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The Impact of High-Temperature Sintering on the Properties of Ceramic and Fiber Composite Materials and Its Optimization Strategies

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Abstract: In today's engineering and industrial fields, the application of composite materials is no longer uncommon, and ceramic and fiber composite materials, as the main ones, can combine the advantages of the two materials and have a wider range of applications. In order to better prepare this material, further improve its performance, or reduce its preparation cost, this article proposes a method of using high-temperature sintering. Moreover, this article also conducts comparative experiments at the end to verify this method. Taking the material strength comparison experiment as an example, the average strength of the materials in the experimental group using high-temperature sintering is 288.9Mpa, while the average strength of the materials in the control group using ordinary sintering is 272.3Mpa. The obvious experimental gap fully demonstrates the effectiveness of this method.

1. Introduction

Due to the excellent performance of ceramic and fiber composite materials in many aspects such as strength, wear resistance, corrosion resistance and high temperature stability, this material has been widely used in many engineering fields. In order to further improve its performance and save material preparation costs, this article proposes a high-temperature sintering method.

This article first analyzes the application directions of ceramic and fiber composite materials and points out the sources of demand for their special properties. This article then further studies the main factors that determine the quality and structure of sinter, analyzes the brief process of high-temperature sintering, and then applies high-temperature sintering. Finally, the method in this article is verified through comparative experiments.

2. Related Work

Ceramic and fiber composite materials, as a type of composite materials, are widely used in many fields. Egbo M K pointed out that composite materials were engineering materials composed of two or more materials. The appropriate combination and smelting method can give composite materials excellent physical and chemical properties [1]. Krauklis A E pointed out that thermoplastic composite materials were used in large quantities in automobile production, so it was necessary to recycle materials during application [2]. Fayzimatov S N proposed a systematic approach to non-technical drilling of polymer composites to improve their productivity and quality issues [3]. De Zanet A pointed out that ceramic composites usually used acid-based etching and mechanical processing for surface texturing [4]. Skorulska A believes that polymer ceramic composite materials are one of the important technologies in current modern prostheses, which can meet the high aesthetic and functional requirements of prostheses [5]. Akhtar S S pointed out that ceramic composite materials were also commonly used in cutting tools, which can reduce tool wear and save production costs [6]. This shows the application capabilities of this material.

In order to better prepare this material, this article believes that high-temperature sintering is needed. Kermani M believes that new technologies such as ultra-fast high-temperature sintering and flash sintering can significantly reduce the consolidation time compared with traditional sintering [7]. Dong J further proposed that ultra-fast high-temperature sintering can consolidate ceramics in just tens of seconds, which can be of great help in the preparation of ceramic and fiber composite materials [8]. Ihrig M also confirmed through research that high-temperature sintering can significantly increase the sintering rate, thereby reducing material preparation costs [9]. Taking silicon carbide as an example, Maity T pointed out that the preparation of this ceramic material had high bending strength and room temperature strength retention capabilities, so it required ultra-high temperature sintering for auxiliary preparation [10]. Therefore, this high-temperature sintering method does have many functions.

3. Method

3.1 Application of Ceramic and Fiber Composite Materials

As an engineering material, or a composite material, ceramic and fiber composite materials have the advantages of ceramics and fiber reinforced materials. Zhang X H proposed that this composite material had various properties such as high strength, lightweight, high temperature resistance and corrosion resistance, and was extremely applicable [11]. Moreover, this article also needs to analyze the application direction of ceramic and fiber composite materials to show that these properties are sufficient.

Table 1: Applications of ceramic and fiber composite materials

Application area	Improvement
AEROSPACE	Improve material strength, reduce weight, and enhance high-temperature resistance.
Automobile making	Improve the performance, fuel efficiency, and safety of cars.
Energy industry	Improve wear resistance and corrosion resistance.
Sports	Improve the strength and durability of the product.
Medical treatment	Improve equipment biocompatibility and wear resistance.

Table 1 lists the application directions of various ceramic and fiber composite materials. Wen Z P pointed out in his research that ceramic and fiber composite materials were a new type of ultra-high temperature structural materials that had emerged with the development of aerospace technology [12]. Thanks to its high strength, wear resistance, corrosion resistance and high temperature stability mentioned above, the aerospace field is indeed one of its home fields. For specific tasks such as manufacturing aircraft structural parts, engine parts and spacecraft shells, the application of ceramic and fiber composite materials can improve the strength of aerospace equipment, reduce weight and improve high temperature resistance. This material can be used in aerospace manufacturing, and naturally it can also be used in automobile manufacturing. In automobile manufacturing, ceramic and fiber composite materials are often used to manufacture braking systems, engine parts, and body structures. In this way, the car's performance, fuel efficiency and safety are improved. In fact, the shadow of ceramics and fiber composite materials can also be seen in the energy industry. Generally speaking, blades, turbine parts and gas turbine components in solar and wind energy equipment can be designed and assembled using ceramic and fiber composite materials, and their properties can be used to improve the overall wear resistance and corrosion resistance of the equipment. Finally, there are many other fields. Zhu ZH proposed that the medical field where composite materials can be used was a typical example [13]. There are many high-end sports equipment in the sports field that uses composite materials to improve the strength and durability of the product. Of course, part of the reason is that some sports products are luxury goods, and the use of high-end materials can be a reason to increase the selling price. In the medical field, ceramic and fiber composite materials can also become the material of choice for some special medical equipment, such as artificial joints and dental restoration materials. These devices are made mainly because ceramic and fiber composite materials have certain biocompatibility and wear resistance.

3.2 The Significance of High Temperature Sintering

In the process of preparing ceramic and fiber composite materials, it generally needs to go through steps such as material preparation, mixing, molding, sintering and surface treatment. In the complex preparation process, Yang C C pointed out that sintering was one of the very important steps [14]. Zhang D further believed that sintering was an important process for phase transformation of composite materials [15]. In order to demonstrate the necessity and role of sintering, he analyzed the main factors that determine the quality and structure of sinter in his research.

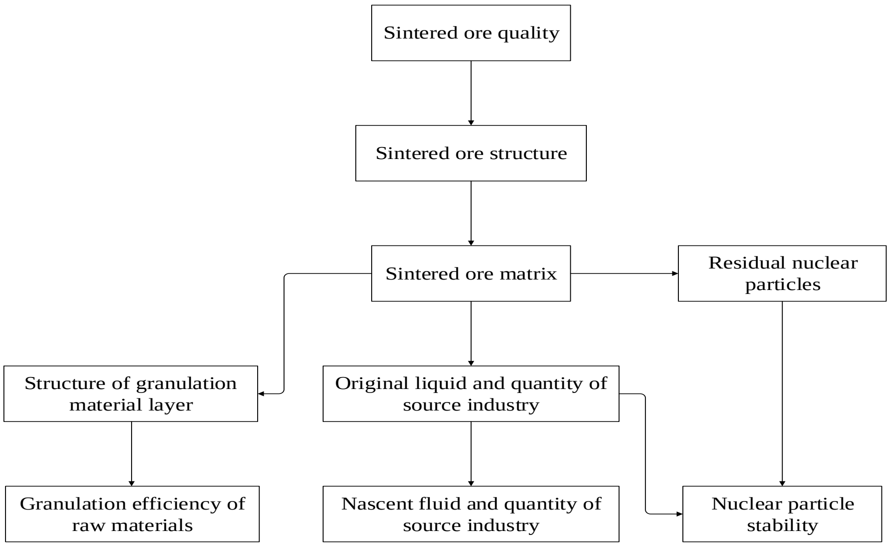

Figure 1: Main factors determining sinter quality and structure

Figure 1 illustrates some of the main factors that determine sinter quality and structure. First, the quality of the sinter needs to be examined, and then the structure of the sinter can be analyzed. After the completion of sintering of composite materials, there will be remaining sinter matrix and residual core particles, and the analysis of these two can become the main determinant of the quality and structure of sinter. According to the sinter matrix, the layer structure of the granulated material and the properties and quantity of the original liquid phase can be obtained respectively. The former can further determine the granulation efficiency of raw materials, while the latter can further infer the nature and quantity of the primary liquid phase, and collect residual core particles to determine the stability of the core particles. Tan Z Y stated in his research that understanding the properties and structure of sinter can help judge the evolution of the coating microstructure [16].

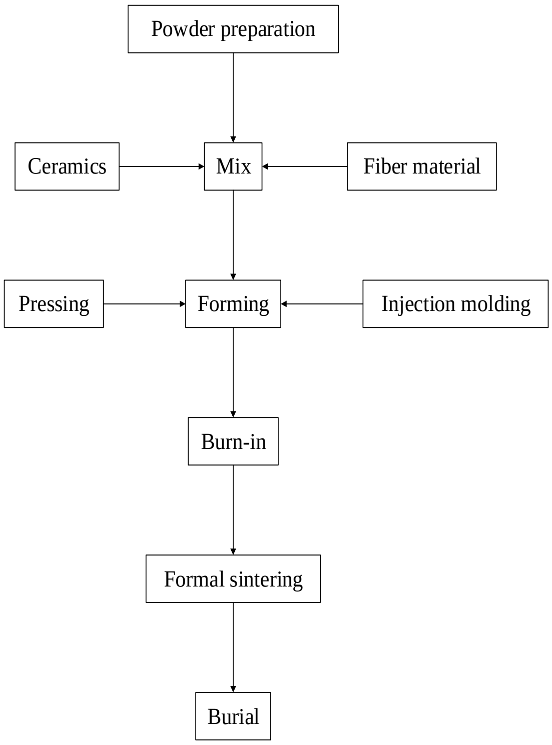

Figure 2: Brief process of composite material sintering

Figure 2 shows the brief process of composite sintering. In this process, powder preparation first needs to be carried out, that is, the raw materials are ground and made into a powder that is easy to handle. Then the materials are mixed. For example, the core purpose of this article is to prepare ceramic and fiber composite materials, so ceramic and fiber materials need to be mixed. After the mixing is completed, they still need to be shaped into shaped bodies. Huang Y L pointed out that the plasticity during the sintering process can be performed by pressing or injection molding [17]. Then the formal processes of pre-firing and firing can be carried out respectively. During the paper-firing process, the embryo body will be placed in a high-temperature environment for sintering, and the powder particles will combine at high temperature to form a dense crystal structure. After sintering is completed, the material is cooled to room temperature again. The cooling environment also needs to be paid attention to and the experimental conditions must be strictly controlled, otherwise the quality of the composite material will be affected.

3.3 The Role of High Temperature Sintering

After the sintering is completed, the ceramic and fiber composite materials prepared based on high-temperature sintering are basically completed, and Xue Q and Zhang K described the role of high-temperature sintering in detail [18-19].

Table 2: Effect of high temperature sintering

Function	Details
Particle binding	Causing the powder particles in composite materials to melt and combine at high temperatures, forming a dense structure.
Improve strength and hardness	During the sintering process, the combination of powder particles leads to an increase in the overall strength and hardness of the composite material.
Improve high temperature resistance	Enable composite materials to maintain their structural integrity in high-temperature environments, making them suitable for high-temperature working conditions.
Increase corrosion resistance	This allows them to have a longer lifespan in harsh environments.
Realize optimization of microstructure	During the sintering process, the arrangement and bonding mode of powder particles can affect the microstructure of composite materials.

Table 2 shows the role of high-temperature sintering in the preparation of ceramic and fiber composite materials. As mentioned earlier, the sintering process requires powder shaping by pressing or injection molding, so particle bonding will be the main role of high-temperature sintering. It can cause the powder particles in ceramic and fiber composite materials to melt and combine at high temperatures to form a dense structure, thereby increasing the density of the composite material. During the sintering process, the combination of powder particles can also lead to an increase in the overall strength and hardness of the composite material, which is very important in applications that require resistance to bending, compression and wear, especially in aerospace and automotive manufacturing, two major application areas. The second is to improve the high temperature resistance, because high temperature sintering helps to improve the stability and high temperature resistance of the ceramic matrix. This allows the composite to maintain its structural integrity in high-temperature environments and is suitable for high-temperature working conditions. In order for ceramic and fiber composite materials to have a longer service life in harsh environments, sintering is also very necessary because it can increase the corrosion resistance of composite materials. The final function of sintering is to optimize the microstructure. Generally speaking, during the sintering process, the arrangement and combination of powder particles will affect the microstructure of the composite material, and by controlling the sintering conditions, the microstructure of the composite material can be optimized, thereby adjusting its performance.

4. Results and Discussion

4.1 Material Strength Comparison Experiment

In order to verify the effectiveness of this method, this article believes that it is necessary to conduct comparative experiments, and the verification indicator is to test the material strength. Assuming A is the strength index of the material after sintering, B is the strength index after the core particle assimilation experiment, and a_i, b_i are the original strength index of material i and its core particles respectively, of which $\lambda(i<1mm), \lambda(i>1mm)$ are the two particle sizes respectively quality fraction, then:

$$A = \frac{\sum a_i \lambda(i<1mm)}{\sum \lambda(i<1mm)} \tag{1}$$

$$B = \frac{\sum b_i \lambda(i > mm)}{\sum \lambda(i > mm)} \quad (2)$$

Through the confirmation of the intensity index, the intensity detection can be carried out according to the experimental target. The specific method is to conduct a strength comparison experiment on composite materials obtained by two preparation processes using high-temperature sintering and ordinary sintering. The former is set as the experimental group and the latter is set as the control group.

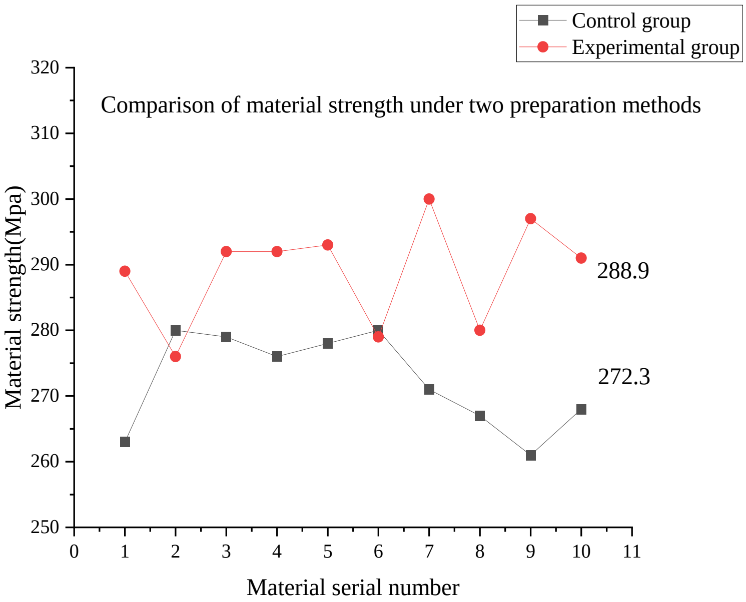

Figure 3: Material strength comparison experiment

The results of material strength comparison experiments are shown in Figure 3. It can be seen that in this experiment, the strength test results of the two groups of 10 blocks each have obvious differences. Only the strength of the second and sixth blocks of the control group exceeds that of the experimental group, and the others are not as good. The final average intensity of the experimental group was 288.9Mpa, and the average intensity of the control group was 272.3Mpa.

4.2 Material Heat Resistance Comparison Experiment

Chen Q proposed that heat resistance and thermal conductivity were also properties of composite materials that were worth improving [20]. Therefore, this article will conduct a comparative test on heat resistance of a total of 20 materials from two groups in the last experiment.

The results of material heat resistance comparison experiments are shown in Figure 4. It can be seen that the experimental group completely outperformed the control group in terms of heat resistance. The final performance was that the average tolerable temperature of the experimental group was 1342.1 ℃, and the average tolerable temperature of the control group was 1271.6 ℃.

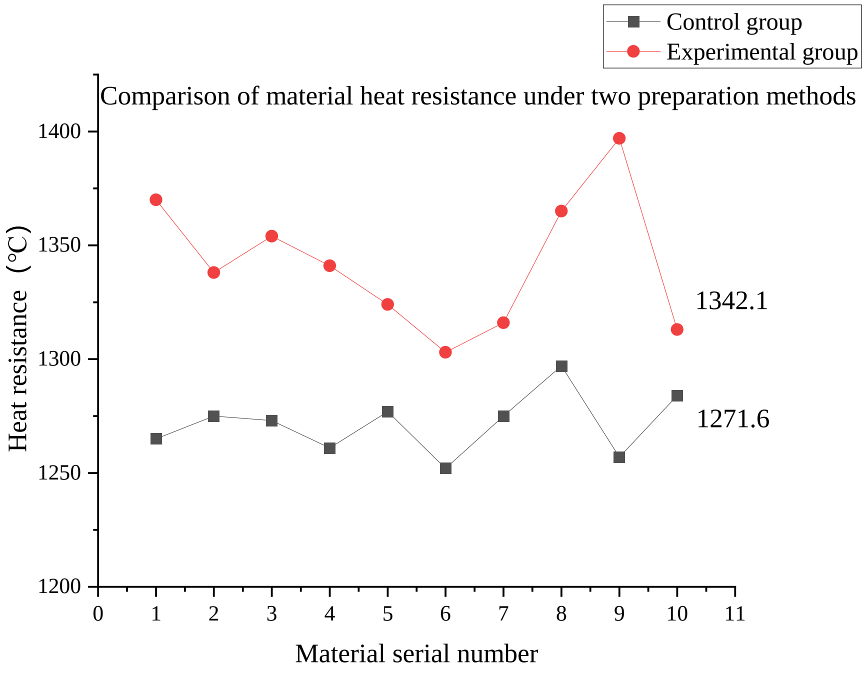

Figure 4: Material heat resistance comparison experiment

5. Conclusion

The core ideas of this article is to analyze the application of ceramic and fiber composite materials and the brief process of composite sintering, and then study the role of high-temperature sintering, and complete the verification of this article's ideas through two comparative experiments. However, the experiment in this article still has shortcomings, that is, only 10 pieces of materials were prepared. The smaller number of experimental materials may affect the accuracy of the experiment. While in general, the prospects of ceramic and fiber composite materials are still worth looking forward to. With the continuous advancement of sintering technology, the cost performance and effectiveness of this material will inevitably continue to improve.

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