Development of a New Bonded Abrasive Diamond Tool

Hikari Tanaka¹, Yuta Shiina¹, Masanobu Nakatsu³ and Osamu Kamiya²

¹Department of Mechanical Engineering, Faculty of Engineering and Resource Science, Akita University, 1-1 Tegata, Gakuen-machi, Akita 010-8502, Japan
²Department of Mechanical Engineering, Graduate school of Engineering and Resource Science, Akita University, 1-1 Tegata, Gakuen-machi, Akita 010-8502, Japan
³Sanwa Tekki Corporation, 6-5-19 Minami – Shinagawa, Shinagawa – Ku, Tokyo 140-0004, Japan

E-mail : hkr0106knd@gmail.com

In the development of a bonded abrasive diamond tool, it was studied that the wettability of Cu-Ag solder on carbon steel plate, gel density, maximum temperature, and holding time. The test results were evaluated by “JIS Z 3191 Method of wetting test for brazing filler metals”. From the experimental results, the best conditions for producing the new diamond tool are as follows: Cu-Ag solder, 80-20(mass%); gel density, 0.2(mass%); maximum temperature, 1163 K; and holding time at maximum temperature, 300 s. A diamond jigsaw was constructed by using these processes and demonstrated that the new diamond tool could cut a brick. In addition, the degree of vacuum is important during fabrication; therefore, vacuum equipment with sufficient capacity is required for producing these tools.

Key Words : diamond tool, bonded abrasive, titanium hydride, partial pressure, wettability

1. INTRODUCTION

It has previously developed that a diamond saw wire for precise cutting with tungsten wire with a diameter of 100 µm or less. However, durable diamond tools which can cut fast and use to cut recyclable composite materials are still needed.

In this work, it was developed that a diamond saw wire for a new diamond tool that can cut fast. The tool contains a carbon steel basal plate. It was examined that the effect of the joining conditions on the wettability of the high temperature brazing metal for diamond and carbon steel plate. First, it was selected that a suitable brazing metal by examining the wettability of various brazing metals for carbon steel plate (referred to hereinafter as plate). A gel density that produced optimum wettability between the diamond and plate and measured the effects of the maximum temperature and the holding time at the maximum temperature was used. Then it was used the optimum brazing metal, gel density, maximum temperature, and holding time from these experimental results to produce a jigsaw with high cutting capacity and measured its cutting performance. And % symbols apart from expansion mean mass % on this report.

2. EXPERIMENTAL METHOD

SK105 (1.10% C) steel plate degreased with acetone and it wasn’t polished was used. A desktop vacuum furnace (MILA-3000, ULVAC) was used. The diamond was MBG*660 (Diamond Innovation Corp., US Mesh: 270/325, 44-53 µm). The wettability was determined by “JIS Z 3191 Method of wetting test for brazing filler metals”, the brazing metal (0.004 g) was placed on the plate and the spread area was measured by taking pictures above same height and the pictures were analyzed the area of brazing metal with image analysis system.

In the test about effect of brazing metal composition, it was used that the brazing metal was high strength silver solder and the ratios of Cu%-Ag% were 90-10, 80-20, 70-30, and 60-40. Titanium hydride was used to improve wettability. It was held at 1123 K for 600s.

In the test about effect of gel density, the gel binder was a mixture of xanthan gum, water, and tripropylene glycol (0.05 mL). The amount of xanthan gum was 0.1%, 0.2%, 0.3% 0.5%, and 1%. Previously, it was found that the gel decreased wettability; therefore, this test was attempted at 1163 K for 600s. The plates were held vertically to check the hold strength of the gel. First, the brazing materials were mixed with a ratio of metal:titanium hydride:diamond:gel of 50:4:2:10. This ratio has done research before, and it is good terms to make diamond tools. To make diamond saw wire with gel density:6% was successful, however the term couldn’t make diamond jigsaw because it contains too much carbon and the carbon exert a bad influence to wettability. So it is necessary to find optimum gel density to make a diamond jigsaw. Gel density means mass% of xanthan gum. The mixture (0.004 g) was placed on the center of the plate (diameter 3 mm) and dried at 313 K for 1 h. Solder diameter was measured by taking pictures above same height and the pictures were analyzed the maximum diameter of brazing metal with image analysis system.

In the test about maximum temperature, it was examined that the wettability of the diamond and plate at the maximum temperature with 80-20 Cu-Ag solder and gel density of 0.2%. The holding
time and heating time were the same with the test about effect of gel density. The maximum temperatures were 1023, 1073, 1123, and 1163 K.

In the test about the holding time at the maximum temperature, it was examined 60s, 300s, and 600s. The other terms were same with the test about maximum temperature.

Expansion on this report means that the first area of brazing metal (diameter 3 mm) is 100% and the results measured by image analysis system was compared with first area (diameter 3 mm). The material of a basal plate of the jigsaw is HSS. The surface of a jigsaw was polished and degreased, and then the edge of the jigsaw was sharpened. Next, the jigsaw was coated with a mixture of brazing metal: titanium hydride: diamond: gel 50:4:2:10. Then the jigsaw was dried and heated.

3. EXPERIMENTAL RESULTS FOR PLATE

3.1 Effect of brazing metal composition

Table 1 shows the results of this test. The area of the 90-10 Cu-Ag brazing metal was not changed by heating. The brazing metal powder was sintered, although it did not melt completely. 80-20 Cu-Ag showed good wettability, and 70-30 Cu-Ag melted more and the area was larger. 60-40 Cu-Ag showed the largest area. Therefore, the wettability of the brazing metal increased with Ag content.

Figure 1 shows a Cu-Ag binary phase diagram calculated with CaTCalc software (National Institute of Advanced Industrial Science and Technology). The ratio of the solid to liquid phase was calculated by the lever rule in the phase diagram. An x-axis of Figure 1 was indicated by mass%, so the parameter synchronizes with the results of the test. 4 Plots of Figure 1 shows the condition of Cu-Ag brazing metal at 1123 K and it synchronizes with terms of this test Cu-Ag: 90-10, 80-20, 70-30 and 60-40 from left side.

Figure 1 shows that 90-10 Cu-Ag is almost completely solid at 1123 K, In 80-20 Cu-Ag, the solid to liquid phase ratio is roughly 1:1, and 70-30 and 60-40 Cu-Ag are almost completely liquid. If the proportion of the liquid phase is too high, the brazing metal cannot hold the diamond. However, if the proportion of the solid phase is too high, the wettability is poor. Therefore, 80-20 Cu-Ag solder, which contained a 1:1 solid-to-liquid phase ratio, was the best for manufacturing the diamond tool.

3.2 Effect of gel density

The results are shown in Table 2. Gel densities of 0.1% to 1.0% were used. For a density of 0.1%, the brazing metal detached from the plate during the drying step. For a density of 1%, part of mixture was carbonized, and was detached during heating.

For gel densities of 0.2%, 0.3%, and 0.5%, the brazing metal did not detach; however, at high gel densities, carbonization occurred. Therefore, lower gel densities were better, and the optimum gel density was 0.2%. The gel was carbonized at high temperature, decreasing the wettability.

3.3 Plate wettability and maximum temperature

The maximum temperatures during heating were 1023, 1073, 1123, and 1163 K, and the results are shown in Table 3.

At 1073, 1123, and 1163 K, the wettability was good. The best wettability was at 1163 K, with an area spread of 130%. Figure 1 shows that 80-20 Cu-Ag solder was almost liquid above 1163 K and could not hold the diamond.

3.4 Diamond wettability and maximum temperature

The diamond wettability was observed by scanning electron microscopy (SEM).

At 1023 K, there were cracks between the diamond and the brazing metal and the diamond was not wetted. At 1073 K, the brazing metal did not melt sufficiently, and the brazing metal accumulated around the diamond. At 1123 K, the metal melted more than at 1073 K, although the metal was still accumulated. At 1163 K, the brazing metal melted and was flat (Figure 3). Additionally, the brazing metal fixed the diamond well to the plate and the diamond was exposed above the surface. This was expected...
Development of a New Bonded Abrasive Diamond Tool

Int. J. Soc. Mater. Eng. Resour. Vol.21, No.½, (Mar. 2016)

3.5 Effect of heating holding time on wettability

Holding times were 60s, 300s, and 600s at 1163 K. Table 4 shows that the holding time at maximum temperature did not affect the spread area. The spread was about 130% for all holding times, indicating good wettability. The test pieces were also observed by SEM.

For a holding time of 60s, the SEM image shows that there were many lumps and the brazing metal did not melt sufficiently (Figure 4). For a holding time of 300s, the diamond was more wetted and fixed to the plate better, and the brazing metal was flat (Figure 5). For a holding time of 600s, the brazing metal was unstable and non-uniform because it was oxidized with the small amount of oxygen over the long heating time (Figure 6). Thus, the interfaces that had been wetted separated and the wettability decreased. So the optimum holding time was 300s at the maximum temperature.

3.6 Effect of heating holding time on wettability

The past research showed that the degree of vacuum affects the wettability, and that the jigsaw should be fabricated under a high vacuum. So degree of vacuum should be considered to produce diamond jigsaw. However, the gas that evolves from the plate and the titanium hydride decreases the degree of vacuum temporarily. Therefore, the effect of the temperature control program on gas evolution should be considered. Titanium hydride improves the wettability, although it reacts with oxygen to form steam via the reaction 2TiH₂ + O₂ → 2Ti + 2H₂O (gas). The steam decreases the degree of vacuum. Data from the previous research are shown in Figures 7-9.

Figure 7 shows that the optimal TiH₂ content was about 6%. New diamond jigsaw was made with about 6% TiH₂, so TiH₂ effect good wettability in this report.

Figure 8 shows that TiH₂ suddenly creates partial pressure at about 673 K(400°C), thus the temperature control program should pause heating at 673 K to maintain the degree of vacuum.

Figure 9 shows that large amounts of H₂ and H₂O are generated at 673 K(400°C), which decreases the degree of vacuum. If oxygen reacts with TiH₂ (0.004 g) and reacts completely, water vapor is generated (0.00008 mol). The furnace capacity is 0.000589 m³, and

Table 4 Areas for each holding time at maximum temperature

| Time (s) | Area (mm²) | Expansion (%) |
|---------|------------|---------------|
| 60      | 9.01       | 127.4         |
| 300     | 9.24       | 130.7         |
| 600     | 9.23       | 130.6         |

Figure 2 Images of solder on the steel plate at maximum temperatures of (a) 1023 and (b) 1163 K

Figure 3 SEM image of diamond heated at (a) 1023 and (b) 1163 K

Figure 4 SEM image of test piece fabricated at a holding time of 60s at 1163 K

Figure 5 SEM image of test piece fabricated at a holding time of 300s at 1163 K

Figure 6 SEM image of test piece fabricated at a holding time of 600s at 1163 K

To improve cutting performance.
thus the partial pressure was calculated to be 760.15 Pa at 673 K. To return the degree of vacuum to $10^{-3}$ Pa would require several minutes, which should be reflected by the pause in heating at 673 K.

4. CUTTING TRIAL WITH JIGSAW

Based on the results, the optimum conditions for fabricating the jigsaw were 80-20 Cu-Ag solder, gel density of 0.2%, maximum temperature of 1163 K, and holding time at maximum temperature of 300s. It was fabricated that a bonded abrasive diamond jigsaw under these conditions. Figure 10 shows the temperature program. The program paused heating at intervals of 400 K to maintain a high vacuum.

Figure 11 shows a photograph of the finished jigsaw blade and it has a metallic luster.

Figure 12 shows the brazing metal fixed to the diamond and it has good wettability. The jigsaw cut through brick with water-cooling, although the edge of the saw deteriorated fast, and a higher efficiency jigsaw is required. In addition, a high vacuum is very important for fabricating the jigsaw; however mass-producing jigsaws in a high vacuum is impractical. The jigsaw that was fabricated under a low vacuum was unstable and the diamond...
Development of a New Bonded Abrasive Diamond Tool

5. CONCLUSION

The results show that a new bonded abrasive diamond tool could be fabricated with 80-20 Cu-Ag solder, 0.2% gel density, maximum temperature of 1163 K, and a holding time at the maximum temperature of 300s. In addition, maintaining the degree of vacuum is crucial, and thus considering the quantity of titanium hydride and the partial pressure is essential to maintain the degree of vacuum above $10^{-3}$ Pa. Mass production of these jigsaw blades would require vacuum equipment with sufficient capacity.

References

[1] Oga, Y., Kamiya, O., Miyano, Y., Takahashi, M., Kawase, H., Sekiguchi, K., Suto, M.; “Development of the fixed abrasive type diamond saw wire”, B. JSME, 2010(46), 135-136 (2010).

[2] Kamiya, O., Uchida, T., Kimura, M., Ishikawa, T.; “Ecological micro-cutting wire saw bonding diamond grain and metal wire”, Scientific and Technical Reports of Faculty of Engineering and Resource Science, Akita University, 23, 41-47 (2002).

[3] Inoue, M., Kawagishi, S., Hagiwara, Y., Tomiyoshi, T., Inoue, H., Murata, Y., Yokota, M., Nakahira, A.; “Development of a new type saw wire fixed diamond abrasive grains with solder and Ni electroplating and its application to slicing of sapphire ingots”, J. Jpn. Soc. Powder Powder Metall., 59(8), 465-472, (2012).

[4] Suzumura, A., Yamazaki, T., Takahashi, K., Onzawa, T.; “Solidification phenomena and bonding strength at the interface of diamond and active-metal-brazing-filler: study on the bonding of diamond to metals (Report 1)”, Quart. J. Jpn. Weld. Soc., 12(4), 509-514 (1994).

[5] Kawakatsu, I., Osawa, T.; “Wettability of silver brazing alloy on carbon steel”, J. Japan Inst. Met. Mater., 37(8), 828-833 (1973).

[6] Material design technique research laboratory, “CaTCalc”, http://www.materials-design.co.jp/catcalc/

[7] Ishikawa, T.; “[Evaluation of diamond abrasive grain, straightening and application of diamond–metallic composite material]” (in Japanese), Scientific and Technical Reports of Faculty of Engineering and Resource Science, Akita University, 70,72,81, (1998).

Figure 13 Photograph of unstable jigsaw

Figure 14 SEM image of detached diamond material from unstable jigsaw
detached from the blade. Figure 13 shows the unstable jigsaw. It has many areas of carbonization and poor wettability.

Two type jigsaw were made, first type has zigzag edge, and it was necessary to check that cutting capacity of diamond, so second type which has straight edge was made. If straight edge type can cut something, it means that something was cut by only capacity of diamond. Straight type jigsaw was made by shaving zigzag edge jigsaw with a grindstone.

The results of cutting trial show good cutting capacity of jigsaw. Both two types jigsaw could cut a brick. So diamond jigsaw can cut other things, and the results show that it can be used to cut recyclable composite materials.

Figure 14 shows an SEM image of the surface of the unstable jigsaw after the cutting trial.

The diamond detached from the surface and the blade was unable to cut. Therefore, a fabrication process that overcomes the low durability of blades produced in low vacuums must be developed.