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A Saw Blade Drill Bit with Reduced Heat Loss

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Abstract: We adopt microwave sintering technology prepared a low-cobalt Fe-Co-Cu diamond saw blade bit. The bit can achieve densification sintering which meets the index of diamond saw blade heads. Furthermore, the use of microwave non-pressure sintering significantly shortens the total sintering time and saves more than 20% energy. This environmentally friendly saw blade head can stimulate the development of the sawing industry and would be vastly used in the field of high and new technologies.

Keywords: Fe-Co-Cu Binder; Microwave Non-Pressure Sintering; Density; Wear Resistance; Energy Conservation.

1. Introduction

Diamond as a superhard tool material has been used in cutting processing for hundreds of years, from the end of the nineteenth century to the middle of the twentieth century, the tool material is mainly represented by high-speed steel; In 1927, Germany first developed cemented carbide tool materials and was widely used; In the fifties of the twentieth century, Sweden and the United States synthesized synthetic diamond, and cutting tools entered a period represented by superhard materials. In the seventies of the twentieth century, people used high-pressure synthesis technology to synthesize polycrystalline diamond (PCD), which solved the problem of scarce and expensive natural diamond. Diamond superhard material products are not only widely used in basic industries such as steel, housing, roads and bridges, but also in precision processing in high technology fields such as aerospace, military and photovoltaic[1-3]. The research and development of high performance and low energy consumption diamond superhard material products belongs to the key development direction of national strategic emerging industry policy, which plays an important role in promoting economic development and guaranteeing national security[4].

Microwave sintering technology was first proposed by TINGA et al [5] in the 1950s, and has been widely used in sintering high-end ceramic materials. It has now developed into a new type of powder metallurgy rapid sintering technology in the field of materials science. Its main principle is to use the special band of microwave to couple with the basic fine structure of the material to generate heat, and the dielectric loss of the material in the electromagnetic field causes the material to be heated to the sintering temperature as a whole to achieve densification. Among them, metal powder microwave sintering technology since ROY et al[6] wrote an article in Nature, its application has rapidly expanded to cemented carbide[7], magnetic materials[8], metal-ceramic composites[9] and other sintering fields, showing the advantages of low sintering temperature, short sintering time and good tissue uniformity[10-12], which is extremely beneficial to the low temperature sintering of diamond saw blades with low cobalt formulation and is expected to solve the problem of diamond thermal damage caused by high temperature sintering. Cobalt is the metal element with the best compatibility with carbon[13]. Its wetting angle to diamond reaches 50°~70°, and has low temperature bonding properties not found in any other metal. The iron-cobalt (Fe-Co) based powder compact has a good ability to absorb microwaves, with a penetration depth in the order of centimetres for microwaves with a frequency of 2450MHz[14-15], which is equivalent to the size of the saw blade head. Therefore, cobalt-based diamond is widely used in the preparation of blades[16]. The partial substitution of cobalt by inexpensive homologous iron elements is a feasible way to achieve low cost and reduced energy loss in low cobalt type diamond saw blades.

2. Experiment

2.1. Apparatus and Materials

Three-dimensional blender (MX2), purchased from Zhengzhou Jinhaiwei Technology Co., Ltd; graphite mould, purchased from Xinruida Graphite Manufacturing Co., Ltd; microwave sintering furnace, purchased from Hunan Changyi Microwave Technology Co., Ltd; iron (Fe), cobalt (Co) and copper (Cu) metals, purchased from Beijing Nonferrous Metals Industry Co., Ltd. and Wuxi Shengzhengren Metal Materials Co., Ltd.

2.2. Characterization

The microstructure of the sintered samples was observed with a JSW-5510LV scanning electron microscope from Japan. The densities and hardnesses of the samples were measured with an HV-120 Vickers hardness tester from Qingdao Aeneix Microwave Automation Equipment Co. and a PEM-type densitometer. The wear of the diamond saw blade tips was measured with a SJ5730 high-precision roughness profiler from Shenzhen Zhongtu Instrument Co.

2.3. Preparation of Fe-Co-Cu Diamond Saw Blade Bit

First, we mixed the saw blade formula ingredients (mass fraction, the same below) according to the ratio of Fe:Co:Cu:Ni: rare earth compound to 9:4:3:2:2 (the particle size of various metal powders is distributed in the range of 20.4~31.7um, and the purity is higher than 99.5%). Then put the selected formula powder mixed on a three-dimensional mixer for 1.5h at 1000r/min, and add the diamond powder treated with liquid paraffin (particle size 40/45um), the formula raw materials will mixed evenly after 30min. After that, using high-precision graphite molds to cold press and molding, and then hot pressed into blocks by microwave sintering furnace. Finally, peel off the hot-pressed head from the mold and polish the corners to flatten the edges.

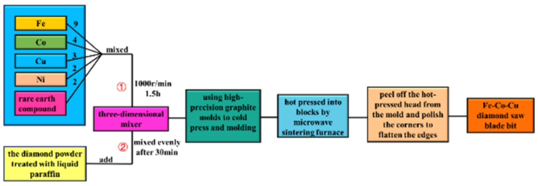

Fig 1. Flow chart of preparation of Fe-Co-Cu diamond saw blade bit

2.4. Sample Performance Testing

2.4.1. Dielectric Properties of Raw Materials

The real part of the dielectric constant (complex permittivity) of the metal represents the dispersion of electromagnetic waves, and the imaginary part represents the absorption of electromagnetic waves. Usually, we use the free electron gas model (Drude model) of metals to derive the expression of the dielectric constant of metals:

$$\varepsilon_{\Upsilon}(\omega) = 1 - \frac{\omega_p^2}{\omega(\omega + i\omega_c)} \quad (1)$$

Among them, ω indicates the frequency of incident light, ω_c indicates the damping frequency, and ω_p indicates the plasma resonance frequency on the metal surface.

The Drude model [17-18] can match the experimental data well at low frequencies, and the error is extremely large at high frequencies. This model can be used to simplify calculations in the study of near-visible wavelengths and above, but when studying the ultraviolet band, the Lorentz-Drude model needs to be introduced for correction, because when the metal is at high frequencies, the free electrons inside the metal will undergo bandgap transitions, and the influence of this factor needs to be considered.

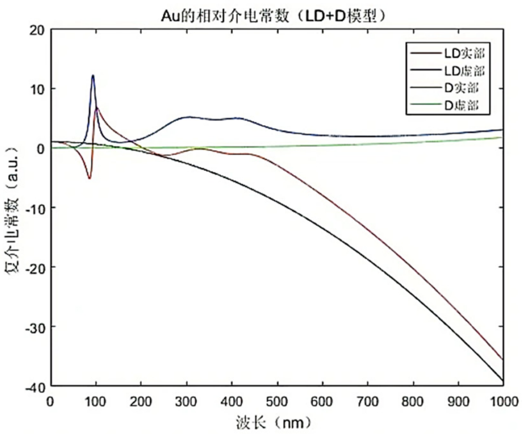

Fig 2. Relative permittivity diagram of Au

As shown in the figure 2, the gap is large at high frequencies, considering the electronic bandgap transition, in fact, the dielectric coefficient fluctuations of metals at high frequencies are very obvious and irregular. Au's fluctuations are smoother. In daily life, we generally think that metals are exposed to visible light between 400nm and 760nm.

Solid materials are converted into heat energy by their own dielectric losses in the microwave field, resulting in microwave heating and densified sintering. For metal powder briquettes, the superiority of the absorbing capacity and the ability of the microwave to penetrate the entire sample to achieve overall uniform heating will determine the homogeneity of the sintered body. The absorbing capacity of metal powder materials is related to their dielectric constant and dielectric loss, the stronger the absorbing capacity of the material, the weaker the microwave penetration. The expression for the depth of microwave penetration is shown below:

$$D_p = \frac{\lambda_0}{2\sqrt{2}\pi} \cdot \left[\sqrt{1 + (tan\,\theta)^2} - 1\right]^{-\frac{1}{2}} \quad (2)$$

In order to fully compare the wave-absorbing characteristics of metal powder materials, a typical SiC strong wave-absorbing material was selected as a reference. The material's dielectric characteristic parameters were tested under the same experimental conditions.

As can be seen from Table1, the dielectric constant and dielectric loss of Fe are comparable to those of SiC, and its wave absorption properties are comparable to those of SiC. Therefore, an appropriate increase in the content of Fe in the saw blade tip formulation is beneficial to the smooth microwave sintering. In addition, although the dielectric constant of Cu is comparable to that of SiC, its dielectric loss is smaller, so the wave absorption ability of Cu is slightly weaker than that of SiC. Through analysis, it was found that the wave absorption ability of the metal materials tested in the experiment was ranked as follows: Fe > Cu > A* > Ni > Co. Despite the differences in their related abilities, they all showed good wave absorption performance. The depth of microwave penetration of the powder RP reached 44.02cm, indicating that the microwave can penetrate the entire thickness of the workpiece (25mm) and achieve overall uniform heating, so the design of this paper is suitable for the microwave sintering process.

2.4.2. Raw Material Heating Characteristics

Different materials have different heating characteristics due to their own differences in absorbing performance in the microwave field. Fe has the fastest heating rate, reaching 900°C in 1360s. A* materials have a heating rate between Fe and Co, reaching 900°C in 1510s. The better the absorbing performance of the material, the faster the heating curve. Figure 2 shows that the A* material can be heated to 900°C in a 1kW microwave field, which means that microwave heating is suitable for the sintering of low cobalt-based diamond saw blade tips.

3. Results and Discussion

Compared with conventional sintering methods, microwaves enhance the diffusion migration of elements and densification reactions during the sintering process through efficient energy in-situ conversion mode and internal heating characteristics, showing the advantages of short sintering time, low sintering temperature and uniform microstructure [24-25]. No graphitization transformation was observed in the samples, effectively avoiding the heat loss of diamond abrasives. The microstructure of the samples obtained by microwave sintering is homogeneous, and microwave sintering can significantly shorten the total sintering time and reduce the sintering temperature while ensuring the same level of denseness and hardness. Therefore, microwave sintering technology has a broad industrialization prospect in the field of diamond material sintering.

In order to compare the energy consumption of microwave and conventional non-pressure and hot-pressure sintering, the energy consumption of a single sintering was measured using an energy meter and averaged five times, the results are shown in Figure 3. The average energy consumption of Cu-based diamond saw blade microwave non-pressure sintering is 3.5 kW·h, while the average energy consumption of conventional non-pressure sintering is 5.5 kW·h, saving energy by 37.2%. The average energy consumption of Fe-based diamond saw blade is 11.6 kW·h for microwave hot-pressing sintering, while the average energy consumption of conventional hot-pressing sintering is 14.5 kW·h, saving energy by 20.2%.

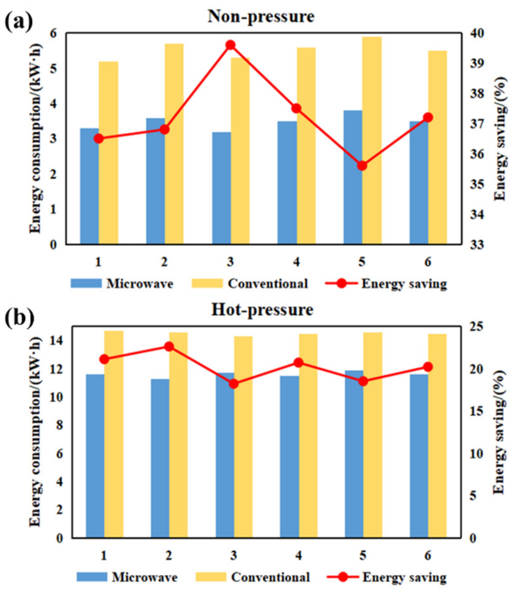

Fig 3. Energy consumption analysis of micr-owave and conventional non-pressure (a) and hot-pressure(b) sintering

4. Conclusion

The Fe-Co-Cu diamond saw blade tips were prepared by microwave sintering method. The analysis of the dielectric and heating characteristics of the raw material confirmed the suitability of the microwave heating method for the sintering of low cobalt-based diamond saw blade tips. This sintering method can achieve densified sintering below 900℃, and the relative densities and hardness values of the metal matrix are much higher than those of conventional sintering methods, which can fully meet the requirements of diamond saw blade tips. The saw blade tip prepared by microwave sintering method not only accelerates the sintering efficiency and product performance, but also notably reduces the energy consumption compared with conventional sintering, saving more than 20.2%. This high-efficiency sintering method is of practical significance to promote the green production and technological upgrading of superhard material tools, and has a spacious market prospect.

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