Int J Adv Manuf Technol (2007) 34:491–495
DOI 10.1007/s00170-006-0626-z

ORIGINAL ARTICLE

Development and performance of monolayer brazed CBN grinding tools

W. F. Ding · J. H. Xu · M. Shen · Y. C. Fu · B. Xiao · H. H. Su · H. J. Xu

Received: 29 June 2005 / Accepted: 20 March 2006 / Published online: 24 May 2006

Abstract CBN grinding tools have been broadly utilized in machining difficult-to-cut materials in recent years. Grains of the conventional grinding tools, however, are held in the tool matrix just through the mechanical incrustation effect induced by the electroplated or sintered metal, which results in the stochastic grain distribution and limited grain protrusion, in addition to the easy grain pullout and premature tool failure by the strong impact forces generated during machining. These properties and shortcomings of the electroplated or sintered tools have restricted the potential of CBN superabrasive grains. Therefore, a new technology has been developed and introduced in this paper to fabricate successfully monolayer CBN grinding tools, in which the highly protruding grains could be planted in the required uniform pattern through the brazing effect among CBN grains, filler alloy and tool substrate at elevated temperature. Finally, comparative grinding tests performed with the conventional electroplated and newly-developed brazed CBN tools have indicated that highly increased efficiency and prolonged tool lives, as well as low fabrication and use cost could be achieved by applying the brazed CBN grinding tools.

Keywords Brazed grinding tools · CBN superabrasive grain · Uniform grain distribution · High grain protrusion

W. F. Ding (✉) · J. H. Xu · M. Shen · Y. C. Fu · B. Xiao · H. H. Su · H. J. Xu
College of Mechanical Engineering,
Nanjing University of Aeronautics and Astronautics,
Nanjing 210016, People’s Republic of China
e-mail: dingwf2000@vip.163.com

1. Introduction

In recent years, CBN grinding tools have found wide acceptance in the various industrial machining fields of difficult-to-cut materials, such as titanium alloy and nickel-based superalloy [1–3]. Demands for CBN tools with higher performance, however, are increasing because the conventional electroplated and sintered ones, on the surface of which about two thirds or more of the grain height has to be covered by the matrix for effective anchorage and thus in some cases the pullout behaviour of CBN grains easily occurred, could not always ensure the free cutting action when a large volume of chips are to be handled during grinding [4–6].

To solve the urgent and crucial problems of the conventional CBN grinding tools mentioned above, depending on the hard joining effects caused by the chemical reaction in the interfacial region among CBN grains, filler alloy and tool substrate in the active brazing process at high temperature, a new type of monolayer brazed CBN grinding wheel is developed with particular reference to its capability to ensure free cutting action by resisting loading and also restraining the premature pullout of grains during working. Meanwhile, this paper also evaluates the comprehensive performance of the newly developed tools in the comparative grinding tests with the electroplated counterparts on Ti-6Al-4V alloy material.

2. Experimental procedure

The average size of CBN abrasive grains model YBN-65 ranged from 300 to 425 μm and the active filler was Ag-Cu-Ti alloy powder. The tool substrate was 0.45%C steel. The substrate and the CBN grains were ultrasonically

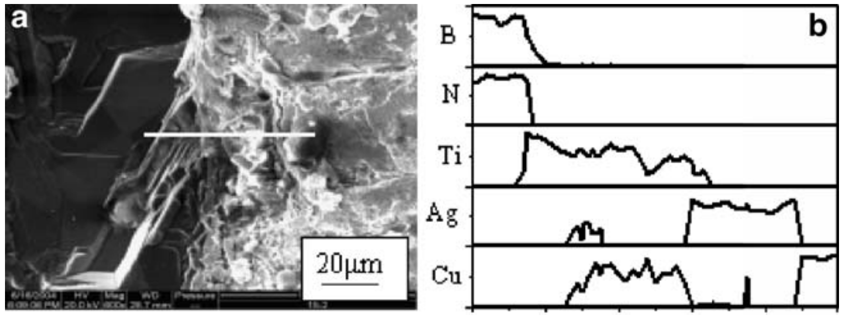

Fig. 1 Cross-section of the brazed joint between CBN grain and filler alloy. **a** SEM micrograph. **b** Elemental analysis

cleaned in acetone, after which the raw materials were assembled as a structure with three layers, i.e. grain/filler alloy/steel substrate. The brazing trial was carried out in the vacuum furnace and the thermal cycle was carefully selected to ensure that the interface formed during brazing would be of an appropriate structure so as to secure the good mechanical properties and resistance to thermal shock.

To evaluate the performance of the newly developed brazed CBN tools, comparative grinding experiments were executed between the brazed and electroplated CBN tools. The machining characteristics and the correlative fabrication and use cost were discussed.

3. Results and discussion

3.1. Joining mechanism of CBN grain and filler alloy during brazing

Generally, the chief problem in preparing the brazed CBN grinding tools is not the bonding of filler alloy and tool substrate but the joining of CBN grains and filler alloy. Difficulty in joining CBN grain to metal may arise as a result of their difference in interatomic bonding and physical properties. The low surface tension of CBN grain crystal makes it unlikely that many molten metals satisfy the wetting condition for the reaction in the interfacial region. An active element, for instance titanium, plays an important role in the filler alloy for the chemical wetting behaviour because of the following factors. First, the active element can reduce the surface tension among the molten filler alloy, CBN grains and vapour phase; and second, the active element could react with the CBN grain.

Figure 1a displays the interface between CBN grain and filler alloy. A typical linear distribution of elements along the white line in the brazed joints is shown in Fig. 1b. Obviously, the composition in the interfacial region is inhomogeneous. The active element, Ti, has diffused markedly from the molten brazing alloy to the interface between CBN grain and filler alloy. Furthermore, B and N atoms also moved into the filler alloy. Accordingly, the behaviour of good wetting and remarkable interfacial diffusion indicates that Ag-Cu-Ti filler could be successfully utilized to join the couple of CBN and steel.

For detecting the variety and shape of the newly-formed reaction compounds in the interfacial region between CBN and filler metal, the specimen was etched deeply to separate the brazed grains from the filler and the tool substrate. As can been seen, there are not any compounds on the surface of the original CBN grain (Fig. 2a); however, many fine compounds, which have been confirmed as TiN and TiB_2 by X-ray diffraction (XRD) in the former discussion [7], have formed around the brazed grain, as shown in Fig. 2b and c. Under such conditions, hard joining between the grain and the filler layer was realized; meanwhile, development of the monolayer brazed CBN tool was accomplished in virtue of the bridge effects of the Ti-N and Ti-B compounds in the interfacial region.

3.2. Features of monolayer brazed CBN grinding tools

More importantly, in the manufacture process of the brazed CBN grinding tools, the particular uniform grain distribu-

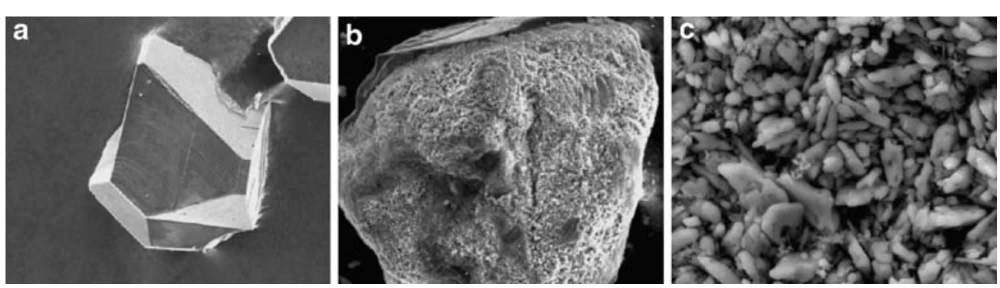

Fig. 2 SEM micrograph of CBN grain and compounds. **a** Original grain. **b** Brazed grain after etched. **c** Fine compounds around brazed grain

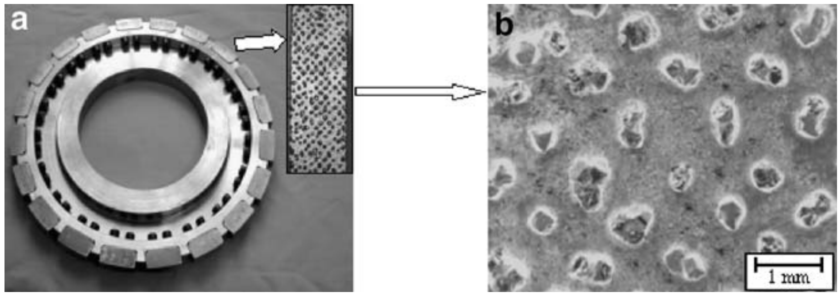

Fig. 3 Surface topography of brazed CBN grinding wheel with grains arranged in a uniform pattern. **a** Whole macrograph. **b** Local micrograph

tion could be realized on the tool surface by effectively regulating the brazing techniques, which is quite different from the stochastic grit distribution on the surface of the electroplated abrasive tools. Thus, not only could almost every grain or cluster of the brazed tools be active during grinding, but the required grains could also be much sparser; therefore, the chip storage space on the surface of the brazed tools was wider than those of the conventional electroplated CBN counterparts, which has been in evidence from the typical topography of the newly-developed monolayer brazed CBN grinding wheels, as shown in Fig. 3. In particular, the inlaid segments of the brazed tool were designed in this experiment in order to be easily installed for working and removed for detecting the wearing behaviour of the CBN grains.

Superior to the electroplated CBN tools, bonding among the superabrasive grains, the connecting layer (here also denoted as the filler layer) and the tool substrate of the epoch-making brazed tools is not due to the physical and mechanical factors but the chemical ones, which arouses the stronger joining effects to meet the requirements of the bonding strength to the grains during the heavy-load grinding. Consequently, the connecting layer of the brazed tools could be much lower and the grain protrusion is much higher than those of the electroplated ones. Ordinarily, the grain protrusion of the brazed tools could be about twice that of the conventional ones, as illustrated in Fig. 4.

The most important feature of the brazed CBN tool is that the improved distribution and retention of the grains could increase the bitting size of active CBN grain without overloading the grain [8]. Meanwhile, according to the practical grinding conditions, such as the machined materials and the process parameters, the interval and protrusion of the grains could be controlled effectively by adjusting the applied planting and brazing technology. The former is governed by grain distribution using a template with grid and the latter is required by grain retention using the special brazing technique.

3.3. Performance of monolayer brazed CBN grinding tools

For evaluating the comprehensive performance of the brazed CBN grinding tools, comparative machining tests on Ti-6Al-4V alloy material have been carried out between two groups of CBN grinding tools: three brazed tools with uniform grain distribution, and electroplated tools with stochastic grain distribution. It should be noted that the brazed tools utilized were fabricated under the same conditions; moreover, the electroplated tools, of which the CBN grains are the same model as those of the brazed tools, were manufactured in an established factory. Similar to the brazed diamond tools, the performance of brazed CBN grinding wheels could also be estimated by the following factors: machining characteristics, fabrication and use cost.

3.3.1. Machining characteristics

Figure 5 shows the comprehensive machining characteristics of the brazed and electroplated tools. All the tests were executed at wheel peripheral speed v_s=25 m/s, workpiece in-feed speed v_w=0.3 m/s and depth of cut per pass a_p=0.08 mm. The synthetic water-based coolant fluids were utilized as refrigerant throughout the machining process. As seen in Fig. 5a, the brazed CBN tools exhibit the tool life at least three times as long as the conventional electroplated tools. In order to further assess suitability of the brazed tools, the surface quality of the ground workpieces has been measured, as illustrated in Fig. 5b. Obviously, the surface roughness at the initial stage

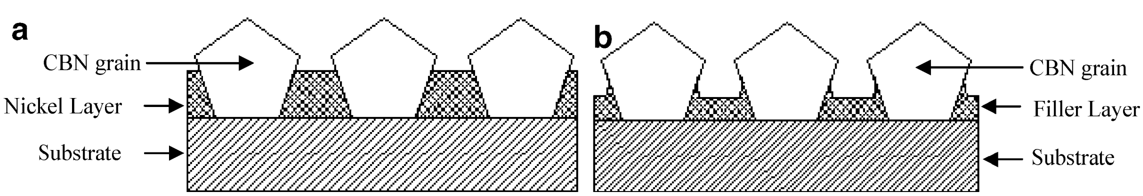

Fig. 4 Schematic representation of different monolayer CBN tools. **a** Electroplated tool. **b** Brazed tool

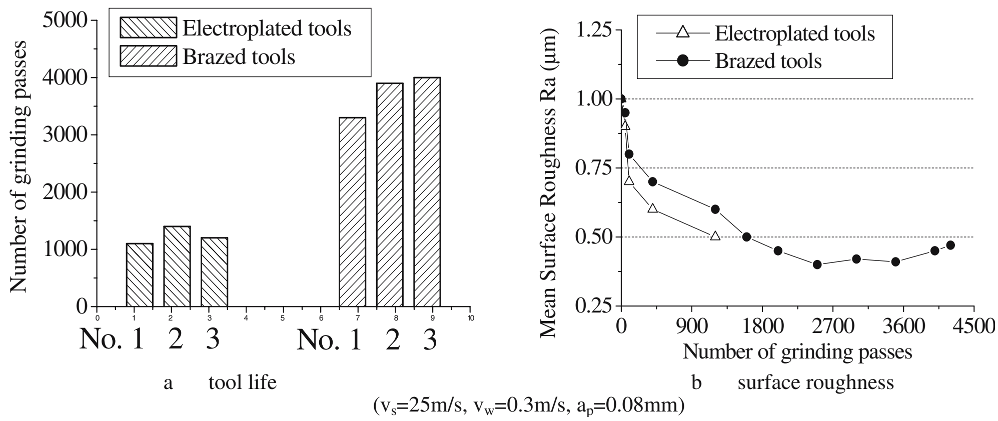

Fig. 5 Tool life and surface roughness of electroplated and brazed CBN grinding wheels (v_s=25 m/s, v_w=0.3 m/s, a_p=0.08 mm). **a** Tool lives. **b** Surface roughness

obtained with the brazed tools was slightly above that with the electroplated counterparts, which has been induced by several CBN grains with higher exposing height than most grains on the surface of the brazed tools. After about 1,500 passes, however, in excess of the working capacity of the electroplated tools, roughness *Ra* dropped below 0.50 μm. Here, the electroplated tools have failed because of the pull-out and abrasion behavior of the grains, as shown in Fig. 6a. A fairly steady value of about 0.4 μm for the surface finish of the workpiece machined by the brazed tools, however, established itself and remained almost constant up to over 4,000 passes. Clearly, after an early transient stage, relying on the abrasion wearing behavior instead of the pull-out effect of the CBN grains (Fig. 6b), the brazed tools display an unvarying working state in spite of their single layer structure, which strongly supports the claimed value and quality of uniform grain distribution [9].

3.3.2. Fabrication and use cost

Considering that the regular space of the grains on the tool surface greatly reduces the redundancy of CBN grains, moreover, the expense of superabrasive grains typically accounts for about half of the production cost of the abrasive tools, the CBN grinding tools produced by the brazing technology could attain a dramatic improvement of performance at a significant reduction of fabrication cost, as shown in Fig. 7.

On the other hand, though it's obvious that the fabrication cost of the tools could be reduced to a large extent, the more important strong-point for the brazed grinding tools is that, because both the long service life and the excellent machining characteristics of the brazed tool have made it likely to reduce the frequency for replacing and changing the tools, the effective working time is increased and the working efficiency is remarkably heightened during machining; hence, prominent profits for the manufacturers could be realized. Based on the critical point, it could be concluded that the brazed CBN tools could revolutionize the corresponding superabrasive grinding tool industry for its high efficiency and low cost. If the brazing technique is applied to other types of CBN tools, the results would be dramatic improvement of productivity accompanied by a sizable reduction of cost [9].

4. Conclusions

Depending on the formation of TiN and TiB_2 in the interfacial reaction region at elevated temperature, CBN grains and filler alloy join hard and thus the monolayer brazed CBN grinding tools are fabricated successfully.

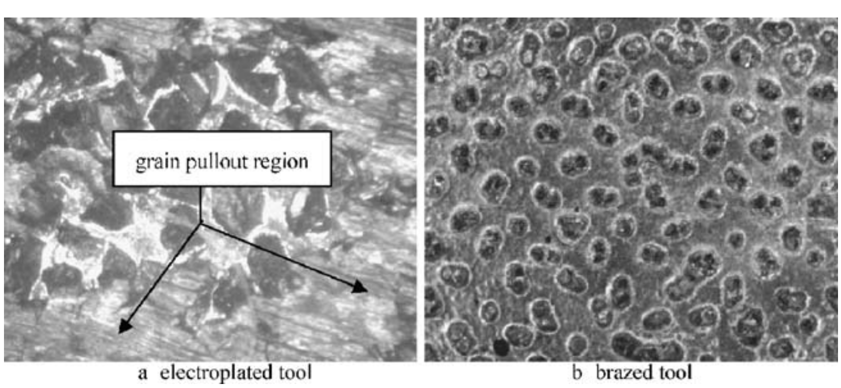

Fig. 6 Different wearing pattern of electroplated and brazed CBN grinding tools. **a** Electroplated tool. **b** Brazed tool

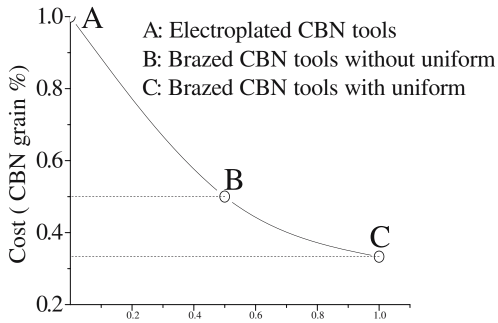

Fig. 7 Manufacturing cost as a function of the average grain interval in the tool

According to practical requirements, uniform grain distribution and high grain protrusion could be realized during the fabrication process, which is the most important feature of the brazed CBN tools.

The comprehensive performance of the brazed CBN tools, high efficiency and low cost, has shown that the brazed tool could promote the CBN grinding tool industry to some extent.

Acknowledgements This research was supported by the National Natural Science Foundation of China (No.50475040).

References

1. Pecherer E, Malkin S (1984) Grinding of steels with cubic boron nitride (CBN). CIRP Ann 33:211–216
2. Golabczak A, Koziarski T (2005) Assessment method of cutting ability of CBN grinding wheels. Int J Mach Tools Manuf 45:1256–1260
3. Rowe WB, Black SCE, Mills B (1995) Temperatures in CBN grinding. Ind Diamond Rev 4:165–169
4. Frank C, Wojciech Z (2004) Fluid performance study for groove grinding a nickel-based superalloy using electroplated cubic boron nitride (CBN) grinding wheels. J Manuf Sci Eng 126:451–458
5. Chattopadhyay AK, Hintermann HE (1992) New generation superabrasive tool with monolayer configuration. Diam Relat Mater 1:1131–1143
6. Xiao B, Xu HJ, Wu ZB (2001) Investigation on brazing of single-layer superabrasive wheel. Key Eng Mat 202:155–158
7. Ding WF, Xu JH, Lu JB et al (2004) Brazed CBN grinding wheels with Ag-based filler alloy. Mat Sci Forum 471:11–15
8. Sung CM (1999) Brazed diamond grid: a revolutionary design for diamond saws. Diam Relat Mater 8:1540–1543
9. Burkhard G, Rehsteiner F (2002) High efficiency abrasive tool for honing. CIRP Ann 51:271–274