



Investigation into the role of cold atmospheric plasma on the precision grinding of RB-SiC ceramic at room temperature

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Abstract

RB-SiC ceramic is one of the most important and useful materials as optical precision elements in many scientific research fields. In this paper, a novel cold atmospheric plasma (CAP) process via oxygen (O₂), which is based on the precision grinding process in surface technology to modify at room temperature for grinding with a combination of plasma oxidation surface modification, is proposed. To identify the performance of the proposed cold atmospheric plasma process via oxygen method on the surface modification of RB-SiC ceramic fabrication of the precision grinding process, precision grinding test was conducted. To reveal the fundamental issue in the grinding of RB-SiC ceramic, surface-modified layer and mathematical model of the grinding trajectory via the point $P(A_p, A_j)$ model analysis were conducted to investigate the effect of the composite process on grinding force and the mechanism of surface material removal in the presence of plasma oxidation. As a result of the method included the kept constant during the precision grinding of the composite process self-adaption-grinding process to avoid the deviation caused by second grinding particle entry. As a summary, we provide a significant cold atmospheric plasma-precision grinding compound process toward the establishment of the basic theory by analyzing the mechanism of the experimental test design and computation. The process and technical difficulties of RB-SiC ceramic and mechanism of surface modified layer material removal during precision grinding were solved.

Keywords Precision grinding process · Cold atmospheric plasma · RB-SiC ceramic · Grinding ratio

Highlights

- The work shows the cold atmospheric plasma via oxygen (O₂) composite methods by the active surface “free radical” is concentration higher than a single type of the precision grinding process.
- The effectiveness of surface modification be measured and evaluated by the magnitude and direction of the RB-SiC ceramic surface modification layer and removal efficiency of Si phase and SiC phase.
- In the work, we propose a new method for cold atmospheric plasma based on the precision grinding process to research on surface modification of RB-SiC ceramic hard-brittle material by precision grinding problems to test its performance. In such cases, the finish-surface quality of the RB-SiC ceramic is easy to be further improved and provide a satisfactory result at an affordable single-precision grinding process cost.

Abbreviations

a_p	Precision grinding depth, μm
Δa_p	The depth of grinding, μm
b	The width of precision grinding face, mm
e_s	The grinding force-the grinding specific energy, J/mm^3
dA	The actual contact area during the grinding process, mm^2
$D_{\text{RB-SiC}}$	The diameter of the RB-SiC ceramic, mm
$E_{\text{RB-SiC}}$	The precision grinding power, W
$f_{\text{grinding wheel}}$	The tangent and normal of the grinding force, N
F	The grinding force, N/mm^2
F_i	The grinding force per-unit area, N/mm^2
F_t	The tangential grinding force, N
F_n	Normal grinding force, N
$N_{\text{Diamond wheel speed}}$	The speed of diamond wheel, r/min
RT	The room temperature, $^{\circ}\text{C}$

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Δ_t	Rotation interval time, min
Ω_s	Constant speed, m/s
$V_{grinding\ wheel}$	The workpiece volume, mm ³ /s or the speed ratio, $\mu\text{m/s}$
θ	Rotating angle of the grinding wheel, deg
Ψ_i	The rotation angle, deg
Ω_s	The constant speed, mm ³ /s

1 Introduction

RB-SiC ceramic is considered to be among the most promising optical precision element engineering materials across a series of application fields. Improving the RB-SiC ceramic properties of the optical hard-brittle materials is considered to be one of the practical engineering application methods to solve the problem of the sub-surface damage. However, in the traditional process of precision grinding such as sub-surface layer damage, grinding ratio and microscale, which affect the precision grinding process are encountered.

To deal with this, cold atmospheric plasma via oxygen (O_2), which is based on the precision grinding process in surface technology to modify at room temperature for RB-SiC ceramic hard-brittle material, has been introduced by the interface characteristics and surface modified layer and mathematical model. Due to the effectiveness of cold atmospheric plasma via oxygen, it has attracted extensive attention in recent years.

Such the phenomenon is known as the surface modification. The high concentration of active atoms in atmospheric plasma process technology ensures the high efficiency of process. In 2006, the removal efficiency of reactive atom plasma technology (RAPT) developed by Fanara et al. [1] (from Cranfield University in the UK) for ULE materials (zero expanding glass materials) is 33mm³/min.

As early as 2004, Hashimoto and Lahoti [2] proposed a steady-state rule, pointing out that the three indexes that affect stability are dynamic, geometric and rotational. The influence of these grinding force on the stability of high speed rotation was analyzed [3]. Barrenetxea et al. [4] revealed the most appropriate parameter selection for

the key consideration variable speed precision grinding processes. Xu et al. [5] by introducing the effect of external field, the directional preparation of micro- or nano-structured functional materials can be fabrication.

In the last twenty years, with the development of the RB-SiC ceramic preparation process, effects have been taken to the actual power of the laser resonator conditions during the grinding processes, including the grinding beating and the grinding depth of a_p and grinding surface-finish accuracy. However, there is no satisfying precision grinding models for engineering applications and theory to explain the grinding problems of the mechanism of surface modification, but profound understanding is very necessary in the precision grinding technology, grinding ratio [6, 7], as well as the RB-SiC ceramic fabrication of the precision grinding process.

In this article, we propose one process and grinding method for cold atmospheric plasma via oxygen based on the precision grinding process. In such cases, the finish-surface quality of the RB-SiC ceramic hard-brittle material is easy to be further improved and provides a satisfactory result at an affordable single-precision grinding process cost. Therefore, we here would like to focus on the cold atmospheric plasma via oxygen based on interface characteristics methods and process for the RB-SiC ceramic hard-brittle material, as shown in Table 1.

From Table S1, we can obtain the properties and parameters of the RB-SiC ceramic.

In this paper, we propose a new process and technique for grinding optical crystal hard-brittle materials by surface modification of grinding layer via precision grinding. In the work, we propose the cold atmospheric plasma process via oxygen based on the chemical reaction of the surface modification processing via the precision grinding process grinding the RB-SiC ceramic with grinding process function system that is designed and studied further from work condition ceramic base of the grinding wheel path of the $A(i, j)$ and $P(P_\varphi, P_{\varphi+1})$ experimental parameters, controllable clearance and eccentricity for the e_s by the grinding depth and fabrication the shape of the surface and surface-finish quality. These are shown in Figs. 3d and 6c, d.

Table 1 The boundary conditions for the cold atmospheric plasma (CAP) flow model

	u	v	P	T	Y
Solid Inside Wall	0	0	0	$\frac{\partial T}{\partial X_i} = 0$	0
Flow Outside	$\frac{\partial u}{\partial y} = 0$	$\frac{\partial v}{\partial y} = 0$	1 atm	$\frac{\partial T}{\partial y} = 0$	$\frac{\partial Y}{\partial y} = 0$
Flow Inside	$u = u_{in}$	0	0.1~0.3 MPa	270~320 K	$Y = Y_{in}$
Solid-Flow Interface	0	0	$\frac{\partial P}{\partial X_i} = 0$	$k_f \frac{\partial T}{\partial X_i} \Big _f = k_s \frac{\partial T}{\partial X_i} \Big _s$	$\frac{\partial Y}{\partial X_i} = 0$

2 The experimental principle and process

The cold atmospheric plasma process via oxygen (O_2) is based on the physicochemical reaction of the surface modification processing principle to reduce the sub-surface damage and softened RB-SiC ceramic surface hardness layer, in the process of surface modification will not introduce other new damage layer. Inspired by the interface properties and surface modification of materials, in this article, we propose one type of the cold atmospheric plasma process via oxygen by the precision grinding process method for solving surface-finish shape quality of the RB-SiC ceramic hard-brittle material in precision grinding process problems. The schematic of the cold atmospheric plasma process via oxygen parameter design with ceramic base grinding wheel precision grinding which can provide the precision grinding process region [8, 9]. The detailed description of the proposed new method is given in the following. This method is simple and feasible.

The particle size of the diamond grinding wheel is 600#. Use the diamond grinding wheel micro-grinding process to finish surface removal. The micro-grinding process parameters of the $X^\#$ test-workpiece are $a_p = 5 \mu\text{m}$, $N_{\text{Diamond wheel speed}} = 3000\text{r/min}$. The un-grinding area of the $X^\#$ test-workpiece was not surface modification by the cold atmospheric plasma process via oxygen (O_2) at room temperature, and obvious defects appeared after the micro-grinding process such as extrusion, micro-holes grinding, stacking error, pits, and void (as shown in Figs. 4 and 5). In the micro-grinding area, plow stripes and wear marks are obvious. The micro-grinding process parameters of the $3^\#$ test-workpiece are $a_p = 5 \mu\text{m}$, $N_{\text{Diamond wheel speed}} = 3000\text{r/min}$. The height of the cold atmospheric plasma torch is 8 mm. By adjusting the speed of the properties and parameters of the RB-SiC ceramic workpiece, as shown in Tables 2, S1 and Fig. S2 of the “Appendix A. Supplementary data”.

The surface removal mechanism analysis conducted in $3^\#$ test-workpiece, for instance, shows such a benefit by the cold atmospheric plasma via the oxygen precision grinding process. The surface of the $3^\#$ test-workpiece was modified by the cold atmospheric plasma process via oxygen (O_2). In the un-grinding area, there was black-burning area which reacted with oxygen plasma process via oxygen at room temperature, and majority of the raw hard layer was involved in physicochemical reaction. No obvious extrusion and accumulation occurred in un-grinding and over-grinding areas, in addition stripes in the shape of plastic ridges along the grinding direction.

The large particles of Si phase and SiC phase are obvious, and the size of particles is uniform and the distribution is regular. The distribution is uniform and normal. This phenomenon is related to the height of the plasma torch. Scaly wear marks appeared in the micro-grinding area, and the plow stripes were more obvious.

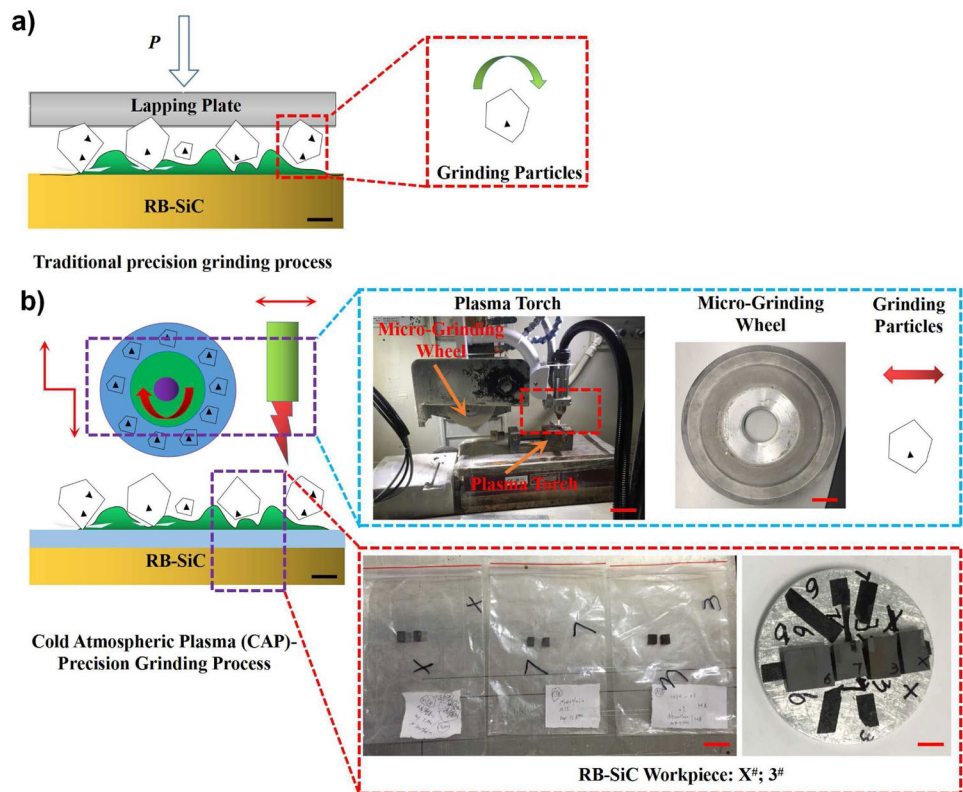
The surface modification process and determination analysis method conducted in physicochemical reaction of the cold atmospheric plasma torch, for instance, show such benefit. In this section, we will first describe the precision grinding of RB-SiC ceramic hard-brittle material grinding process problems and then give a brief discussion of cold atmospheric plasma with the precision grinding process. During the precision grinding error compensation, the grinding edge of the grinding wheel may generate a tiny amount of grinding heat [10–12].

We will study one type of composite process of cold atmospheric plasma and precision grinding process. The definitions are given as follows. Figure 1b shows the schematic diagram of principle and mechanism of surface modification of the cold atmospheric plasma via oxygen process, and the method is proposed for improving the quality of surface-finish shape based on the precision grinding process. Inspired by this observation, we will model the

Table 2 Comparison table of hardness parameters

	Hardness (kg/mm^2)	Mohs Hardness	HV (GPa, Vickers Hardness)	Chemical Bonds	Crystal	Bond Lengths (10^{-12} m)	Bond Energies (kJ/mol)
C layer	—	—	—	—	—	—	—
SiO_2	6–7	7	—	covalent bond	atomic crystal	—	—
Si–C–O	—	—	—	—	—	—	—
SiC	2840~3320	9.5	22.2 ± 2.2	covalent bond	atomic crystal	—	—
C–C	—	—	—	—	—	154	332
C–O	—	—	—	—	—	143	326
Si–C	—	—	—	—	—	185	347
Si–O	—	—	—	—	—	165	460
Si–F $\uparrow$	—	—	—	—	—	171	552

Fig. 1 The single-precision grinding and composite process schematic diagram process of the grinding wheel: **a** Traditional precision grinding process; **b** Cold atmospheric plasma (CAP) via oxygen (O_2) based on the precision grinding process



general of the process of preparing optical elements by precision grinding as a composite process deduced from the two are related technologies: cold atmospheric plasma via oxygen for the surface modification treatment and precision grinding for the removal of surface materials, which are detailed, respectively, as follows.

For the Δa_p , it is necessary to be designed and calculated by the dynamic precision and ultra-precision grinding process. In general, “dressing tool accuracy” determines the surface-finish accuracy of the grinding wheel. Moreover, the relative rotation velocity and the direction of the linear velocity of rotation affect the a_p precision grinding depth in the RB-SiC ceramic material processing. The anisotropy of grinding efficiency is related to the preparation process of RB-SiC ceramic hard-brittle material and the critical phase boundary grinding depth of the a_p based on the brittle-plastic transition.

The finish touch surface of the micro-grinding wheel has a high grinding quality of cylindricity and parallelism, and its tiny effective roughness with tiny grinding particles that form tiny grinding touch-edges has edge effect. Improper adjustment parameters lead to continuous changes in the grinding force and slight pulsation, and the surface and surface-finish quality is not smooth and densification.

The experimental results show that the physical and chemical actions of plasma temperature on the RB-SiC

ceramic workpiece surface finish via softening the raw hard layer reduce the hardness of the workpiece surface and contribute to the plastic removal in the micro-grinding process.

Figures 4 and 5a, b show the experimental results, and phenomena show that both plastic and brittle fracture domains appear in the curving plough stripes caused by the circumferential abrasive grains on the surface of grinding wheel, indicating that the height of the cold atmospheric plasma torch and the abrasive grain protrusion height of grinding wheel have a great influence on the micro-grinding results of RB-SiC ceramics.

3 Micro-grinding force calculation analytic and discussion

For the cold atmospheric plasma method based on the precision grinding process, surface-finish thermal damage and micro-grinding wheel force include the amount of micro-jumping and friction force in grinding process during grinding. The grinding wheel deformation force includes the grinding tangential force and normal force along the A_{ij} at the points $a_p(A_i, A_j)$ and $P(A_i, A_j)$.

The basic idea of cold atmospheric plasma is that a plasma torch is produced by oxygen (O_2) at room temperature for the extent of surface-finish modification was evaluated by precision grinding process test with a single type

of the grinding problem to a low-dimensional surface free radical activated surface removal problem using an functional groups and surface radicals and then search for the best acceptable process method inside the Si phase and SiC phase interface features model space.

Then, we describe the interface characteristic chemical reaction mechanism as shown in (1–3) by converting it to a new process problem. These composite process anticipated reaction is expressed as follows:



The utilization of cold atmospheric plasma process via oxygen fabricate to the surface-finish data acquisition a very thin and high tension precision grinding surface without the other mechanical, chemical treatment of the strong acting components to increase adhesion.

Parameter Selection: In the paper, we discuss the function and the main parameter selection of parameters involved in our algorithm and design, i.e., ρ , e_s . Then, we discuss the determination

method of effectiveness of surface modification and difference between the cold atmospheric plasma measure and the single type of the precision grinding process, as shown in Fig. 1b.

Along the tangential direction and normal direction of the grinding profile, the RB-SiC ceramic is subjected to a tangential grinding force F , and the equilibrium force equation is:

$$\begin{cases} F_N = F_n, F_T + F_t \\ M = F_n \cdot L(t) \end{cases} \quad (4)$$

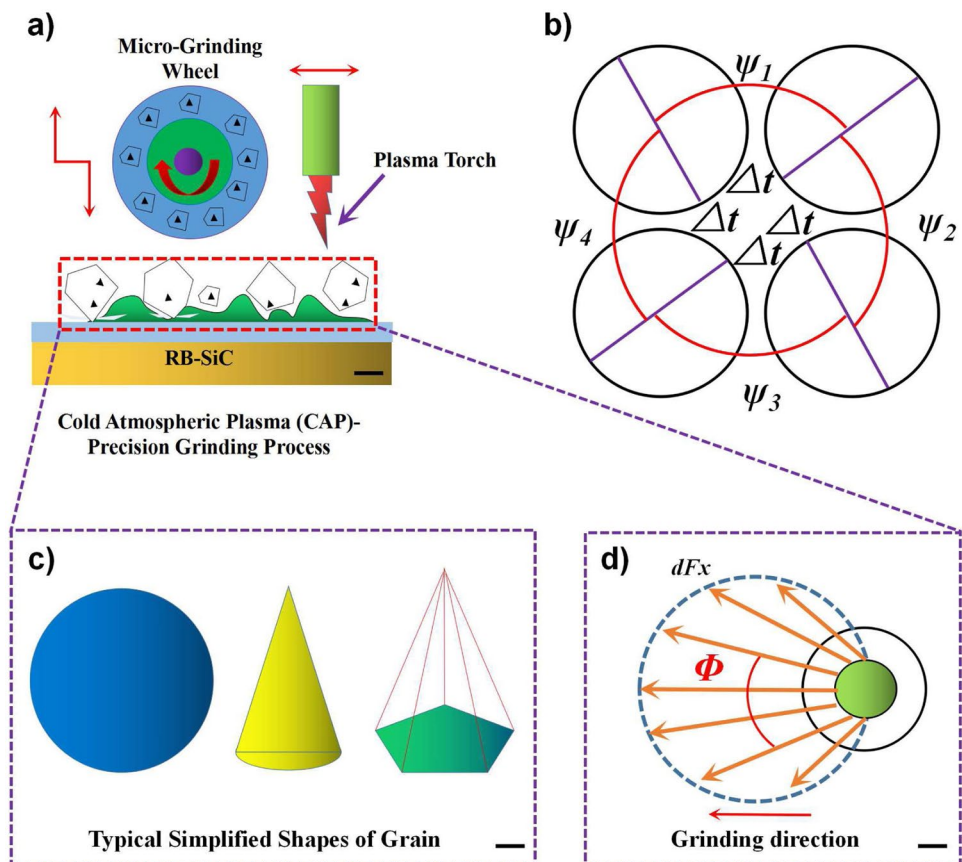
However, with this design and grinding method, the RB-SiC ceramic is improving the grinding efficiency calculation model. These are shown in Figs. 2b and 6d. The relative density (ρ relative) and porosity [13] of the RB-SiC workpiece were calculated with respect to the theoretical density (ρ theoretical) by the equation:

$$\rho_{\text{relative}} = (\rho_{\text{specimens}} / \rho_{\text{theoretical}}) \times 100\% \quad (5)$$

$$\rho_{\text{relative}} \% = 100 / \left(\frac{\omega_1}{\rho_1} + \frac{\omega_2}{\rho_2} \right) \quad (6)$$

$$\text{RB-SiC}_{\text{porosity}}(\%) = 100 - (\rho_{\text{specimens}} / \rho_{\text{relative}} \times 100) \quad (7)$$

Fig. 2 Cold atmospheric plasma (CAP) via oxygen (O_2) based on the precision grinding process schematic diagram: **a** Composite process schematic diagram; **b** Direction of rotation of the Ψ ; **c** Typical simplified shapes of grain; **d** Grinding direction



3.1 Grinding ratio and force calculus method

At room temperature, the design parameters of the effect of cold atmospheric plasma via oxygen (O_2) surface modification and activity of surface free radicals directly affect a_p of the precision grinding depth. The cold atmospheric plasma is produced in the atmosphere (open-operating condition) at room temperature environment, as well as under the condition via oxygen rate of flow, while the free path of particles in atmospheric cold plasma via oxygen is much smaller than the characteristic scale of the discharge.

The touch point in precision grinding process is the force point of the tangent and normal direction its path of the rotate to beat parameter A_{ij} .

The calculation method of rotation speed of the RB-SiC ceramic by the optical elements is shown in Fig. 1b:

$$\omega = \psi_i / \Delta t \quad (8)$$

where Ψ_i —rotation angle, Δ_t —rotation interval time.

The equilibrium equation for uniform rotation [14, 15] is:

$$\Omega_s = 2V_{\text{grindingwheel}} / D_{\text{RB-SiC}} \quad (9)$$

where Ω_s —constant speed, $V_{\text{grindingwheel}}$ —grinding wheel, and $D_{\text{RB-SiC}}$ —the diameter of the RB-SiC ceramic.

Therefore, the precision grinding of the tangent and normal force density function is:

$$df(\psi) = g_d(\beta) f_{\text{grindingwheel}}(\theta) d\theta \quad (10)$$

The component of the grinding force in the Cartesian coordinate system can be described as the three-dimensional structure of the component [16] in $ZY-\theta$ coordinate:

$$f_{\text{grindingwheel}} = \begin{Bmatrix} f_{gx}(\theta) \\ f_{gy}(\theta) \end{Bmatrix} = \begin{bmatrix} \cos\theta & \sin\theta \\ \sin\theta & -\cos\theta \end{bmatrix} \begin{Bmatrix} f_{gt}(\theta) \\ f_{gr}(\theta) \end{Bmatrix} \quad (11)$$

where $f_{\text{grindingwheel}}$ is the tangent and normal grinding force supply with the $ZY-\theta$ coordinate by the density function.

In the mathematical model of the tangential and normal force F_t and F_n per-unit of the precision grinding width [17] and grinding depth a_p can be determined as:

$$\begin{cases} F_{tc} = \sum \phi F_{enc} = \phi K \sum Qi = \phi K \frac{V_w}{V_{\text{grindingwheel}}} a_p \\ F'_{tc} = K' \frac{V_w}{V_{\text{grindingwheel}}} a_p \\ K' = \phi K \end{cases} \quad (12)$$

The lower limit of the integral is θ , the upper limit is $\pi/2$, so:

$$S = 2\pi R \cdot R(1 - \sin\theta) \quad (13)$$

The mapping relationship between the three-dimensional Cartesian's coordinate system of the sphere (R, θ, Ψ) and the rectangular coordinate system (X, Y, Z) is:

$$\begin{cases} X = R \sin \theta \cos \psi \\ Y = R \sin \theta \sin \psi \\ Z = R \cos \theta \end{cases} \quad (14)$$

Hypothesis, the precision grinding process of the rotational motion is uniform, and in the Cartesian's coordinate system. The equation of polar coordinates is:

$$\Gamma : X = \rho \cos \theta, Y = \rho \sin \theta, Z = k\theta, 0 \leq \theta \leq 2\pi \quad (15)$$

In the precision grinding process of the RB-SiC ceramic and optically difficult-to-grinding hard-brittle material, it is related to k , but it is necessary to control the precision grinding gap via the depth of surface interface modification by the cold atmospheric plasma method (Room temperature, in Fig. 2a, c).

In the Cartesian's coordinate system, the mapping relation along the base and the tangent direction is:

$$\begin{cases} dL(R) = dR \\ dL(\psi) = R \sin \theta d\psi \\ dL(\theta) = R d\theta \end{cases} \quad (16)$$

3.2 The grinding force-the grinding specific energy of e_s

When the surface removal depth is proportional to the standing time of the cold atmospheric plasma, the removal $a_p(A_i, A_j)$ at the point $P(A_i, A_j)$ on which the micro-grinding wheel for time t can be expressed as:

$$a_p(A_i, A_j) = a_s(A_i, A_j)t \quad (17)$$

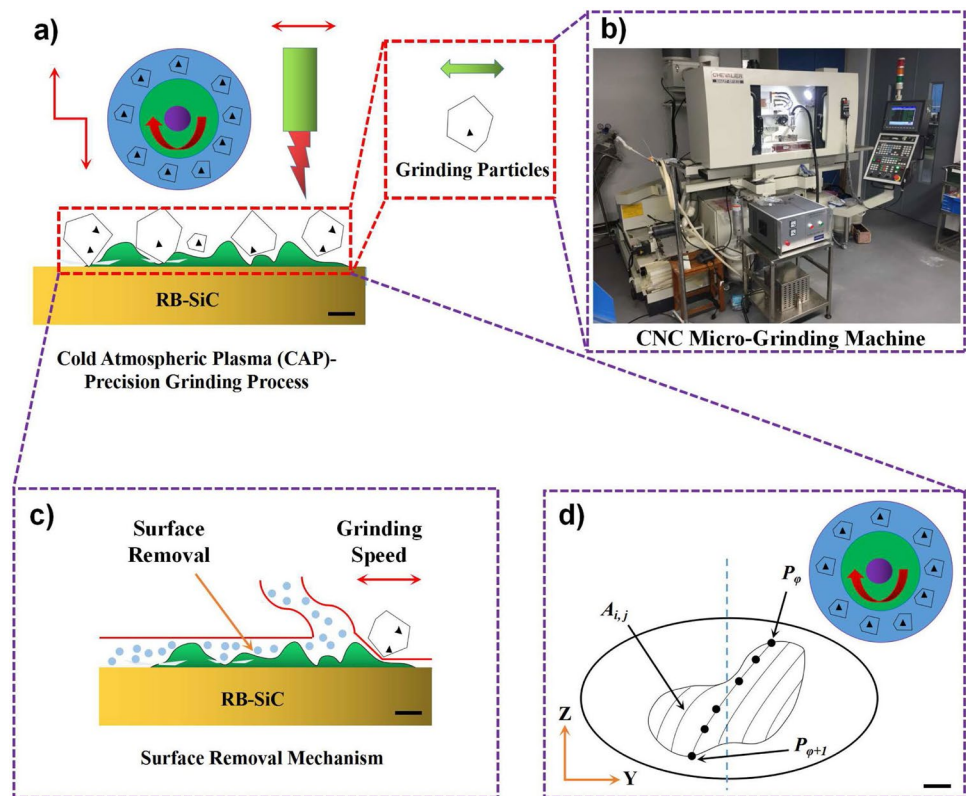
Here, the v is expressed as $v(P_\phi, P_{\phi+1})$. So the $t_{A_{ij}}$ for which elements by A_{ij} at the points $a_p(A_i, A_j)$ and $P(A_i, A_j)$ is:

$$t_{A_{ij}} = \Delta x / v(P_\phi, P_{\phi+1}) \quad (18)$$

When the cold atmospheric plasma treatment to the finish surface based on the precision grinding process contact with the RB-SiC ceramic, it will produce rotational resistance as shown in Figs. 2b and 3c. We design the effect of the removal of finish-surface workpiece and microscopic mechanism of abrasive grinding direction results. The thrust in the normal direction increases the normal force of the abrasive particles. The force on the abrasive grain is shown in Fig. 1a. By the design for a series of the precision grinding process

Fig. 3 Cold atmospheric plasma (CAP) via oxygen (O_2) based on the precision grinding process schematic diagram:

a Composite process schematic diagram; **b** CNC micro-grinding machine; **c** Surface removal mechanism schematic diagram; **d** Grinding area removal function of the grinding depth a_p



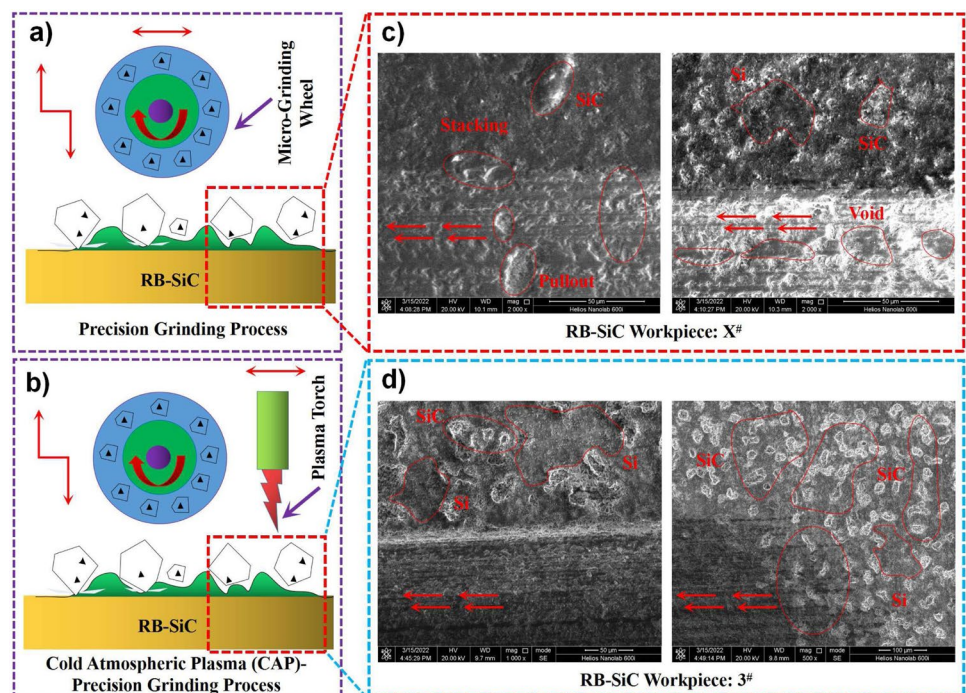
experiment in the precision grinding process of errors on the grinding specific energy is e_s , as shown in Fig. 3d.

Also, the precision grinding force mathematical model formula is:

$$dF_s = F_i dA \cos \theta \cos \psi \quad (19)$$

where F_i —grinding force per unit area (N/mm^2) and dA —the actual contact area during the grinding process (mm^2).

Fig. 4 RB-SiC ceramic removal mechanism based on the precision grinding process surface modification via cold atmospheric plasma (CAP): (a; c) Traditional precision grinding process and the $X^\#$ test-workpiece of the RB-SiC ceramic; (b; d) Cold atmospheric plasma (CAP) process via oxygen (O_2) based on the precision grinding process and the $3^\#$ test-workpiece of the RB-SiC ceramic



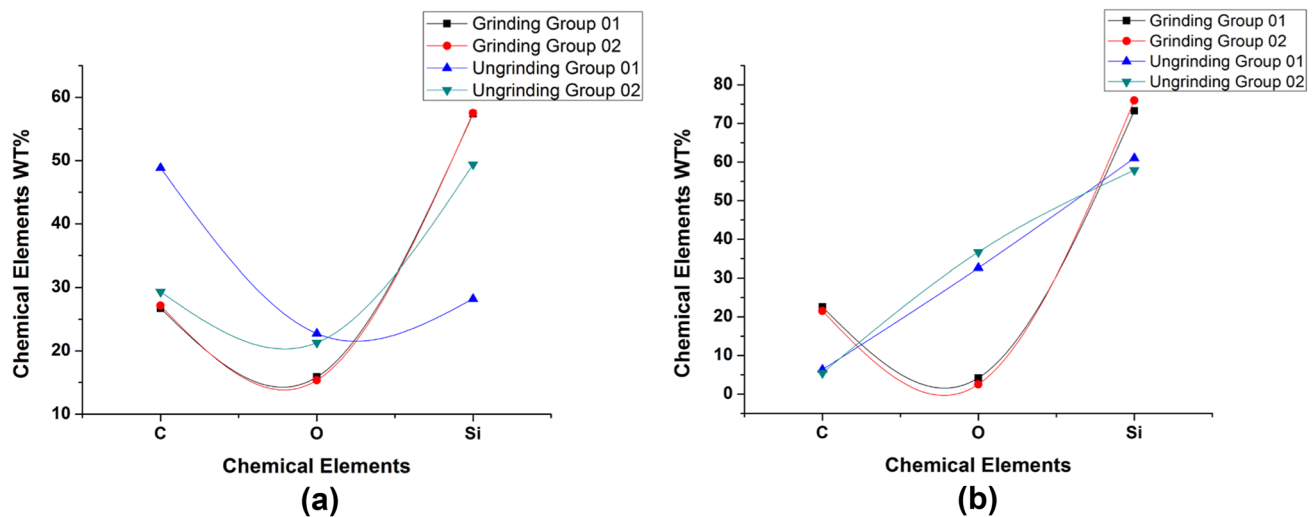


Fig. 5 RB-SiC ceramic EDS surface composition of (a) the X[#] test-workpiece of the RB-SiC ceramic; (b) the 3[#] test-workpiece of the RB-SiC ceramic

Grinding specific energy calculation formula by Eqs. (20)–(22) [18, 19]. Defining e_s as the specific grinding energy of the RB-SiC ceramic, then:

$$e_s = \frac{F_t v_s}{b v_w a_p} [J/mm^3] \quad (20)$$

$$e_s = \frac{F'_t v_s}{v_w a_p} [J/mm^3] \quad (21)$$

$$e_s = \frac{E_{RB-SiC}}{V_{grindingwheel}} = \frac{F_t}{V_{grindingwheel}} v_s = \frac{F_n}{V_{grindingwheel}} v_s [J/mm^3] \quad (22)$$

where E_{RB-SiC} —the precision grinding power (W), e_s —the specific grinding energy of the RB-SiC ceramic (J/mm^3), F_t —the tangential force by grinding (N), F_n —normal grinding force (N), b —the width of precision grinding face (mm), and $V_{grindingwheel}$ is the workpiece volume (mm^3/s) or the speed ratio ($\mu m/s$).

Where the trying division method is applied element-wise.

3.3 Area removal of the grinding depth a_p

Figure 3 shows the schematic diagram for the linear grinding wheel removal. The center of the micro-grinding wheel movement in a curves from $P_\phi(x_a, y_a)$ to $P_{\phi+1}(x_b, y_a)$. An area of the unit ever-changing removal and scanning path of the center of micro-grinding wheel. The part of the section by the shape of the ever-changing precision grinding hard-brittle material surface removal path (Room temperature, as shown in Figs. 3d and 6b).

Area removal of the grinding depth a_p calculation formula by Eqs. (23)–(25). Defining z_{area} as the specific area removal of the RB-SiC ceramic and mark are expressed as $a_p(A_i, A_j)$ at the point $P(A_i, A_j)$, as shown in Figs. 3 and 5, then:

$$z_{area}(A_i, A_j) = \frac{1}{v} \int_{P_\phi}^{P_{\phi+1}} z_A(A_i, A_j) dA \quad (23)$$

As shown in Fig. 3d, in the micro-grinding wheel movement from $P_\phi(x_a, y_a)$, $P_{\phi+1}(x_b, y_a)$ on the mark line of six points, the area removal of the grinding depth a_p for the $z_{area,0}$ at the point $A(A_i, A_j)$ can be expressed as:

$$z_{area,0}(A_i, A_j) = \frac{1}{v} \int_{P_\phi - (x_b - x_a)}^{P_{\phi+1}} z_A(A_i - x_a, A_j - y_a) dA \quad (24)$$

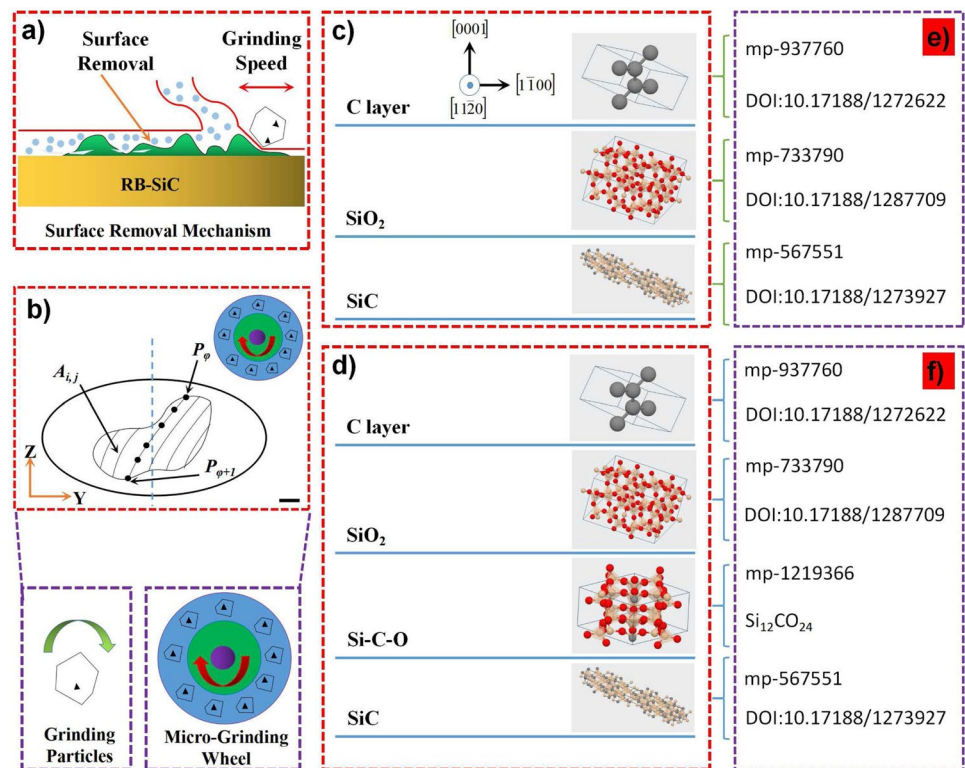
$$z_{area}(A_i, A_j) = \sum_{n=0}^m z_{area,n}(A_i, A_j) \quad (25)$$

4 The result of the ceramic wheel grinding force analysis of the particle size result

Table 1 shows the boundary conditions for the cold atmospheric plasma flow model. Supplementing the grinding feed for a_p affects surface and surface grinding quality of the RB-SiC ceramic hard-brittle material by the calculus method of the precision grinding (as shown in Figs. 2b and 3b, d).

Figure 6 shows the RB-SiC ceramic removal mechanism based on the precision grinding process surface modification by the cold atmospheric plasma via oxygen (O_2) process at room temperature. We know the key grinding

Fig. 6 RB-SiC ceramic removal mechanism based on the precision grinding process surface modification via cold atmospheric plasma (CAP): (a) surface removal mechanism; (b) Grinding area removal function of the grinding depth a_p ; (c, d) Surface modification layer; (e, f) Material ID and DOI via *Materials Project* computational software and models



RB-SiC ceramic removal mechanism via cold atmospheric plasma process with surface modification layer. Table 2 shows the comparison table of hardness parameters. Also, the material ID and DOI from *Materials Project* (<https://materialsproject.org/>) computational software and models structure analysis. The characteristics and properties of covalent bonds: (1) The greater the covalent bond by the bond energy, the more firmly the two atoms that form the covalent bond are bound together, the closer they are to each other; (2) the higher the bond energy of a covalent bond, the shorter the bond length; Similarly, the longer the covalent bond, the lower the bond energy.

Due to the surface modification effect of cold atmospheric plasma on RB-SiC ceramic such as C layer, SiO₂ layer and Si-C-O layer are generated, which makes the original Si-C bond length and bond energy change. Therefore, the surface modification layer can be quickly removed to improve the grinding efficiency of RB-SiC ceramic (as shown in Table 2).

Figure S1 shows the cold atmospheric plasma results is the torch of the length by torch (as shown in Fig. S1 of the “Appendix A. Supplementary data”). Figure S2 shows the RB-SiC workpiece: X[#] (by the precision grinding process) and 3[#] (by the cold atmospheric plasma process via oxygen (O₂) at room temperature based on precision grinding process). For the other mains and key of the results and parameters, such as the properties and parameters of the

RB-SiC ceramic, please see the supporting materials via “Appendix A. Supplementary data” with Table S1.

From the cold atmospheric plasma based on the precision grinding process of the mechanism of surface material removal analysis results, it provides a profound insights into the grinding specific energy e_s and the complex grinding of the RB-SiC ceramic raw hard-brittle materials by the precision grinding process and mathematical theoretical models. All those properties show the great value and effective of the cold atmospheric plasma via oxygen (O₂) based on the precision grinding process method.

The results obtained in this research work can be applied directly to the optical precision elements of the RB-SiC ceramic precision grinding process problems, such as removal of the surface difficult grinding layer, and find a method of improving the grinding removal efficiency. All these process and technical parameters are under this research paper and test works.

The abrasive adhesion wear is mainly caused by the softening of free-Si phase in RB-SiC workpiece. Because the Si phase has a lower melting point (1410 °C) than SiC phase (2700 °C), it is easier for Si phase to adhere to the surface of abrasive particles under the physicochemical reaction of the cold atmospheric plasma torch temperature.

This paper mainly studies and discusses the influence regular pattern of the micro-grinding process after the surface modification of the RB-SiC workpiece under the cold

atmospheric plasma via oxygen (O_2) physicochemical reaction at room temperature, as well as the influence regular on the hard-brittle ceramic material surface removal mechanism. In this paper, we will present the detailed studies on this surface modification process.

5 Conclusions

This paper presents the cold atmospheric plasma method for improving the quality of surface shape based on the precision grinding process and a surface free radical activated surface modification layer removal technique via surface modification. In this paper, we design the cold atmospheric plasma via oxygen (O_2) with one mathematical model and precision grinding process which are supported as effective processes to control the RB-SiC ceramic surface-finish and grinding accuracy characters. For the cold atmospheric plasma process, the precision grinding process can be only at room temperature of 25 ± 1.5 °C. There is the surface modification between interface characteristics and the surface precision grinding depth a_p in the grinding effectiveness which control the precision grinding amount during the RB-SiC ceramic hard-brittle material finish-surface grinding process.

In order to improve the grinding efficiency and improve material removal rate, the surface of the RB-SiC ceramic fabrication of the precision grinding process workpiece with high-hardness under the cold atmospheric plasma via oxygen (O_2) surface modification process produce SiO_2 or C layer, C-O, Si-C-O compound through physicochemical reaction at room temperature. The reaction layer was removed by the micro-cutting force via the diamond grinding wheel. Need to consider changes from the plasma torch height. In order to achieve better RB-SiC ceramic hard-brittle material surface-finish quality and material removal efficiency.

The RB-SiC ceramic surface-finish and surface fabrication and precision grinding process has been proved to be a surface modification control methods for solving the grinding ratio and surface shape quality problem. In summary, the some contributions of this research work are mainly three points. Our main conclusions and the key points are as follows:

1. The work shows the cold atmospheric plasma via oxygen (O_2) composite methods by the active surface “free radical” is concentration higher than a single type of the precision grinding process.
2. The effectiveness of surface modification can be measured and evaluated by the magnitude and direction of the RB-SiC ceramic surface modification layer and removal efficiency of Si phase and SiC phase.
3. In the work, we propose a new method for cold atmospheric plasma based on the precision grinding process

to research on surface modification of RB-SiC ceramic hard-brittle material by precision grinding problems to test its performance. In such cases, the surface-finish quality of the RB-SiC ceramic is easy to be further improved and provides a satisfactory result at an affordable single-precision grinding process cost.

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Data availability No applicable.

Code availability The concepts of coding were presented with pseudocode in the article; thus, there is no access for the custom code.

Declarations

Ethical approval The research does not involve human participants and/or animals.

Consent Consent to submit the paper for publication has been received explicitly from all co-authors.

Conflict of interest None. The authors have no conflicts of interest to declare that are relevant to the content of this article.

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