Evaluation of brazed monolayer CBN grinding wheel on high-speed steel (HSS)

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Abstract. Shaping and forming of high-speed steel (HSS) tool with complicated geometry has been a challenge for the cutting tool industry. HSS grades generally display high hardness at high temperature and high wear resistance due to its constituent elements like a high amount of tungsten with the addition of chromium, vanadium and cobalt. HSS being used extensively in the manufacturing industry for machining difficult-cut-materials due to its high hardness and abrasion resistance. CBN grinding wheel is being used extensively for shaping the HSS. In this work, cBN brazed wheel with monolayer configuration is being used to grind HSS. Usually, reasonably uniform grit distribution, adequate spacing between the grits, 50-70% grit protrusion over the brazed surface and strong chemical bond strength are key features of brazed CBN wheel to perform satisfactorily. In the current investigation, the brazed CBN wheel showed limitations of its capability while grinding HSS in dry condition. The high chip load due to adverse grinding combinations, high attrition wear of grit due to its interaction with constituent elements like tungsten, chromium, vanadium and cobalt, fracturing and pull out of the grits are the limitation of the brazed wheel. The paper also concluded with facts to overcome limitations of brazed CBN wheel.

1. Introduction

There is an extreme demand for manufacturing HSS tool of complicated geometry to shape difficult-to-cut materials. The HSS has been one of the subsets of tool steels and is high-performance special steels, extensively used in cutting tool industry, has a high hardness at temperatures up to 500°C and high wear resistance. The alloying elements like tungsten, molybdenum, vanadium and chromium which can form strong carbides. The shaping and forming of the HSS tool always have been a challenge for the cutting tool industry. CBN is being used in resin, vitrified and metal bonded grinding wheel for grinding ferrous based alloy, titanium and nickel-based super-alloy in the various industrial applications due to its high hardness, chemically inactive towards ferrous alloys, unlike a diamond. There are ample of work done on a selection of grinding parameters, the effect on grit size for grinding steels [1][2]. In dry and wet grinding severe cracking on HSS observed but it was absent while grinding with cryo-cooling [3]. Work has been carried out in high-speed grinding, high efficiency deep grinding for alloy steel with conventional wheel, plated wheel and exhibited their performance [4]. The brazed monolayer CBN wheels have drawn considerable attention in the recent past due to its better grit distribution probability, 50-70% grit protrusion and strong chemical adhesion with base metal [5][6] An Ag-Cu base alloy, being activated with TiH2 powder, is the key alloy for brazing CBN grit with the steel base materials [7]. Induction brazing technique is being used for brazing cBN and residual stress has been estimated by finite element process [8]. It has established that vacuum
brazing exhibited the best results. The process of uniform distribution of CBN grit has been well established on the periphery of the circular cylindrical job. This effective distribution of CBN grit on the brazed wheel has been the key parameters for its excellent performance [9][10]. The work has been carried out on titanium alloy, nickel-based superalloy [11][12] and different metallic materials [13] by monolayer CBN wheel.

All these work has been done very extensively with CBN brazed wheel but less work has been carried out to understand the performance of the brazed wheel on grit density. In this study, an attempt has been made to distribute the grit uniformly with specified grit density. This work has been carried out in said grit density and evaluating the performance of brazed CBN wheel on HSS work material in dry conditions.

2. Materials and Method
2.1 Preparation of sample
In the present study, a base alloy (72%Ag and 28%Cu) was activated by adding TiH₂ powder and form the paste. The wheel blank was placed in the milling indexing head for providing the rotational movement continuously. The paste (alloy) is being applied on the cylindrical surface of the wheel blank. The sieve was carefully attached on the x-y-z table of a travelling microscope and then placed on the periphery of the wheel. The CBN grits were poured regularly on the sieve. The grits were passed through the sieve and placed on the periphery of the wheel. This process is continued till wheel surface get uniformly distributed with grits [6].

![Fig.1. Distribution of cBN grit on the wheel](image1)

![Fig.2. Grinding set up](image2)

| Table I: Grinding Specifications | Table II: Experimental Conditions |
|----------------------------------|----------------------------------|
| Brazed Grinding Wheel            | Wheel speed, vₚ (m/s)            |
| Grits: Borazon 570 (GE Superabrasive, USA) B151 | table speed, vₚ₀ (m/min) |
| Wheel Diameter, d 15 mm          | downfeed, d, µm                  |
| Work piece Material High speed steel | Remarks                          |
| Environment Dry                  | Long duration test up to specific volume 100 mm³/mm² |
| Wheel-work piece contact width, w 3 mm | 27.5 4 30 Adverse situation with high chip load |
| Length of cut per pass, L 80 mm |
| Speed of the spindle Maximum speed 80000 rpm | 41 2 30 Favorable situation with less chip load |

2.2 Brazing
Brazing process was conducted at 850°C temperature. The pressure in the furnace has kept around 10⁻⁵ torr to prevent oxidation during brazing. After completion of the brazing process, the brazed wheel was examined under Scanning Electron Microscope (SEM) [LEO 430i, England] as shown in Fig.1. It
observed that the process of seeding of the grits on the wheel has been done very effectively. Adequate spaces are provided between the grits for free accommodation chips to prevent loading during grinding operation [6]. The grit density has been calculated and it is found 8-9 grit per square mm of wheel surface. The assessment of cBN brazed wheel has been evaluated on this said grit density.

2.3. Grinding

The experiments were carried out in a surface grinding machine which was retrofitted with the high-speed spindle as shown in Fig.2. The spindle has been run at 20k, 35k, 45k and 52k to get the peripheral speed of 16 m/s, 27.5 m/s, 35 m/s and 41 m/s respectively. The maximum run out on the wheel was less than 5 μm. The high-speed steel (Length 80mmxWidth 3mmXDepth 20mm), was placed in a specially made fixture and mounted on a 3- D Kistler dynamometer [KISTLER 9257B, Switzerland] to measure the grinding forces as shown in Fig.2. The grinding specification and experimental combinations are indicated in Table I and Table II respectively.

3. Results and Discussion

3.1 Grinding forces

The magnitude of the tangential grinding force $F_t$ and the normal grinding force $F_n$ are recorded with the variation of the grinding process parameters, cutting speed, $v_c$, table speed, $v_w$ and downfeed, $d$. The magnitude of both $F_t$ and $F_n$ decreases with the increase in $v_c$ for all combinations. This may be attributed to: i) it is evident from equivalent chip thickness ($t_e=v_c d/v_c$) that increase in $v_c$ will lead to small chip thickness which leads to lesser chip load and ii) increase in $v_c$ lead to high energy input which leads to plasticization of work material ahead of the grinding zone. But the forces increased with the increase in $v_w$ and $d$ for all combinations due to an increase in chip load.

The normal force, $F_n$, is always higher than the tangential force, $F_t$, in all conditions. The magnitude of the normal force, $F_n$, primarily depend on the hardness of the work material, grit tip geometry (sharpness), large negative rake angle of grit and resistance to penetration of the cutting points in the work surface. The tangential force, $F_t$, mainly depend on rubbing interaction with chip-grit, chip-bond interfaces and chip load. It is very much clear that the normal force component take major share to penetrate the work material and tangential force component follows the path to finish the work and formed chips.

The increase in table speed, $v_w$ and downfeed, $d$, are desired for higher productivity. The productivity increases with the increase of $v_w$ and $d$ which increases the chip load and consequently the grinding forces. It is evident that the grinding process has been discontinued in very adverse combinations like the low cutting speed, $v_c$, high table speed, $v_w$, and high downfeed, $d$, ($v_c=16$ m/s, $v_w=3$ m/min, $d=40$ μm and $v_c=16$ m/s, $v_w=4$ m/min, $d=40$ μm). It indicates that the performance of brazed cBN grinding wheel would be tested for long-duration test with specific grinding parameters to avoid premature wheel loading.

The long duration test has been conducted in two conditions:

i) Favorable condition ($v_c=41$ m/s, $v_w=2$ m/min, and $d=30$ μm) and $t_e=0.024$ μm.

ii) Adverse conditions ($v_c=27.5$ m/s, $v_w=2$ m/min, and $d=30$ μm) and $t_e=0.036$ μm.

In adverse condition, the equivalent chip thickness is 50% more than the favourable condition. It indicates that with said grit density the load per grit will be double. Effectiveness of brazed wheel depends on the sharpness of grit, cutting rather than rubbing & ploughing, grit density and wheel loading.

Fig.3(a) indicates the CBN wheel worked satisfactorily without any wheel loading in favourable conditions up to specific material removal of 100 mm$^3$/mm$^2$. As the less number of grit in action with the work material, the chip load per grit is much higher. Owing to high chip load and wider grit spacing, it has performed effectively. Fig.3(b) depicts the performance of adverse grinding conditions. It indicates that each grit has been subjected to a load which is twice that of favourable conditions.
Accordingly, grinding forces are relatively higher as compared with the favourable condition. Moreover, the HSS offered high resistance to grit penetration due to hot hardness and strong alloying elements like tungsten, molybdenum, vanadium and chromium carbides. The attrition wear rate at grit tip was excessive. Worn grit is incapable to penetrate into the work material and more rubbing, ploughing has happened than cutting resulted in high grinding forces in adverse condition. The grinding performance has been discontinued after 78 mm³/mm² due to excessive grit wear as shown in Fig.3(b).

| Favourable Conditions | Adverse Conditions |
|-----------------------|--------------------|
| $v_s = 41$ m/s $v_w = 2$ m/min, and $d = 30$ μm | $v_s = 27.5$ m/s $v_w = 2$ m/min $d = 30$ μm |

![Grinding forces (N) vs Specific Material removal (mm³/mm²)](image)

| Wheel condition: specific material removal after 25 mm³/mm² |
|-------------------------------------------------------------|
| ![Surface condition](image) |

| Specific material removal after 100 mm³/mm² | Specific material removal after 78 mm³/mm² |
|--------------------------------------------|--------------------------------------------|
| ![Surface condition](image) | ![Surface condition](image) |

Fig.3. Condition of CBN grinding wheel with the progress of grinding HSS

3.2 Wheel topography

Fig.3(c) shows the active surface of the brazed CBN wheel after removing of specific material removal of 25 mm³/mm² and 100 mm³/mm² at the favourable grinding condition. No sign of wheel loading and grit pull out observed even up to the removal of 100 mm³/mm². It discloses that the strong chemical bond has prevented dislodging of the grits from the bond but it reveals that the HSS caused a good level of fracture on the CBN grits. In Fig 3(d) it depicts that the grit wear very excessive. After 78 mm³/mm² of material removal, the surface of the brazed wheel was remarkably deteriorated by wear of the grits. The high chip load and the hot hardness of the HSS are the possible reason for excessive attrition of the grits. The grinding performance has been aborted due to lack of cutting action.
4. Conclusions

a) The current process has been useful for achieving uniform distribution of grits and observed that 50-60 mesh size will realize the distribution of 8-9 grit per square per mm on the wheel surface.

b) The brazed wheel has been tested in two conditions i.e. i) Favorable condition \((v_c=41 \text{ m/s}, v_w=2 \text{ m/min}, d=30 \mu \text{m})\) and ii) Adverse condition \((v_c=27.5 \text{ m/s}, v_w=2 \text{ m/min}, d=30 \mu \text{m})\)

c) In favourable condition with said density, the grinding wheel has worked very effectively up to 100 \(\text{mm}^3/\text{mm}^2\). Localized wheel loading, the interaction of work material with trapped chips, improper penetration of grit into work material and grit wear caused a sharp increase in the grinding forces (Fig. 3(a)). The grits were flattened (Fig. 3(a)) but still intact with the bond for continuing grinding process.

d) In adverse condition, the brazed wheel continued to grind the HSS up to 78 \(\text{mm}^3/\text{mm}^2\) of specific material removal. Grinding process has been discontinued due to excessive wear of grit (Fig. 3(d)).

e) In spite of large protrusion of the grit from bond and high forces acting on the grits, there was no significant grit pull out on the brazed wheel which indicates that the grits are strongly held with bond on its surface.

f) Higher grit density will reduce the chip load per grit resulting to enhance the overall service life of the brazed wheel in adverse condition by reducing attrition wear, fracturing and pull-out of the grits.

g) To derive maximum overall benefits of the brazed wheels, its configuration especially grit spacing density need to be optimized through further intensive research.

5. References:

[1] S. Malkin, “Selection of Operating Parameters in Surface Grinding of Steels,” J. Eng. Ind., vol. 98, no. 1, p. 56, Feb. 1976.

[2] T. W. Hwang, C. J. Evans, and S. Malkin, “Size effect for specific energy in grinding of silicon nitride,” Wear, vol. 225–229, pp. 862–867, Apr. 1999.

[3] S. Paul and A. B. Chattopadhyay, “The effect of cryogenic cooling on grinding forces,” Int. J. Mach. Tools Manuf., vol. 36, no. 1, pp. 63–72, Jan. 1996.

[4] D. J. Stephenson, T. Jin, and J. Corbett, “High Efficiency Deep Grinding of a Low Alloy Steel with Plated CBN Wheels,” CIRP Ann., vol. 51, no. 1, pp. 241–244, Jan. 2002.

[5] A. K. Chattopadhyay, L. Chollet, and H. E. Hintermann, “Improved monolayer CBN wheel for load free grinding,” Int. J. Mach. Tools Manuf., vol. 32, no. 4, pp. 571–581, Aug. 1992.

[6] B. Pal, “Development and Performance of Brazed Type Monolayer CBN Wheel.” [Online]. Available: http://www.idr.iitkgp.ac.in/xmlui/handle/123456789/7701. [Accessed: 31-Jan-2019]

[7] W. F. Ding, J. H. Xu, J. B. Lu, Y. C. Fu, B. Xiao, and H. J. Xu, “Brazed CBN Grinding Wheel with Ag-Base Filler Alloy,” Mater. Sci. Forum, vol. 471–472, pp. 11–15, Dec. 2004.

[8] W. Xu, Y. ZHU, B. DU, and W. DING, “Residual stresses of polycrystalline CBN abrasive grits brazed with a high-frequency induction heating technique,” Chinese J. Aeronaut., Jul. 2018

[9] B. Pal, A. K. Chattopadhyay, and A. B. Chattopadhyay, “Development and performance evaluation of monolayer brazed CBN grinding wheel on bearing steel,” Int. J. Adv. Manuf. Technol., vol. 48, no. 9–12, 2010.

[10] B. Pal, A. K. Chattopadhyay, and A. B. Chattopadhyay, “Effect of chip morphology during grinding bearing steel using single layer brazed and galvanic bonded cubic boron nitride (cBN) wheel,” Mater. Manuf. Process., vol. 26, no. 8, 2011.

[11] U. Teicher, A. Ghosh, A. B. Chattopadhyay, and K. Künanz, “On the grindability of Titanium alloy by brazed type monolayered superabrasive grinding wheels,” Int. J. Mach. Tools Manuf., vol. 46, no. 6, pp. 620–622, May 2006.

[12] D. Wenfeng, X. Jiuhua, C. Zhenzhen, S. Honghua, and F. Yucan, “Grindability and Surface Integrity of Cast Nickel-based Superalloy in Creep Feed Grinding with Brazed CBN Abrasive Wheels,” Chinese J. Aeronaut., vol. 23, pp. 501–510, 2010.

[13] W. Ding et al., “Review on monolayer CBN superabrasive wheels for grinding metallic materials,” Chinese J. Aeronaut., vol. 30, no. 1, pp. 109–134, Feb. 2017.