Research of dry tribochemical mechanical polishing SiC with an innovation abrasive-catalytic abrasive cluster

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Research Article

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\textbf{ABSTRACT:} Abrasive particles have a crucial influence on the material removal rate and surface quality of the workpiece in tribochemical mechanical polishing. Therefore, this article selects a self-made catalytic abrasive cluster to polish the 6H-SiC and explore the removal mechanism of polishing silicon carbide in the new catalytic abrasive cluster. The tribochemical mechanical polishing test and friction and wear test of 6H-SiC were carried out with three different abrasives, and the evaluation parameters such as material removal rate, surface roughness and friction coefficient were obtained. Quanta 200 scanning electron microscope(SEM) and oxfordinca 250 energy dispersive spectrometer (EDS) and
x-ray diffraction (XRD) diffractometer were used to observe the surface, analyze the elements and determine the composition of silicon carbide workpiece after tribochemical mechanical polishing. The experimental result shows that oxygen is produced in the tribochemical mechanical polishing of silicon carbide by catalytic abrasive cluster, which makes the silicon carbide surface generate SiO$_2$ shear film that is easy to be removed. Comparing with iron-based white corundum mixed abrasive and Al$_2$O$_3$ abrasive, the catalytic abrasive cluster has better processability for 6H-SiC, and the material removal rate can reach to 42.928nm/min.

**Key words:** Catalytic abrasive cluster; Dry tribochemical mechanical polishing; Silicon carbide; Friction and wear; Material removal rate; Surface quality.

**1. Introduction**

With the continuous improvement of the surface quality and accuracy, the requirements of the manufacturing industry for mechanical parts and semiconductor materials, mechanical processing technology are developing in the direction of precision processing. Modern industry requires the perfect and reliable performance of products [1-3]. Chemical mechanical polishing is a technology to realize ultra-precision machining [4, 5]. Abrasive plays a very important role in chemical mechanical polishing, and often were used in the processing of semiconductor materials, aerospace and other fields [6-8]. In recent years, many scholars have studied different abrasives, such as magnetic abrasives, mixed abrasives, polycrystalline diamond abrasives etc [9-13]. Good results have been achieved. However, in the process of abrasive processing the workpiece, there are still some problems, such as low material removal rate and poor surface quality of the
workpiece. How to improve the material removal rate of the workpiece by the abrasive and have a better surface quality are the prerequisites to achieve realizing the ultra-precision machining of mechanical parts.

Many scholars have conducted various researches on abrasives. Chen et al. [14] introduced the mixed abrasive of polystyrene core and cerium oxide shell into chemical mechanical polishing, analyzed and evaluated the material removal rate and surface roughness cross section profile of copper chemical mechanical polishing characteristics. The average material removal rate of abrasive is 254nm/min. This abrasive is helpful to reduce the damage to the workpiece surface and obtain better surface quality. Wang et al. [15] combined the new mixed abrasive polishing solution with the photocatalysis effect to polish 4H-SiC, the mixed abrasive polishing solution was composed of Al₂O₃ and ZrO₂ grain, and the external line light was used for irradiation. The experimental results show that the material removal rate of silicon carbide can reach 649nm/h, and the surface roughness of 0.489 nm can be obtained. Zhang et al. [16] prepared spherical and near-spherical magnetic abrasives by gas-solid two-phase flow double nozzle atomization water cooling method, and carried out grinding on the plane magnetic abrasive device. The results show that the surface quality has been improved, and the magnetic abrasive still has good precision finishing ability after 40 minutes of using. Jiang et al. [17] used the gas-solid atomization method to prepare iron-based white corundum abrasive, and characterized the distribution of Al₂O₃ abrasive inside and outside of iron-based by scanning electron microscopy. The results showed that the average particle size of the abrasive particles prepared by the gas-solid physicochemical method is smaller than that
prepared by the aerosol method. There were almost no Al$_2$O$_3$ particles inside the iron matrix, so the performance of the abrasive was improved. Zhu et al. [18] made single crystal diamond into polycrystalline diamond with larger particle sizes to grind quartz glass through the action of adhesive. The results show that the surface roughness of the two abrasives is similar, but the material removal rate of polycrystalline diamond is higher and stabler than that of single crystal diamond. Chen et al. [19] studied the polycrystalline abrasives, bonded the fine abrasive particles with adhesives, and bonded the particles more compactly through sintering. The produced abrasive particles have good wear resistance, high polishing efficiency, and good self-sharpening, which can better improve the surface quality of the workpiece.

Tribochemical mechanical polishing is a new technology in the field of Ultra-precision machining [20,21]. It uses abrasives and chemical additives to conduct tribochemical reactions on the polishing pad, change the surface structure of the workpiece through chemical action, and effectively remove the workpiece materials through mechanical action. The core of tribochemical mechanical polishing is the tribochemical reaction [22,23], which includes the tribochemical reaction under dry friction and the tribochemical reaction under wet conditions. The polishing solution used in tribochemical mechanical polishing does not contain free abrasives [24,25], the polishing solution is deionized water or chemical solution, and the workpiece material removal method is mostly removed by tribochemical wear [26,27]. Due to the advantages of good surface flatness and fewer scratches on the workpiece obtained by this method, it has attracted extensive the attention of many scholars. Qi et al. [28] used five different solid-phase
oxidants for the tribochemical mechanical polishing of silicon carbide and found that oxygen was generated on the surface of silicon carbide, and the experiments showed that all five oxidants could have a tribochemical reaction with silicon carbide, and the oxygen generated by the tribochemical reaction between the solid-phase oxidants and silicon carbide could oxidize the surface of silicon carbide and generate a shear film that could be easily removed. Ootani et al. [29] mainly studied the friction properties of Si$_3$N$_4$ and SiC in water, and explored their mechanisms. Zhou et al. [30] investigated the frictional wear behaviour of amorphous carbon nitride coatings against silicon carbide balls in water. They found that the wear mechanism in water was related to microscopic fracture of the ceramic and instability of the chemically reactive layer.

As mentioned above, many scholars have conducted various researches on the preparation of abrasives, its main purpose is to ensure the surface quality of the workpiece and improve the material removal rate of the abrasive to the workpiece. At present, most abrasives are prepared by combining the same abrasive particles or different abrasive particles in some way. To a certain extent, it improves the surface quality and material removal rate of the workpiece to a certain extent. Therefore, in this paper, oxidant Cr$_2$O$_3$ is added in the process of preparing abrasive, and catalytic abrasive particle is prepared by sintering, followed by a dry tribochemical mechanical polishing method for processing silicon carbide workpieces [31-33]. No water or chemical solution is added in the polishing process, which avoids the use and discharge of polishing liquid, reduces environmental pollution and waste of water resources. It is of great theoretical significance to deeply study the performance of the abrasive, improve the surface quality of the workpiece, and
the polishing efficiency of the abrasive.

2. Experimental process

2.1. Preparation of catalytic abrasive cluster

In this experiment, a kind of catalytic abrasive cluster was prepared by mixing reduced iron powder (average particle size 13μm) with white corundum (average particle size 7μm) and oxidant Cr₂O₃ in a certain ratio, adding high-temperature bonding agent and adhesive, and then pressing the clusters into a billet. Electric blast drying oven (101-3AB, Tianjin Taist Instrument Co., Ltd, China) is selected for drying treatment. High-temperature calcining furnace (XH1L-14, Zhengzhou Xinhan Instrument Equipment Co., Ltd, China) is selected for sintering to keep the iron powder in a semi molten state. After holding it in a high temperature furnace for a period of time, the white corundum particles and Cr₂O₃ are inlaid on the iron powder to obtain the required catalytic abrasive particles. The specific experimental parameters are shown in Table 1. After preparation, it was crushed by crusher (XH1L-14, Zhengzhou Kefeng Instrument Equipment Co., Ltd, China) and then sieved by vibrating screen (JS14S, Xinxiang Concentric Machinery Co., Ltd, China). After crushing and sieving, these catalytic abrasive clusters were observed with an ultra-deep field microscope (Leica DM2500 Leica microsystem, Germany) at an eyepiece magnification of 10× and an objective magnification of 4×~1000× to check the uniformity of the grain size of the catalytic abrasive cluster. Take the abrasive sample and use the laser particle size distribution tester (JL-1197, Chengdu Jingxin Powder Testing Equipment Co., Ltd, China) to test the particle size of catalytic abrasive clusters. The burnished catalytic abrasive cluster, iron-based white corundum mixed abrasive and Al₂O₃ abrasive were used
to rub tribochemical mechanical polishing silicon carbide respectively, and the performance of the three abrasives was compared.

Table. 1 Detailed experimental parameters.

<table>
<thead>
<tr>
<th>Experimental condition</th>
<th>Detailed parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fe and Al₂O₃ mass ratio</td>
<td>3:1</td>
</tr>
<tr>
<td>Add an oxidizer</td>
<td>Cr₂O₃</td>
</tr>
<tr>
<td>Apply pressure</td>
<td>50MPa</td>
</tr>
<tr>
<td>Drying temperature and time</td>
<td>110℃;8h</td>
</tr>
<tr>
<td>Sintering temperature and time</td>
<td>1200℃;8h</td>
</tr>
<tr>
<td>Average particle size</td>
<td>25um-30um</td>
</tr>
</tbody>
</table>

2.2. Tribochemical mechanical polishing experiment

In this experiment, three kinds of abrasives were selected, namely Al₂O₃ abrasive, iron-based white corundum mixed abrasive, and catalytic abrasive cluster for tribochemical mechanical polishing of silicon carbide. The polishing pad used is a polyurethane polishing pad, which was tested on the polishing machine (ZYP330, Shenyang Maike Material Processing Equipment Co., Ltd, China). The processing principle is shown in Fig. 1. The test sample is 6H-SiC single crystal substrate (Beijing Tianke Heda, China) with a thickness of 0.4 mm and a diameter of 50.8 mm. The polishing process parameters are shown in Table 2.
Fig. 1 Tribochemical mechanical polishing of silicon carbide by catalytic abrasive clusters.

Table. 2 Technological parameters of catalytic abrasive cluster tribochemical mechanical polishing silicon carbide.

<table>
<thead>
<tr>
<th>Factors</th>
<th>Speed of Polishing (r/min)</th>
<th>Polishing pressure (psi)</th>
<th>Polishing time (min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parameter</td>
<td>60</td>
<td>4</td>
<td>30</td>
</tr>
</tbody>
</table>

The above prepared catalytic abrasive clusters were used for the tribochemical mechanical polishing of silicon carbide, and 8 g of the abrasives were taken in a single pass and evenly distributed on the polishing pad. The purpose of this experiment is to verify the effect of catalytic abrasive cluster, and add two groups of control group experiments. Fig. 2(a) (b) and (c) are the diagrams of Al₂O₃ abrasive, iron-based white corundum mixed abrasive and catalytic abrasive cluster tribochemical mechanical polishing silicon carbide respectively. For the accuracy of the test, each group of experiments is conducted three times, and the average value is taken.
A precision electronic balance (BSA224S-CW, Sartorius Scientific Instruments (Beijing) Co., Ltd,) was used to measure the mass of the silicon carbide samples in the experiment. Calculate the difference of silicon carbide before and after tribochemical mechanical polishing, and calculate the material removal rate (MRR, nm/min) of silicon carbide by catalytic abrasive cluster using Eq (1) as follows:

\[
MRR = \frac{\Delta m}{\rho \times s \times t} \times 10^7 (\text{nm/\text{min}})
\]  

(1)

In the Eq (1), \(\Delta m\) refers to the mass difference before and after tribochemical mechanical polishing of silicon carbide, \(\rho\) prefers to the density of silicon carbide workpiece, taken as 3.2 g/cm\(^3\), \(s\) refers to the area of silicon carbide, the radius of silicon carbide is taken as 25.4 mm, \(t\) is the time, measured in min.

2.3. Friction and wear test

The friction and wear experiment was conducted on the MWF-500 reciprocating friction and wear machine (MWF-500, Jinan Huaxing Test Equipment Co., Ltd, China), maintaining the same working conditions and parameters as the grinding and polishing
machine. The upper sample was a polyurethane polishing pad and the lower sample was a silicon carbide sample. The silicon carbide sheet and the carrier were pasted on the bearing groove of the friction and wear machine. The experimental process is shown in Fig. 3. The reciprocating motion of the friction and wear machine is set as 10 mm, and the legal load is set as 20N. The single factor experiment is conducted under the working conditions of Al₂O₃ abrasive, iron-based white corundum mixed abrasive and catalytic abrasive cluster. The specific parameters of the experiment are shown in Table 3.

Fig. 3 Enlarged view of experimental instruments, equipment and samples. Note: (a) Polyurethane pad sample, (b) Enlarged drawing of polyurethane pad and silicon carbide sample, (c) Diagram of experimental equipment.

<table>
<thead>
<tr>
<th>Experimental condition</th>
<th>Detailed parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Velocity</td>
<td>100 r/min</td>
</tr>
<tr>
<td>Polishing solution type</td>
<td>Al₂O₃ abrasive, Iron-based white corundum mixed abrasive, Catalytic abrasive cluster</td>
</tr>
<tr>
<td>Tribochemical mechanical polishing object</td>
<td>SiC samples</td>
</tr>
<tr>
<td>Polishing pad type</td>
<td>Polyurethane polishing pad</td>
</tr>
<tr>
<td>Interfacial pressure</td>
<td>20 N</td>
</tr>
</tbody>
</table>

3. Experimental results
3.1. Particle size distribution of the prepared catalytic abrasive cluster

The average particle size of the catalytic abrasive cluster prepared here is 25um - 30um. Crush the sintered blocks with a crusher and screen them with a sieve to ensure the accuracy of silicon carbide polishing with three different abrasives with the same particle size. Fig. 4 shows the figure before and after abrasive crushing.

![Comparison diagram of abrasive before and after crushing.](image)

Fig. 4 Comparison diagram of abrasive before and after crushing.

Fig. 5 shows the particle size measured by the particle size meter for three groups of abrasives after sintering and crushing. (a) - (c) represent Al₂O₃ abrasive, iron-based white corundum mixed abrasive and catalytic abrasive cluster respectively. From the measurement results, the particle sizes of the three abrasives are relatively uniform and accurate, with good consistency.
3.2. Material removal rate and surface quality

The catalytic abrasive cluster fired in this experiment tribochemical mechanical polishing the silicon carbide with the other two abrasives respectively. Each group of experiments was done three times, and the average value was taken. It can be seen from (a) in Fig. 6 that the material removal rates of the three abrasives with the same particle size differ greatly when used for tribochemical mechanical polishing of silicon carbide. The material removal rate of Al$_2$O$_3$ abrasive, iron-based white corundum mixed abrasive and catalytic abrasive cluster to silicon carbide is gradually increased. The material removal rate was 3.36nm/min, which was the lowest among the three when the Al$_2$O$_3$ abrasive was used for tribochemical mechanical polishing of silicon carbide. The material removal rate of silicon carbide can be improved by tribochemical mechanical polishing with iron-based white corundum mixed abrasive. Compared with Al$_2$O$_3$ abrasive, iron-based white
Corundum mixed abrasive had better abrasive performance. The catalytic abrasive cluster showed the highest material removal rate for silicon carbide among the three, with a material removal rate of 42.928 nm/min. To evaluate the performance of abrasive, it is necessary to have a good surface quality while having a material removal rate. It can be seen from (b) in Fig. 6 that the initial surface roughness of silicon carbide is 10.620 nm. Compared with the initial silicon carbide surface, the surface roughness of silicon carbide polished by three kinds of abrasives tribochemical mechanical polishing has increased. However, the surface roughness of silicon carbide polished with three kinds of abrasives were basically the same. Use a white light interferometer (Contour GT-X3/X8 three-dimensional surface profiler, Bruker, Nano, Inc.) to observe the polished silicon carbide surface. As shown in Fig. 7, it can be seen that the surface of silicon carbide wafer is relatively flat without large scratches.

![Fig. 6 Removal rate and surface roughness of silicon carbide by three abrasives](image)
Fig. 7 Surface roughness of silicon carbide after tribochemical mechanical polishing of catalytic abrasive cluster. Note: (a) Initial surface roughness, (b) Al$_2$O$_3$ abrasive, (c) Iron-based white corundum mixed abrasive, (d) Catalytic abrasive cluster.

3.3. Friction coefficient

Fig. 8 (a) shows the friction coefficient curve of Al$_2$O$_3$ abrasive, iron-based white corundum mixed abrasive and catalytic abrasive cluster after tribochemical mechanical polishing of silicon carbide. The friction coefficients are 0.2685, 0.2866 and 0.3447.
respectively. It is observed that the friction coefficient is initially low during the test. But with the test, the friction coefficient shows an upward trend then enters a relatively stable state. This is due to the small resistance at the beginning of friction. With the extension of friction time, when the number of abrasives on the contact surface tends to a stable value, the friction curve gradually becomes stable. Three abrasives show different sizes of friction coefficient with the increase in the number of friction leads to increased wear. Different abrasives friction silicon carbide shows different amounts of wear, the material removal rate will be different. In this experiment, we want to express the different friction coefficients of three kinds of abrasives in tribochemical mechanical polishing of silicon. Under the condition that the hardness, applied pressure and friction time of the workpiece (silicon carbide) are the same, three different abrasives are selected, and the size of the friction coefficient is compared and observed to verify the speed of abrasive tribochemical mechanical polishing of the workpiece, that is, the three abrasives show different material removal rates. Fig. 8(b) is the average friction coefficient when three kinds of abrasives rub silicon carbide. It is found from Fig. 8 that the catalytic abrasive cluster had better tribochemical properties for silicon carbide than the other two abrasives.
3.4. Composition change of workpiece surface before and after polishing

The initial silicon carbide sample and the sample polished with catalytic abrasive cluster were tested. The sample was observed by SEM (Quanta 200 scanning electron microscope, FEI, USA) after being magnified 10000 times. The results are shown in (a) and (d) in Fig. 9. Fig. 9 (d) compared with Fig. 9 (a), there are blocky spots on the surface of the silicon carbide sample, and it is presumed that some tribochemical reaction may have occurred. The detection of the elements was performed using EDS (OXFOBRD INCA250 energy spectrometer system) and the results are shown in (b) and (e) in Fig. 9. It is detected that the initial silicon carbide surface only contains C and Si, and the element percentage is about 1:1, without other elements, as shown in Table 4. After polishing by catalytic abrasive cluster, oxygen (O) element appears, and the content is shown in Table 5. The formation of new substances was detected by XRD diffractometer (Bruker D2 PHASER, Germany) [34]. The results are shown in (c) and (f) in Fig. 9. Some oxide of
silicon (Si$_x$O$_y$) is detected on the surface of silicon carbide.

<table>
<thead>
<tr>
<th>Element</th>
<th>C</th>
<th>Si</th>
</tr>
</thead>
<tbody>
<tr>
<td>Atomic percentage of SiC surface elements</td>
<td>49.3</td>
<td>50.7</td>
</tr>
</tbody>
</table>

Table 4 Initial surface elements and content of SiC

<table>
<thead>
<tr>
<th>Table 5 The percentage of oxygen produced by dry polishing silicon carbide with three kinds of abrasives</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abrasives</td>
</tr>
<tr>
<td>Specific gravity of oxygen production</td>
</tr>
</tbody>
</table>

4. Discussion

From the analysis of the above experimental results, it can be seen that the material removal rate of silicon carbide by catalytic abrasive cluster is much higher than that of Al$_2$O$_3$ abrasive and iron-based white corundum mixed abrasive. In friction and wear experiment, it was also demonstrated that catalytic abrasive cluster wear silicon carbide faster. Compared with Al$_2$O$_3$ abrasive and iron-based white corundum mixed abrasive, the catalytic abrasive cluster had better grinding and polishing performance for silicon carbide materials.

Observe Fig. 9 (d) and (a) in Fig. 9. Small blocky spots appear on the surface of silicon carbide in Fig. 9 (d), and oxygen (O) is detected in Fig. 9 (e). The proportion of oxygen (O) in the initial silicon carbide workpiece increases from 0 to 1.06%. The catalytic abrasive cluster promotes the generation of oxygen in the process of tribochemical
mechanical polishing of silicon carbide workpiece, and it is speculated that some chemical reaction may have occurred. By analyzing (c) and (f) in Fig. 9, we can see that the intensity of the peak in Fig. 9 (f) is stronger than that in Fig. 9 (c), the compound SiO$_2$ appears at about 36° and 75° according to the instrument. When the incidence angle is 68°, there is a smaller peak. The intensity of the wave peak is weaker than that of 36° and 75°, and the content is small, so the chemical valence of the compound cannot be completely determined. However, it is enough to show that the tribochemical reaction does occur in the tribochemical mechanical polishing, and silicon oxide similar to SiO$_2$ is generated in this process. This is mainly due to the combination of some carbon (C) elements and oxygen (O) in tribochemical mechanical polishing silicon carbide. The CO or CO$_2$ generated diffuses into the air, and the content of carbon (C) element is reduced compared with that before. The silicon (Si) on the silicon carbide surface combines with oxygen (O) to form a certain oxide of silicon (Si$_x$O$_y$). The oxide (Si$_x$O$_y$) generated by tribochemical mechanical reaction adheres to the surface of silicon carbide. In the presence of oxygen, the silicon carbide surface forms a reaction film that is easy to shear under the tribochemical mechanical reaction. The reaction formula is shown in (2). Make silicon carbide surface generate SiO$_2$ which can be easily removed by mechanical action [35, 36].

$$\text{SiC} + 2\text{O}_2 \rightarrow \text{SiO}_2 + \text{CO}_2 \uparrow$$

The reaction formula (2) also proves that the oxygen (O) element is increased after the tribochemical mechanical polishing of silicon carbide, and the generated CO$_2$ diffuses into the air. In this process, the carbon (C) atoms are brought into the air, and the carbon (C) atoms are reduced [37-40].
The high flash point temperature during tribochemical mechanical polishing will stimulate the occurrence of the above formula (3) - (5) [41]. On the other hand, the flash point temperature during polishing will also promote the reaction between water molecules and oxygen in the air and Cr\textsubscript{2}O\textsubscript{3}, as shown in formula (6). In formula (6), OH\textsuperscript{-} ionized by the product absorbing water molecules in the air and silicon bond suspended in silicon carbide will undergo tribochemical reaction [42,43], the reaction is shown in formula (7). However, the content of water molecules in the air is relatively small compared with the amount of Cr\textsubscript{2}O\textsubscript{3} in the catalytic abrasive cluster. The reaction of formula (6) and formula (7) will only be carried out partially. There is still a large amount of Cr\textsubscript{2}O\textsubscript{3} in the catalytic abrasive cluster. This reaction accelerates the transformation of the workpiece from a hard silicon carbide material to a shear film removed by shearing

\begin{equation}
\text{SiC} + 2\text{H}_2\text{O} \rightarrow \text{SiO}_2 + \text{C} + 2\text{H}_2\uparrow \quad (3)
\end{equation}

\begin{equation}
\text{SiC} + 4\text{H}_2\text{O} \rightarrow \text{SiO}_2 + \text{CO}_2\uparrow + 4\text{H}_2\uparrow \quad (4)
\end{equation}

\begin{equation}
\text{SiC} + \text{O}_2 + \text{H}_2\text{O} \rightarrow \text{SiO}_2 + \text{CO}\uparrow + \text{H}_2\uparrow \quad (5)
\end{equation}

Thus, as mentioned above, the surface of silicon carbide is transformed into SiO\textsubscript{2} or silicon oxide (Si\textsubscript{x}O\textsubscript{y}), and whatever the state of the product, the hardness is lower than that of the silicon carbide material, and the oxide layer is easily removed by catalytic abrasive cluster. Compared with Al\textsubscript{2}O\textsubscript{3} abrasive and iron-based white corundum mixed abrasive, the catalytic abrasive cluster will produce oxygen during the tribochemical mechanical polishing of silicon carbide, accelerating the reaction and play a catalytic role. It not only
removes carbon (C) atoms, but also removes silicon (Si) atoms. This is also why the catalytic abrasive cluster will have a high material removal rate when tribochemical mechanical polishing silicon carbide, and the reaction process is shown in Fig. 10.

Fig. 9 Inspection results before and after tribochemical mechanical polishing. (a) Initial silicon carbide surface, (b) Elements contained in initial silicon carbide, (c) Compounds contained in the initial silicon carbide, (d) Polished silicon carbide surface, (e) Elements contained in the polished silicon carbide, (f) Compound contained in silicon carbide after polishing.
5. Conclusion

(1) Three kinds of abrasives tribochemical mechanical polishing silicon carbide, catalytic abrasive cluster has the best material removal rate of silicon carbide, Al$_2$O$_3$ abrasive is the worst, and the effect is obvious.

(2) In terms of surface roughness, the surface roughness of the three abrasives in this paper is basically the same after tribochemical mechanical polishing of silicon carbide.

(3) Catalytic abrasive cluster tribochemical mechanical polishing of silicon carbide, the catalytic abrasive cluster of Cr$_2$O$_3$ does not directly react with silicon carbide, but in the process of tribochemical mechanical polishing with silicon carbide workpiece to produce
oxygen. In the silicon carbide material surface to promote the generation of silicon carbide softening layer SiO$_2$ and silicon (Si) and oxygen (O) combined to produce a silicon oxide (Si$_x$O$_y$), through the role of mechanical wear makes the workpiece material removal rate to rise.

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**Availability of data and material**

All data generated or analyzed during this study are included in this manuscript.

**Declarations**

**Ethics approval:** Not applicable.

**Consent to participate:** All authors agree to participate.

**Consent for publication:** All authors agree to publication.

**Declaration of competing interest**

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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