressure was controlled at 50 Pa. Brazing temperature was fixed at 780 degrees C and the brazing time was fixed at 600 sec. Accuracy of temperature control at brazing temperature was within ±10 degrees C.

Results and discussion

Sound brazing joints without discoloration, oxidation or lack of brazing alloy flow were obtained in any brazing conditions. SEM images of cross-section of specimens were shown in Fig. 2. Thickness of the brazing alloy layer did not become constant regardless of brazing time. It is assumed that there was variation as specimen was prepared even though the amount of brazing alloy was controlled to some amount. No gap control of brazing alloy thickness was done in both laser brazing and vacuum brazing. It is understood that these factors were influenced the thickness of the brazing alloy layer. The microstructure of the brazing alloy layer tended to become larger as the brazing time increased.

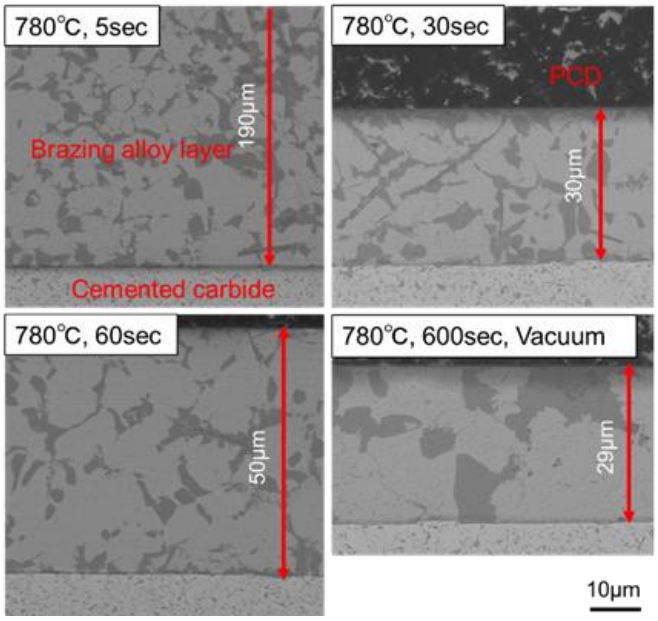


Fig. 2 SEM images of cross-section of specimens

Relationship between brazing time and shear strength is shown in Fig. 3. In the case of laser brazing, the maximum strength showed 184MPa at brazing time of 5 sec and the joint strength was decreased as brazing time increased. In the case of vacuum brazing, joint strength decreased to 107MPa as brazing time increased to 600 sec.

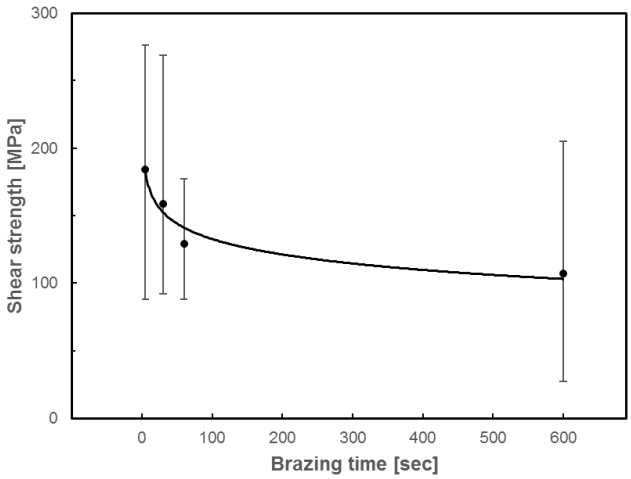


Fig. 3 Relationship between brazing time and shear strength

Typical fracture appearance of the specimens after the shear test on each brazing condition is shown in Fig. 4. As a result of visual observation, all the fracture was occurred at the interface at the cemented carbide side. The fracture occurred in the gray layer as brazing time increased in laser brazing. This gray layer is understood to be intermetallic compound layer of TiC and is considered to be an interfacial reaction layer formed by the reaction between Ti in the brazing material and C in the cemented carbide.

On the other hand, the fracture surface of the specimens brazed in a vacuum furnace showed complicated shape, and metallic surface and gray layer of TiC were mixed. From the

appearance observation on the PCD chip side, there were cracks in the chip layer. In the case of vacuum brazing, it is understood that the brazing time is remarkably long as compared to laser brazing so that the carbonization of PCD was progressed then joint strength was decreased.

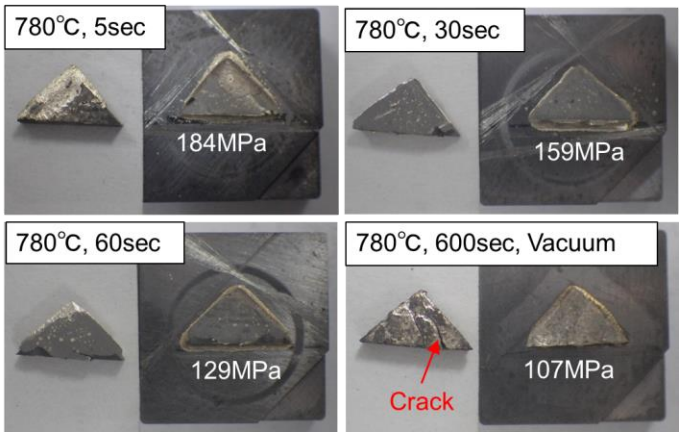
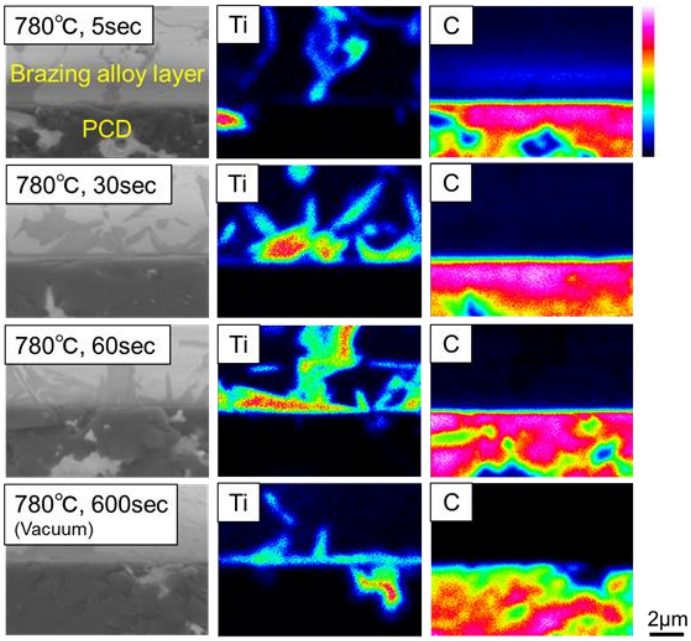


Fig.4 Typical fracture appearance of the specimens after the shear test

In order to understand the behavior of Ti at the PCD side, cross-section of brazed joint was observed by SEM image and elemental distribution was analyzed by EPMA. SEM image and elemental distribution map of Ti and C was shown in Fig. 5. In previous paper, it was reported that when diamond and cemented carbide are brazed with an active brazing alloy, submicron size of intermetallic compound layer of TiC is formed in the brazing alloy layer of diamond side. In laser brazing, the thickness of the intermetallic compound layer at the brazing time of 5 sec was very thin with weak detection. However, Ti was gradually detected clearly as brazing time increased to 30 and 60 sec. In consideration of the distribution condition of C, formation of TiC at the interface is presumed at any brazing time. Since all fracture was occurred on the cemented carbide side in any of the laser brazed specimens, the time for forming the TiC at the interface between the brazing filler metal and the diamond was very short. And it was found that the TiC formed in a very short time is very strong.

On the other hand, the TiC did not grow remarkably in the case of vacuum brazing even though Ti is clearly detected at the interface. It is considered that the Cu-Ti layer was formed on the brazing alloy side of TiC after forming the intermetallic compound layer which was formed by originally contained Ti in the brazing alloy reacted sufficiently to C in the PCD. Regarding the decrease of joint strength, it is considered that not only the growth of the TiC layers but also the long-time heating at elevated temperature to PCD.



We successfully observed the influence of the joint strength with very short brazing time while precisely controlling the temperature. It was found that sufficient joint strength was obtained at the brazing time of 5 sec, and the interfacial reaction of active brazing alloy was extremely faster than we expected.

Conclusions

We have developed the laser brazing system capable with precise temperature control and it was confirmed that brazing can be performed with excellent interfacial reaction control. Furthermore, this laser brazing system is capable with precise temperature control rather than conventional laser systems, so it is possible to suggest precise heat input control to the base metals which are sensitive to heat affect. For further investigation, we will braze various base metals by this laser brazing system to obtain basic data.

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先端産業創造プロジェクト

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