

Retraction

Retracted: Art Decoration Design of Electrochemical Silicon Oxide Ceramic Sculpture Based on 3D Printing Technology

Journal of Chemistry

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This article has been retracted by Hindawi following an investigation undertaken by the publisher [1]. This investigation has uncovered evidence of one or more of the following indicators of systematic manipulation of the publication process:

- (1) Discrepancies in scope
- (2) Discrepancies in the description of the research reported
- (3) Discrepancies between the availability of data and the research described
- (4) Inappropriate citations
- (5) Incoherent, meaningless and/or irrelevant content included in the article
- (6) Peer-review manipulation

The presence of these indicators undermines our confidence in the integrity of the article's content and we cannot, therefore, vouch for its reliability. Please note that this notice is intended solely to alert readers that the content of this article is unreliable. We have not investigated whether authors were aware of or involved in the systematic manipulation of the publication process.

Wiley and Hindawi regrets that the usual quality checks did not identify these issues before publication and have since put additional measures in place to safeguard research integrity.

We wish to credit our own Research Integrity and Research Publishing teams and anonymous and named external researchers and research integrity experts for contributing to this investigation.

The corresponding author, as the representative of all authors, has been given the opportunity to register their agreement or disagreement to this retraction. We have kept a record of any response received.

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- [1] J. Guo, "Art Decoration Design of Electrochemical Silicon Oxide Ceramic Sculpture Based on 3D Printing Technology," *Journal of Chemistry*, vol. 2022, Article ID 9728402, 9 pages, 2022.

Research Article

Art Decoration Design of Electrochemical Silicon Oxide Ceramic Sculpture Based on 3D Printing Technology

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In order to solve the art decoration design of silicon oxide ceramic sculpture, a method for silicon oxide ceramic sculpture based on 3D printing technology is proposed. Firstly, the density of photosensitive resin premix before curing was measured by pycnometer method; the photosensitive resin was coated on tinplate and then put into a self-made UV curing box for curing. Secondly, the critical exposure and critical transmission depth of photosensitive resin without formula are calculated. Finally, the viscosity of ceramic slurry was measured by mixing S2 photosensitive resin formula with ceramic powder with different nano silica content. It is proved that the addition of nano silica powder can promote the decomposition of quartz glass and increase the sintering degree of the ceramic core. The primary sintering shrinkage of ceramic core gradually increases with the increase of nano silica content. In the length direction, the shrinkage increases from 3.33% to 5.61%; in the width direction, the shrinkage increases from 2.98% to 4.74%; and in the height direction, the shrinkage increases from 3.18% to 5.00%.

1. Introduction

Ceramic sculpture is one of the cultural elements with a long history in China. Ceramic products not only have ornamental value but also have a strong practicability. Therefore, ceramic sculpture products are widely used in all walks of life. The production process of traditional ceramic sculpture is relatively complex, and there are many processes, but modern ceramic sculpture production uses 3D printing technology to simplify the manufacturing process and shorten the production time, which makes the traditional ceramic culture and technology sublimate and develop while inheriting. Relevant researchers and technicians use modern advanced technical means for design and 3D printing technology for manufacturing and processing, which can produce ceramic products with rich colors, unique shapes, and strong functionality to meet the needs of various industries and different audiences for ceramic products.

3D printing technology is a kind of rapid prototyping technology. It is based on 3D digital model software and uses curable molding materials such as powder metal or plastic to

realize a 3D digital model as a space object by printing layer by layer, as shown in Figure 1 [1]. This technology appeared in the mid-1990s, and its working principle is basically the same as that of ordinary printing. The 3D printer is equipped with curable "printing materials" such as liquid or powder. After connecting with the computer, the "printing materials" are superimposed layer by layer through computer control, and finally, the three-dimensional digital model on the computer is turned into a real object.

2. Literature Review

With the rapid development of rapid prototyping technology, 3D printing technology can be involved in more and more fields, from printing simple model parts to pistols that can fire bullets to houses for people to live in, from industrial processing to architectural design to medical and health care. We found that 3D printing technology and sculpture art have natural commonalities. They are all involved in space modeling, and they are using some material medium to express their demands on space form. Three-dimensional

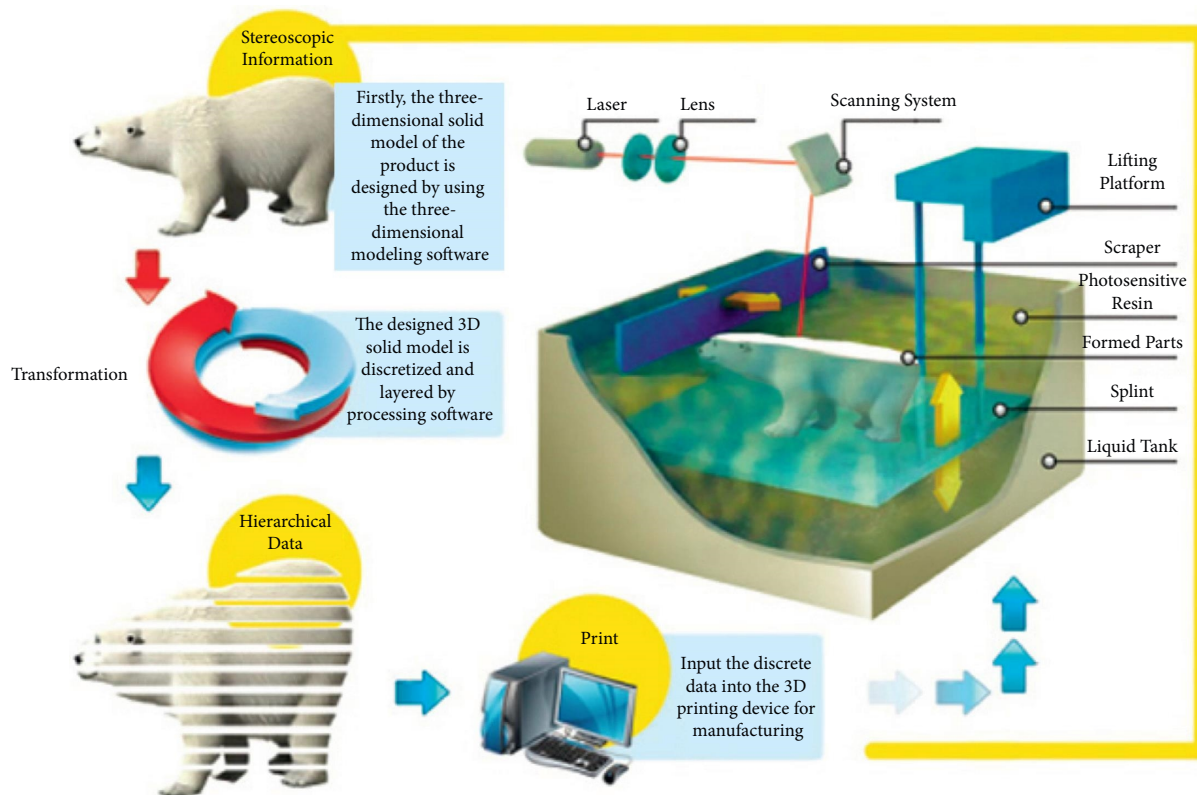


FIGURE 1: 3D printing technology.

printing technology will have a far-reaching impact on the development of sculpture art.

Some progress has been made in the research of 3D printing SiO_2 ceramics at home and abroad. Yao and others directly formed ceramic blank by light-curing technology and studied the relationship between powder volume fraction and slurry viscosity and curing thickness [2]. Qiu and others studied the effect of shear rate on the viscosity of SiO_2 ceramic slurry. When the shear rate reached 100s⁻¹, the slurry viscosity was lower than that when the shear rate was 0 [3]. Torda and others studied the effect of dispersant on the viscosity of water-based SiO_2 ceramic slurry and considered that when the content of sodium polyacrylate dispersant reached 0.3 wt.%, low viscosity silica ceramic slurry could be prepared [4]. Hegyi et al. used Cao powder as precursor material and nano zirconia absolute ethanol as a binder to prepare printing slurry; the sintered ceramic core has high bending strength, low shrinkage, and high hydration resistance [5]. Mei et al. used DLP printing technology to manufacture porous zROC ceramics with an octagonal truss structure. After sintering, the porosity of ceramic samples reached 55.49%, which promoted the application of ultralight and porous ceramics [6]. Belaid by using polyvinyl alcohol (PVA) as the organic binder in the slurry, the method of heat treatment and impregnation of the inorganic precursor is adopted to improve the strength of the core after sintering and reduce the shrinkage of the printed ceramic core after sintering [7]. Khanna invented the stereolithography technology of stacking high molecular polymers cured by UV laser layer by layer [8]. McDonough invented

two methods of manufacturing three-dimensional plastic models using additives of light-curing polymers, and its ultraviolet irradiation area is controlled by a mask pattern or scanning optical fiber transmitter [9]. Arnay first successfully proposed the organic combination of light-curing molding technology and ceramic material preparation molding technology [10]. Zheng studied the effect of particle size on ceramic slurry. The results showed that adding powder with a larger particle size into the powder could improve the fluidity of ceramic slurry [11].

Based on the current research, a 3D printing technology is proposed for silicon oxide ceramic sculpture. By adding nano silicon oxide, the viscosity of ceramic slurry can be appropriately reduced. However, when the content of nano silicon dioxide is too high, the viscosity of the slurry will increase due to the agglomeration of nano powder. When the content of nano silicon dioxide is 0.5 wt.%, the lowest viscosity of the ceramic slurry is 2010. When the content of nano silica is 2.5 wt.%, the highest viscosity of the ceramic slurry is 2,900.

3. Art Decoration Design of Silicon Oxide Ceramic Sculpture Based on 3D Printing Technology

3.1. Ceramic 3D Printing Technology

3.1.1. General. Ceramic 3D printing technology belongs to the detailed classification of 3D printing technology, which is essentially the same as the principle of 3D printing

technology. The raw materials of ceramic 3D printing technology generally choose ceramic slurry or ceramic powder, which is based on digital model files, and then build designed ceramic products in the form of repeated printing layer by layer, which is a new ceramic manufacturing technology that can meet modern needs [12]. Compared with the traditional ceramic manufacturing process, modern ceramic 3D printing technology can effectively reduce the manufacturing cost of ceramic products, simplify the process flow of ceramic manufacturing, and break the confinement of the manufacturing process on ceramic design. In this way, the ceramic products with unique and novel shapes cannot only appear on the drawings but can be manufactured in kind.

3.1.2. Classification. At present, ceramic 3D printing technology is mainly divided into layer-by-layer bonding method and direct molding method. The layer-by-layer bonding method refers to that firstly, the ceramic powder is paved, and then the nozzle sprays adhesive to the ceramic powder according to the specified path. After spraying one layer, another layer of powder is laid. This is repeated until the excess ceramic powder on the model is removed after full molding to obtain a three-dimensional object [13]. The direct molding method is to prepare ceramic slurry from ceramic powder and adhesive and squeeze out the slurry through the nozzle. Because the slurry has certain adhesion, it will be bonded with the previous layer of slurry immediately after extrusion. Then repeat the above steps until fully formed. In principle, this process is similar to the traditional clay bar dish building process, but the works are more fine and orderly due to the control of the computer.

3.1.3. Workflow in Ceramic Design

(1) 3D Model Making. The manufacture of a three-dimensional model is the basis of ceramic product design. Only when the three-dimensional model is determined can the manufacture of ceramic products be carried out. The digital model can more intuitively reflect the designer's ideas on the computer and can also provide technical support to clarify the design scheme and make it more convenient for later production. For example, in the process of polyhedron design, designers need to use software to establish models. These designs can be quickly converted into STL format and sent to 3D printers. The three-dimensional model provides technical support for the production of ceramic products and can design ceramic products with more complex shapes [14]. In order to ensure the beautiful appearance of ceramic products, curves need to be applied, and the smoothness of ceramics needs to be improved in this process. Therefore, 3D technology is needed to design the shape and print it to see the effect. Designers can constantly adjust the data in this process, so as to activate the complex surface flexibly.

(2) 3D Printer Reduces Dimension. The three-dimensional object is processed into a two-dimensional model for printing, and rectangular coordinate points are generated to form a

three-dimensional shape. The application of 3D technology in the design of ceramic products usually uses wet clay as the printing material, but the wet clay has some defects, which are difficult to form, not strong enough, and easy to deform in the printing process. Therefore, hard clay can be used to avoid this problem. The printing layer of 3D printing technology is 10 mm, which cannot better ensure the printing quality and printing speed. Therefore, the thickness can be reduced to improve the printing accuracy. After air-drying, the surface can be polished to ensure its smoothness.

(3) Ceramic Embryo Surface Treatment. The 3D printing technology is not perfect, so the printed surface is not very smooth, and there will be a surplus or lack of materials. During the printing process, the clay will also be brushed and left on the surface. Therefore, it should be further improved and polished after making, so as to form a smooth and useable model, and take out the floating ash on the surface and glaze it. Otherwise, the ideal effect will not be achieved. After glazing, it will be put into the kiln for firing. The traditional production process relies more on manual work, which increases human and material resources. Moreover, the production of the template is very complex and needs to be modified continuously, which increases the workload [15]. Three-dimensional printing technology is a common product model design at present. It makes three-dimensional models by the computer. In this process, the designer's thinking can be accurately reflected by computer, and then the three-dimensional model can be converted into two-dimensional images by software. Finally, the texture can be accumulated through layer-by-layer printing by a 3D printer. If you want a smooth surface, you can polish it. This not only saves time but also reduces costs and saves human and material resources.

3.2. Adaptability of 3D Printing Technology to Sculpture Language. 3D printing technology has basically formed a set of systems, and the applicable industries have gradually expanded, involving many fields such as product design, mold design and manufacturing, material engineering, medical research, culture and art, construction engineering, and so on. Sculpture art, like other art categories, has its own language to express creative ideas. The three-dimensional possession of space, the mass feeling, or the sense of space and volume are the most basic language features of sculpture art. The most basic essence of 3D printing technology is rapid prototyping. At this point, it meets the needs of sculpture art language expression, can quickly realize the spatial materialization of digital-physical state and meets the basic requirements of sculpture art creation for language materials. The advantages of 3D printing technology are: first, save materials, improve material utilization, and reduce costs by abandoning production processes; second, it can achieve high precision and complexity; third, without any traditional mold, we can directly generate any shape state from computer graphics data; fourth, it can automatically, quickly, directly, and accurately convert the design in the computer into a model, so as to effectively shorten the product R & D cycle; and fifth, it can be formed in a few

hours, which makes the artist realize the leap from plan to entity [16]. It can be seen that 3D printing technology can quickly express the artist's artistic purpose in the form of blocks and volumes in the sense of sculpture language in space, realize the artist's creative purpose, and meet the expression needs of sculpture language.

3.3. Impact of 3D Printing Technology on Sculpture Art Creation. Technological innovation can always bring convenience to practical activities and improve the efficiency and success rate of the practice. The impact of 3D printing technology on sculpture art creation mainly includes the following points.

3.3.1. It Enhances the Predictability of Artistic Creation Effect. Sculpture art creation and painting art creation have certain similarities in steps. In the early stage of his creation, the forms of expression are mostly sketches on paper. On this basis, what painting creation needs to do is still the effect treatment on the plane, while sculpture is further deliberation on the physical space. Three-dimensional printing technology can realize the spatial state of sculpture creation from the paper state and shorten the process of sculpture art creation through digital creation intention and rapid prototyping printing. It can also study and judge the spatial state of sculpture in advance by regulating the digital sculpture data to enlarge or reduce the sculpture or adjusting the shape and proportion of sculpture in space. In addition, the possibility of forming material effect of sculpture can be speculated through the selection of printing material [17]. The application of 3D printing technology in sculpture art creation shortens the process from plane to space, increases the prediction of space art effect in the process of sculpture art creation, and saves the time and cost of art creation.

3.3.2. Changed the Single means of Sculpture Art Creation. Manual work has always been the main means of sculpture art creation. The clay sculpture is made by kneading, reducing, and molding the clay by hand. The clay sculpture completed by molding is turned over and then injected into other molding media. For example, what is made with gypsum as the forming medium is called gypsum statue, and what is made with resin is commonly known as FRP. It is also called cast copper, cast iron, and cast bronze due to its different materials. Cutting and chiseling wood or stone is called wood carving or stone carving. These sculpture categories are inseparable from a single manual work, which also increases the amount of labor of artists, increases unpredictable variables for the release of sculpture works of art, and reduces the efficiency of transforming sculpture artists' artistic ideas into sculpture works of art. Three-dimensional printing changed the sculptor's helplessness to heavy physical labor, made the sculptor's creation complete in the design stage of sculpture, and handed over the heavy realization process to the machine that can fully realize the sculptor's intention. Sculptors only need to sit in front of the

computer and express their design intention or creative intention into digital 3D images through 3D software, deliberate and modify them on the computer until the digital 3D images can fully reflect their artistic ideas, and then select appropriate expression materials and supporting structures. The next step is to let the 3D printer easily and quickly realize the physical form of their design ideas [18]. Such examples are numerous.

3.3.3. It Enriches the Form of Sculpture Works of Art. How much material you master always affects the creativity of a sculptor. After mastering the technology of copper casting, the sculptor created copper casting sculpture. After mastering the characteristics of resin materials, sculptors began to use resin to realize their own sculpture works. Knowing the corrosion-resistant characteristics of stainless steel, you can see the "stainless steel monsters" standing in the street squares of various cities [19]. The continuous enrichment of 3D printing materials is also broadening the creative ideas of sculpture artists and enriching the types of sculpture works of art, making artists break the traditional understanding that products in the industrial field only have use value and lack artistic thought [20].

4. Experimental Method

4.1. Experimental Materials and Equipment. The experimental raw materials used in this paper are mainly divided into photosensitive resin system and ceramic core system, as shown in Table 1.

4.2. Experimental Method. This experiment is divided into three parts: the design and preparation of photosensitive resin, nano-silica-modified silicon-based ceramic core, and nano-alumina-modified silicon-based ceramic core. The process diagram is shown in Figure 2.

4.2.1. Design and Preparation of Photosensitive Resin. Ceramic light-curing slurry is made of a certain proportion of photosensitive resin and ceramic powder. The photosensitive resin is made of a series of oligomers, monomers, photoinitiators, and other additives. The parameters such as viscosity, volume shrinkage, curing rate, and double bond conversion shall meet the requirements of 3D printing [21]. In this paper, polyurethane acrylate (PUA) as oligomer, dipropylene glycol diacrylate (DPGDA), 16 hexanediol diacrylate (HDDA), trimethylolpropane triacrylate (TMPTA) as active diluent, 2,4,6-trimethylbenzoyl ethoxy phenylphosphine oxide (TPO) as photoinitiator, and a small amount of defoamer were added to form photosensitive resin premix. The specific research contents are as follows:

- (1) Mix the oligomer PUA: monomer (HDDA, dpgda, TMPTA) = 1:1, then add 4 wt.% (monomer + oligomer) photoinitiator (TPO), stir with a mechanical stirrer at the stirring speed of 600 rpn/min for 60 min, and then let it stand until the bubbles

TABLE 1: Raw materials used in the experiment.

Serial number	Category	Component	Purity	Place of origin
1	Quartz glass powder	Silicon dioxide	>99.95%	City A
2	Mineralizer	Corundum	99.9%	City B
3	Mineralizer	Nano silica	99.9%	City C
4	Mineralizer	Nano alumina	99.9%	City D
5	Oligomer	Polyurethane acrylic resin	Analytical purity	City E

The equipment used in this experiment is shown in Table 2.

TABLE 2: Equipment used in the experiment.

Serial number	Equipment name	Model	Manufacturer
1	Three-dimensional motion mixer	SYH-100	Company A
2	Vertical planetary ball mill	DECO-PBM-V4L	Company B
3	Box roaster	DC-B 460/13	Company C
4	Ceramic additive manufacturing equipment	Autoceramics	Company D
5	Digital rotary viscometer	3D printer	Company E

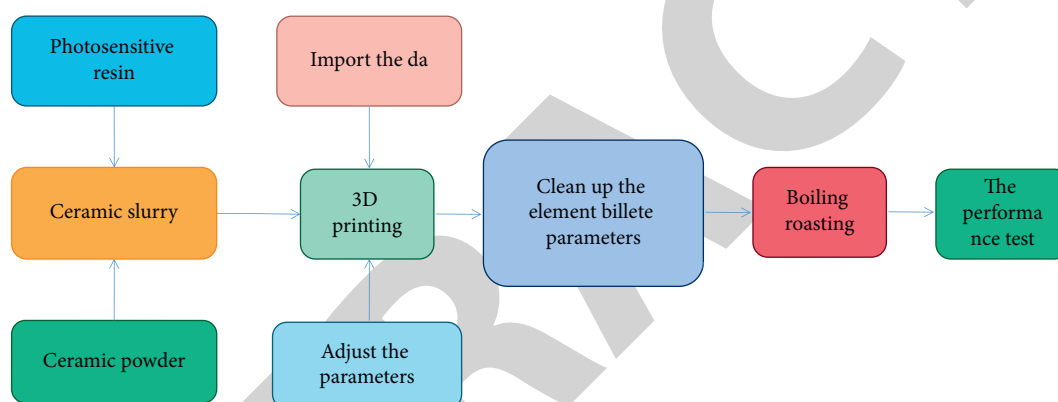


FIGURE 2: Process diagram of 3D printing ceramic core.

disappear completely. So far, the light-sensitive resin premix containing different monomers is obtained; then the effects of different monomers on the properties of light-cured resin were compared by testing its viscosity, volume shrinkage, critical light transmission depth, and critical exposure [22].

- (2) HDDA, DPGDA, and TMPTA are mixed in the ratio of 1:1:1; then the monomer and oligomer are mixed in different proportions (monomer:oligomer = 4:6, 5:5, 6:4, 7:3, 8:2, 9:1); then 4 wt.% (monomer + oligomer) photoinitiator (TPO) is added, stirred with a mechanical stirrer at the stirring speed of 600 rpn/min for 60 min, and then stood until the bubbles disappear completely. So far, photosensitive resins with different oligomer contents are obtained, and then the proportion of oligomer monomers with the best performance is selected for further research by testing its viscosity, volume shrinkage, critical light transmission depth, and critical exposure [23].

4.2.2. Nano Silica Modification Experiment. 85 wt% quartz glass powder (D50 = 6) as the base powder, 10 wt.% 320 mesh white corundum (D50 = 17.9), and 5 wt.% silicate drill

(D50=20.51) as the mineralizer are taken. Nano silica powder (50 – 100 nm) content is 0 wt. %, 0.5 wt. %, 1.0 wt. %, 1.5 wt. %, 2.0 wt. %, 2.5 wt. The ceramic powder was mixed evenly in a three-dimensional motion mixer for 1 h. The prepared photosensitive resin premix and ceramic powder were loaded into a vertical planetary ball mill with a solid content of 56 vol% for ball milling for 6 h to obtain the photocurable ceramic slurry, and its viscosity was tested immediately. Adjust the parameters of the photocuring printer to the appropriate parameters, and import the digital model of the test bar into the 3D printer in advance, then pour into the ceramic paste with uniform mixture to start printing. After printing, put the test bar into the ultrasonic cleaning machine to clean the excess slurry on the surface. After natural drying, measure the length, width, and height of the blank test bar and then bury it into a bowl filled with aluminum oxide powder for degreasing roasting. The final firing temperature of the initial roasting is 1,200°C and kept warm for 6 h [24]. The electronic universal testing machine is used to test the bending strength of the ceramic core after the initial sintering; the vernier caliper is used to test the primary sintering shrinkage; the electronic balance and constant temperature bath pot are used to test the porosity, water absorption, and bulk density, and the pore size distribution

instrument; and X-ray calorimeter and thermal expansion instrument are used to test the physical and chemical properties of the ceramic core. The morphology was analyzed by scanning electron microscope and laser confocal microscope. In order to simulate the performance of the ceramic core in the casting process, the ceramic core test bar after initial sintering was put into the sintering furnace to raise the temperature to 1,540°C, and its performance was tested again after coming out of the furnace.

4.3. Performance Test

4.3.1. Slurry Viscosity. A company's digital rotary viscometer is used to measure the viscosity of photosensitive resin premix and ceramic slurry with different formulations. The measurement accuracy is $\pm 2\%$, and the measurement range is $1\sim 2 \times 10^6 \text{ MPa} \cdot \text{s}$.

4.3.2. Volume Shrinkage of Photosensitive Resin. Use the pycnometer method to test the density ρ_1 of the photosensitive resin premix before curing, smear the photosensitive resin on the tinplate, and then put it into a self-made UV curing box (10 cm away from the UV light source) for curing. The curing time is 5 s. After curing, use an electronic balance to test the density ρ_2 of the photosensitive resin after curing and then calculate the volume shrinkage η , as in the following formulas:

$$\rho = \frac{m_2}{m_1}, \quad (1)$$

$$\eta = 1 - \frac{\rho_1}{\rho_2}, \quad (2)$$

where m is the mass of the pycnometer filled with distilled water and m_2 is the mass of the pycnometer filled with resin.

4.3.3. Critical Exposure and Critical Transmission Depth of Photosensitive Resin. Beer-Lambert theorem is applicable to the classical theoretical basis of light-curing molding, which reveals the absorption and attenuation characteristics of light propagation in the medium. Its expression is as follows:

$$C_p = D_p \ln\left(\frac{E_i}{E_c}\right), \quad (3)$$

where C_p represents the curing thickness of light-curing molding, that is, the thickness measured by curing the photosensitive resin after UV irradiation with a certain intensity; D_p is the penetration depth of the incident light, specifically defined as the depth at which the exposure intensity is reduced to $1/E$ of the incident intensity; and E_c is the critical exposure energy of the photosensitive resin. When the input energy is less than the critical exposure light intensity, the slurry cannot be cured. D_p and E_c are determined by the properties of the light-curing resin itself; E_i is the energy input by the incident light to the resin surface, which is determined by the exposure parameters of the light-

curing equipment, The value is equal to the exposure light intensity W (unit: MW/cm^2) and exposure duration t (unit: s); it can be expressed as follows:

$$E_i = W_i \times t. \quad (4)$$

The maximum input power of the 3D printer used is $30\text{MW}/\text{cm}^2$, and the exposure power increases every 10% from 20% to 100% of the maximum power. In order to be closer to the subsequent printing parameters, set the exposure time of the resin to 5 s. By testing the curing thickness C_p (mm) of photosensitive resins of three different monomers under different exposure power, after fitting the curve, the slope is the curing depth D_p and intercept $= -D_p \ln E$. Finally, the critical exposure and critical transmission depth of photosensitive resin without formula are calculated [25].

4.4. Nano-Silica-Modified Light-Curing 3D Printing Silica-Based Ceramic Core

4.4.1. Degreasing and Sintering System. Figure 3 shows the TG-DTG (thermal weight loss-thermal weight loss rate) diagram of the ceramic core blank. It can be seen that the wet core has mass loss at 262°C, 365°C, and 505°C, and the DTG curve tends to be stable after 600°C, indicating that the thermal decomposition process of the whole resin is completed. After the degreasing process is completed, the mass loss of the core blank is about 25 wt.%. Therefore, the determination of the sintering system should be properly insulated at 262°C, 365°C, and 505°C so that the resin can be fully eliminated.

The adjusted sintering system is shown in Figure 4. During the degreasing process, keep the temperature at 262°C, 365°C, and 505°C for 1 hour. After the degreasing is completed, accelerate the sintering rate to fully sinter the ceramic core.

4.4.2. Influence of Sintered Core Performance. The viscosity of ceramic slurry measured after mixing S2 photosensitive resin formula and ceramic powder with different nano silica content is shown in Figure 5 (black). The viscosity of slurry decreases first and then increases with the increase of nano silica particles. When 0.5 wt.% nano silica was added, the viscosity of the slurry decreased from 2,200 to 2,010. Because the content of nano silica particles is very low, it can be evenly distributed in the gap between ceramic particles, which increases the stacking rate of ceramic particles and forms better particle fluidity (also known as self-lubrication). In addition, nano silica particles with very fine particle sizes are easier to be wrapped by photosensitive resin, which reduces the friction and collision between ceramic particles and further reduces the viscosity of the slurry. However, once the nano silica content exceeds 1.0 wt.%, the viscosity of the slurry increases, and when the nano silica content is 2.5 wt.%, the viscosity of the slurry reaches the maximum value of $2,900 \text{ MPa} \cdot \text{s}$. If the content of nano silica is very high (more than 10 wt.%), these nanoparticles are easy to agglomerate, resulting in a higher

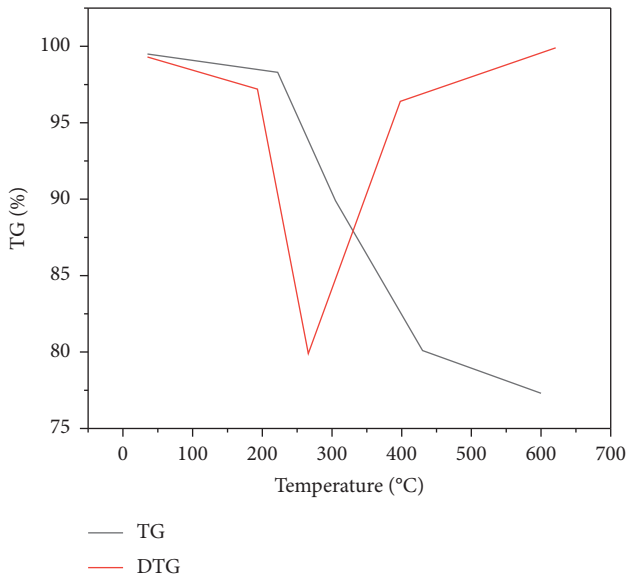


FIGURE 3: TG-DTG diagram of ceramic core blank.

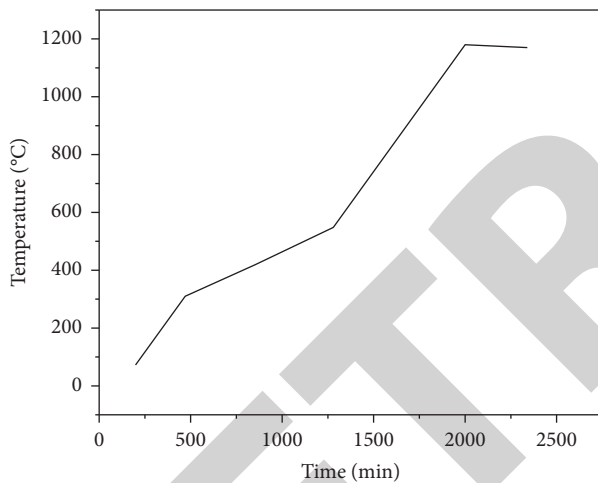


FIGURE 4: Sintering system of core sintering.

viscosity of the slurry, which is extremely unfavorable for paving and printing. The experimental results show that when the viscosity of the slurry is less than $3,000 \text{ MPa} \cdot \text{s}$, the ceramic slurry can meet the requirements of the laying and light-curing process. Figure 5 also shows the surface roughness of the ceramic core after one-time sintering. When the content of nano silica increases from 0 wt.% to 2.5 wt.%, the surface roughness of the ceramic core decreases from $1.85 \mu\text{m}$ to $1.65 \mu\text{m}$. This is mainly due to the high surface energy of nano silicon oxide. In the sintering process, nano silicon oxide is easy to form liquid phase, which promotes the sintering of ceramic particles, enhances the adhesion between printing layers, and gradually reduces the aging of interlayer cracks. Therefore, with the increase of nano silicon oxide content, the surface roughness of the core tends to decrease, and the lower surface roughness will make the inner cavity of the subsequent alloy blade have better surface quality.

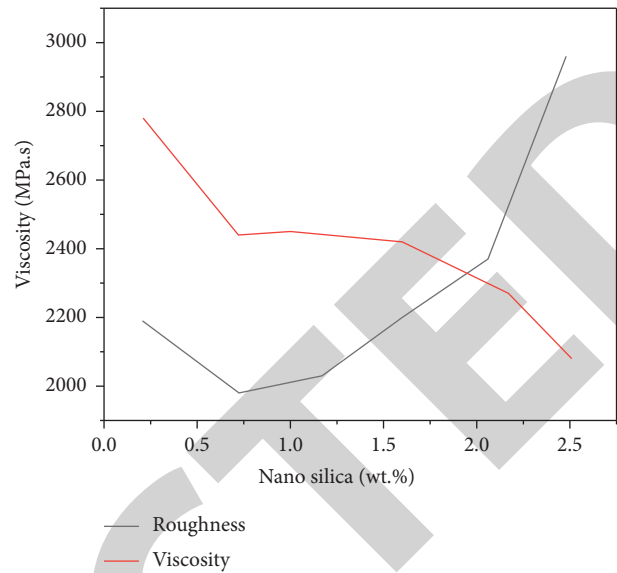


FIGURE 5: Slurry viscosity and surface roughness after core sintering.

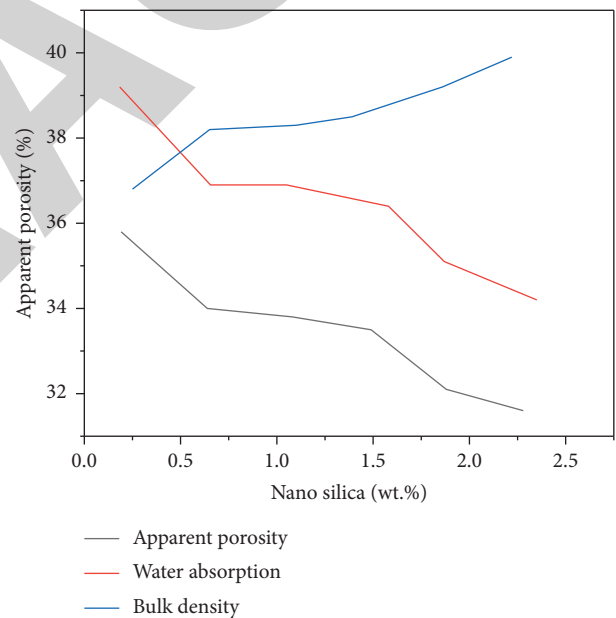


FIGURE 6: Porosity, water absorption, and bulk density of the ceramic core.

Figure 6 shows the porosity, water absorption, and bulk density of ceramic cores containing different nano silica after initial sintering. With the increase of nano silica content, the porosity and water absorption of the core gradually decreased, and the bulk density gradually increased. The porosity of the core sample without nano silica powder is 35.83%; the water absorption is 23.83%; and the bulk density is 1.50 g/cm^3 . When the content of nano silica powder is 25 wt.%, the porosity of the ceramic core is the lowest, 31.56%; the water absorption is the lowest, 19.6%; and the bulk density is the highest, 1.61 g/cm^3 .

5. Conclusion

Through thermogravimetric analysis, the sintering system of the ceramic core is determined: the viscosity of ceramic slurry can be appropriately reduced by adding nano silica, but when the content of nano silica is too high, the viscosity of slurry will increase due to the agglomeration of nano powder. When the content of nano silica is 0.5 wt.%, the lowest viscosity of ceramic slurry is 2,010 MPa · s: when the content of nano silica is 2.5 wt.%, the highest viscosity of ceramic slurry is 2,900 MPa · s. After the initial sintering, with the increase of nano silica powder content, the apparent porosity and pore diameter of the ceramic core gradually decrease, and the bulk density increases. When the nano silica content is 2.5 wt.%, the ceramic core reaches the lowest porosity of 31.56%, the lowest water absorption of 19.6%, and the highest bulk density of 1.61 g/cm³. At the same time, the printing layer spacing is significantly reduced, the surface roughness is reduced, and the bending strength is improved. When the nano silica content is 2.5 wt.%, the surface roughness of the ceramic core is 1.65 μm, and the bending strength is 13.8 MPa. It is found that the addition of nano silica powder can promote the decomposition of quartz glass and increase the sintering degree of the ceramic core. The primary sintering shrinkage of ceramic core gradually increases with the increase of nano silica content. In the length direction, the shrinkage increases from 3.33% to 5.61%; in the width direction, the shrinkage increases from 2.98% to 4.74%; and in the height direction, the shrinkage increases from 3.18% to 5.00%.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The author declares that there are no conflicts of interest.

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