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Mathematical Description of Nano Indentation Unloading Curve of Ceramic Materials and Test Method of Film Thickness

Long Zhang*

Chongqing University of Posts and Telecommunications, China

**corresponding author*

Keywords: Ceramic Materials, Nano Indentation, Unloading Curve, Film Thickness Test

Abstract: The indentation unloading curve of ceramic materials describes the contact position and thickness between solid film and substrate. Ceramic films are widely used in modern industry, national defense, military and electronic devices. They have the advantages of low density, high specific strength, high temperature resistance and good oxidation resistance. The film thickness is one of the important parameters reflecting the preparation process. It will not only affect the material itself, but also damage the adjacent surface. Therefore, the mechanical properties should be improved by controlling the pressure applied to the substrate interface. Based on the preparation process, this paper introduces the nano indentation unloading curve test of ceramic thin-layer samples by indentation method, studies the changes of material properties and mechanical properties under different thickness and temperature, and describes the microstructure of ceramic thin-film and analyzes its compactness and microstructure by load displacement curve. After a series of experimental tests, the mathematical description of nano indentation unloading curve of ceramic materials and the method of film thickness measurement are summarized.

1. Introduction

Ceramic materials play an important role in modern science and technology and are closely related to people's daily life. Metal film has been widely used in various fields because of its excellent performance, and the indentation problem affects whether the whole industrial application field can realize energy conservation, environmental protection, energy conservation, resource conservation and so on. Ceramic materials have excellent properties such as low density, high hardness, high temperature resistance, easy molding and strong corrosion resistance. It is essential to measure and test the thickness of metal film in practical industrial production.

Many scholars have studied the nano indentation unloading curve and film thickness measurement of ceramic materials. XD Hou proposed a new analysis method to better estimate the true value of infinite modulus, which is the simplest index of the maximum size change of polymer material components under long-term load [1]. Yu y believes that further analysis of the charge depth (PH) curve shows that the microstructure of beryllium, including pores and BeO content, has a certain impact on the nano indentation behavior of beryllium metal [2]. F bernachy Barbe suggests using rich information, including the spatial coordinates of indentation, and using hierarchical clustering algorithm to analyze the indentation statistical results of cement-based materials. The results show that the potential variance of this method can be reduced by eliminating the test of potential heterogeneous regions and independently identifying the patterns of different stages [3]. Tserpes K tested and simulated tungsten copper alloys with rough and nanocrystalline structures. Using this model, the influence of Berkovich indenter sharpness was examined. The experimental results show the advantages of nanocrystalline materials, which can be explained by hall page effect. Good convergence between model and experiment is obtained [4]. Borc J led and discussed the nature of the charge-displacement curve, ejection events and the effect of nanoindentation deformation on the indentation size of the KDP crystal (001) and (100) surfaces under various loads on the head according to Berkovich [5]. Bamber solved the difficulty of coordinating the statistical properties of ceramic failure with the deterministic properties of the specification, and suggested that this can only be achieved through the verification test method [6]. The nanomechanical and wear properties of luminescent ceramic composites ZrB2 + Al2O3: Cr and Nd (Al2O3 Co doped Cr and nd ions) were studied by nano indentation and Tribological experiments. Nanoindentation was performed using a Berkovich diamond tip using a continuous stiffness measurement (CSM) mode with a maximum depth of 200 nm. The wear behavior of silicon carbide pairs during dry sliding with external loads of 5 and 50 N and sliding speed of 0.1 M / s in air has been studied [7]. In order to improve the surface quality of packaging materials and meet the requirements of industrial production, aerospace, daily life, etc. The surface morphology, phase structure, crystallization temperature and wear resistance of nickel coating were examined by electron microscope, X-ray diffractometer, DSC differential thermal analyzer and friction and wear tester [8]. In nanoindentation experiments, e. Borisenko studied various mechanical properties, such as hardness, Young's modulus of nanoindentation, residual indentation depth, and the contribution of elastic and plastic components to overall deformation. For comparison, micro indentation experiments were carried out on gaseous single crystals [9]. Golovin y I is committed to studying the behavior and mechanical properties of various materials in the submicron and nano range. He believes that the progress in this field largely depends on the development of a variety of precision nano force test methods called "nano indentation" [10]. The mathematical description of nanomaterial indentation unloading curve and film thickness test method have been studied above. In recent years, researchers have put forward a lot of related work. However, the existing research work does not consider the impact of ceramic materials at the same time in mathematical description and test method, that is, in ceramic materials. The unloading curve of nano indentation and the influence of film test methods on it.

The innovations of this paper are as follows: (1) Take ceramic film as the research object to test and analyze, and establish a reasonable interpretation equation solution method to quantitatively calculate the experimental data and results, so as to obtain accurate conclusions, so as to reveal the truth. (2) The void size and expansion ratio between the sample particles after stretching were measured by spectroscopy and infrared ray, and the film thickness was calculated. (3) At the same time, the surface microstructure characteristics of metal film can be observed by scanning electron

microscope, and combined with relevant microscope images to obtain intuitive and clear tensile curve graphics, so as to further predict the future development trend.

2. Experiments and Methods

2.1. Research Content

The indentation performance of ceramic materials is an important standard to measure the level of material science and engineering application. Before preparing metal films with different thicknesses, appropriate process parameters must be determined first, and the stress and strain maps corresponding to the size must be obtained through testing to characterize the mechanical properties (yield strength or tensile test) and film-forming state of the samples. The effects of the number and distribution of ceramic film layers on the change law of sealing efficiency and pore size were also studied. The relationship between vessel depth and load and temperature field under single-layer graphene indentation is analyzed [11-12].

2.2. Nanoindentation Technology

On the micro nano scale, the overall macro characteristics of the composite are determined by the thermodynamic characteristics of the reinforced fiber / ceramic matrix interface according to the in-situ dynamic characteristics of each phase [13-14]. Therefore, when studying the processing methods, thermoforming technology and process application of composites, the in-situ dynamic characteristics of each phase and the dynamic characteristics of the interface formed with the reinforced fiber / ceramic matrix will become the most important. Among them, the dynamic characteristics such as rigidity and hardness are important indexes in the study of composite removal mechanism and process methods. However, because the reinforced phase and interface of raw composites are in the micro nano range, and the mechanical characteristics of raw materials in the micro nano size range are often significantly different from those at the macro level, it is difficult to judge the micro dynamic characteristics of raw composites. Nano indentation technology is the most efficient method to determine the in-situ dynamic characteristics of micro nano composites. Nano indentation technology is also the most efficient method to detect the in-situ mechanical properties of micro nano composites. Compared with traditional methods, it has high resolution, high visibility, high stability, scientific detection mechanism and simple sample design. Nano indentation testing technology was developed in the middle of 1970. It can analyze and study the rigidity, hardness, creep characteristics, residual stress, crack extension characteristics and constitutive relationship model of metal raw materials. Although the nano indentation instrument can very accurately measure the in-situ dynamic characteristics of composites at the micro nano scale, it is very small because of the measurement of mold size [15-16].

2.3. Nano Ceramic Materials

Nano ceramic material refers to a new system designed and constructed according to law with the internal structure of nano materials as raw materials or ceramics prepared in nano size. The properties of ceramic materials obviously have many excellent properties, but to a large extent, they are limited by their disadvantages such as high brittleness, poor uniformity, low strength, low-temperature impact and difficult processing, which seriously limits the application and promotion of ceramics [17-18]. Since 1984, H. gleiterl from Germany has used high-purity ultrafine

particles produced by gas condensation process as raw materials to extract nano materials through in-situ compression molding process, and put forward the concept of nano materials. It has attracted great attention of experts. And scientists in various fields around the world have produced nano ceramic materials. Due to the characteristics of nano ceramic materials, the grains are small and the number of grain boundaries increases greatly, which can make ceramic materials brittle and improve toughness. Some properties of some functional materials have also been improved, which is a good thing for the long-standing problem of ceramic toughness. Certain high-temperature treatment makes nano powder particles grow, crystallize and firmly bonded to the matrix material, so as to prevent or heal microcracks. At the same time, relatively dense bulk sintered materials can be obtained, which can significantly improve the tensile strength, wear resistance, corrosion resistance and fatigue resistance of matrix ceramic materials [19-20].

2.4. Nano Film Thickness Measurement Method

2.4.1. Ellipsometry

Ellipsometry is one of the most widely used methods in the field of nano film thickness measurement. It can measure the film thickness and optical sensing constants of semiconductors, metal films and multilayer films. The basic principle of ellipsometry is to estimate the thickness of the film by analyzing the change law of the polarization state of the reflected light on the film surface, that is, the change law of the phase and amplitude of p-polarized light and s-polarized light before and after reflection. After passing through the polarizer, the light generated by the laser becomes linearly polarized light, and then passes through the quarter wave plate to convert the light incident on the sample surface into elliptically polarized light. When this elliptically polarized light is reflected on the surface of the film to be detected, the change of the polarization state (phase and amplitude) of the light wave can be obtained by the following calculation formula [21-22].

$$\rho = \frac{r_p}{r_s} = \frac{r_p}{r_s} e^{i(\alpha_p - \alpha_s)} = tg \cdot e^{i} \tag{1}$$

Where, r_p and r_s are the complex amplitudes of P component and s component respectively. The parameters measured by ellipsometer are TG and E, which have a unique corresponding relationship with the refractive index and thickness of the film. The thickness of the sample to be measured can be obtained through inversion calculation.

2.4.2. Spectroscopy

Spectroscopy is a kind of method to measure the film thickness through the interference effect of light, mainly including reflection method and transmission method. Through the reflection and transmission of incident light on the film interface, the multi light interference effect is formed. The reflection and transmission curves of film materials with various characteristics are different, relative to the thickness' all-optical spectrum in the film. In this way, the thickness and optical parameters of the film can be obtained through the spectral characteristics [23]. Relative to the single-layer film, the spectral reflection equation is:

$$R = \frac{\left(n_j - n_g\right)^2 \cos^2\theta + \left(\frac{n_j n_g}{n} - n\right)^2 \sin^2\theta}{\left(n_j + n_g\right)^2 \cos^2\theta + \left(\frac{n_j n_g}{n} + n\right)^2 \sin^2\theta} \quad (2)$$

In the above formula, N, NJ and ng represent the refractive index of single-layer film, incident medium and its substrate respectively; d is the coating thickness. In the above formula, since the reflectivity R is a function related to the coating thickness d and its refractive index n, as long as the reflectivity and transmittance spectra are observed and obtained, the parameters such as thickness can be obtained by using the spectral inversion algorithm.

$$I_0 = I_1 + I_2 + 2\sqrt{I_1 I_2}\cos\left(\frac{2\pi}{\lambda}\Delta L\right) \quad (3)$$

$$\beta = \beta_1 R_1 + \beta_1 R_2 \quad (4)$$

$$\delta = \frac{2\beta_1\beta_2\sqrt{R_1 R_2}}{\beta_1^2 R_1 + \beta_2{}^2 R_2} \quad (5)$$

I is the incident light intensity of the light source; R1 and R2 are the reflectance of the front surface of the sample and the mirror respectively; $\beta 1$ $\beta 2$is the transmittance of the two arms of Michelson interferometer; Δ L is the optical path difference of two interference beams; δ is the interference fringe contrast.

2.4.3. Infrared Measurement

In industrial production, the film thickness is often relatively small. When measuring its thickness with a thickness gauge, accurate measurement is required to reach the due accuracy index. The relationship between transmitted light intensity and medium thickness is as follows:

$$I = I_0 \cdot e^{-\beta T} \quad (6)$$

In the expression, I is the transmitted infrared light intensity, I0 is the incident infrared light intensity, and t is the measured film thickness, β is the absorption coefficient of the film to infrared light.

2.5. Nanoindentation Algorithm

Compared with the existing nano indentation instruments, the processing of indentation test data for hardness and modulus calculation is mainly based on the theoretical model developed by Oliver and Pharr, also known as o-P method. Different from the traditional hardness test, which calculates the mechanical properties by directly measuring the geometry of the indentation, the nano indentation uses the empirical formula to calculate the contact area, and then calculate the mechanical properties of the material. The o-P method adjusts the relationship between load and displacement described by the unloading curve to an exponential function:

$$P = \alpha\left(h - h_f\right)^m \quad (7)$$

Where α, M is the fitting parameter related to the indenter geometry, the respective elastic modulus and Poisson's ratio of the indenter and the sample. Differential equation (7) at the maximum load point to obtain the system contact stiffness s:

$$S = \left(\frac{dp}{dh}\right) = am\left(h_{\max} - h_f\right)^{m-1} \tag{8}$$

Then the depression depth H1 can be calculated as follows:

$$h_1 = \frac{p_{\max}}{s} \tag{9}$$

Where s is a constant related to the geometry of the indenter, and then the contact depth H2 can be obtained.

$$\mathrm{h}_2 = h_{\max} - h_s \tag{10}$$

Once the contact depth is determined, the projected contact area R can be calculated according to the area function of the indenter commonly used in instrumented indentation experiments. The projected contact area of the actual indenter is expressed as a series:

$$R = h_2^{\ 2} + \sum_{i=1} C_i h_2^{\ 1-i} \tag{11}$$

The hardness of the material can be calculated from the load and projected contact area. The hardness obtained by this method is also called indentation hardness. Namely:

$$H = \frac{P_{\max}}{R} \tag{12}$$

When the indentation depth is large, the scale effect is not obvious, but when the indentation depth is less than, the hardness will increase sharply or even increase in geometric order, and the scale effect becomes more intense.

3. Results and Analysis

3.1. Film Measurement

The same film material has different degrees of infrared light absorption in different thickness. The functional relationship between the thickness and the transmitted light intensity is determined, and the thickness corresponding to the transmitted light intensity in the measurement range is obtained. The framework is mainly composed of analog part, digital part and human-computer interaction part. The analog part includes signal generation and detection circuit and signal processing circuit. The digital part includes ad digitization module and DSP data processing module. The interaction part with the computer is mainly the design of touch screen communication module and display module. The whole measurement block diagram is shown in Figure 1.

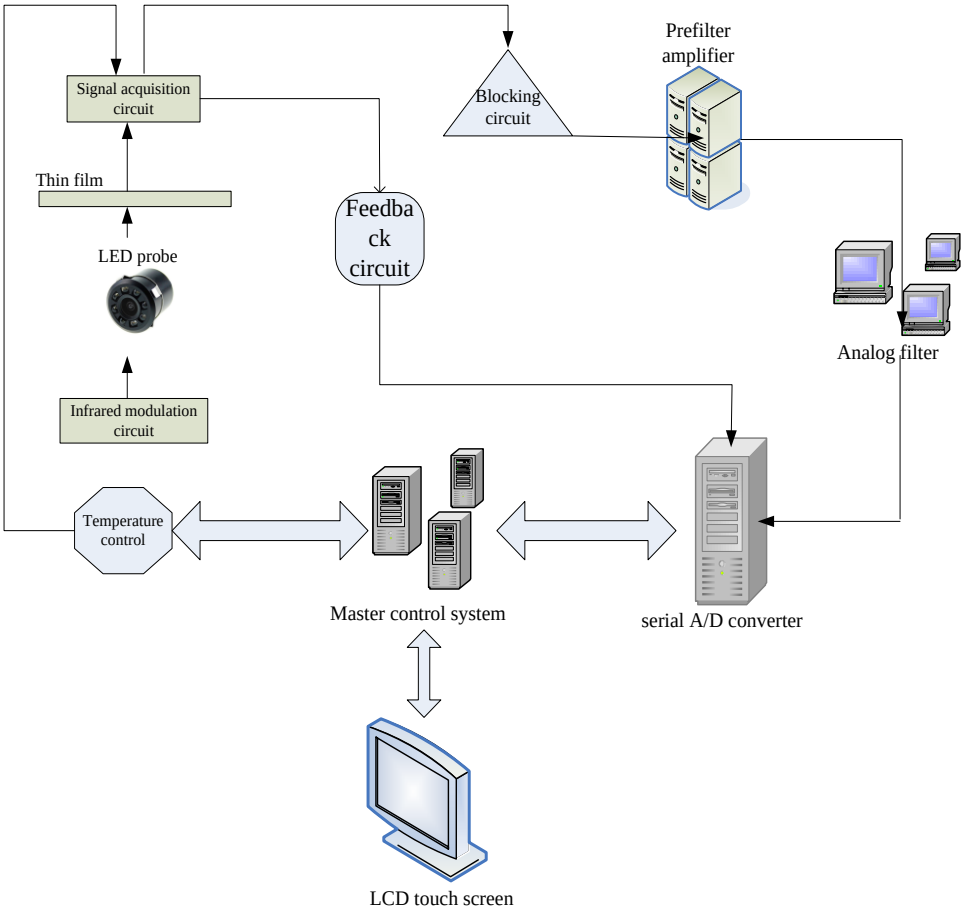


Figure 1. Thin film measurement and design structure

Because thin film materials usually contain hydrocarbon bonds, their spectral properties are very similar even if the types of thin film materials are completely different. Due to the influence of hydrocarbon bond, the infrared wavelength corresponding to the infrared absorption peak in the infrared spectrum is relatively small, usually in the first absorption peak, and the wave corresponding to the length difference d and the adjacent peak is relatively small, so it has little influence. It is the best choice for the wavelength of infrared measurement light. In addition, polyethylene and polyvinyl chloride are widely used. Polyvinyl chloride film is acid and alkali resistant, high temperature resistant, excellent mechanical properties, non-toxic, environmental protection and safety.

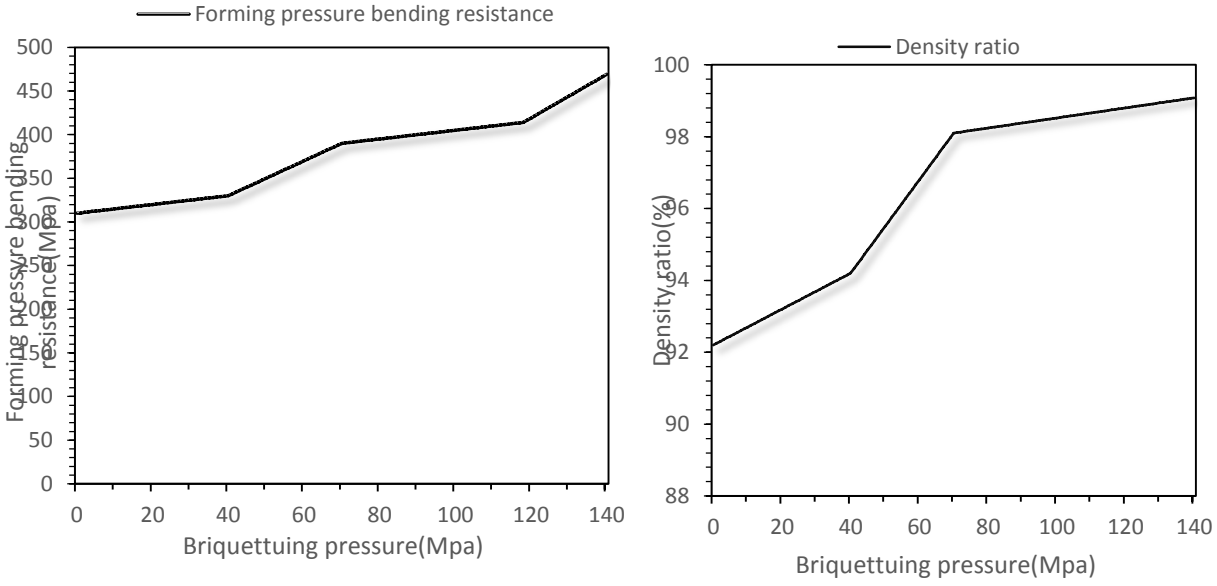
Ceramic material has the advantages of high hardness, high melting point, wear resistance, corrosion resistance and good insulation. It is one of the most widely used ceramic materials. It has incomparable characteristics of metal materials under bad conditions. Its manufacturing process can make it mass production and low cost. It is one of the most important materials in various fields and one of the most important basic materials to expand new materials. Alumina ceramic materials are mainly used in cutting tools, structural parts, wear-resistant parts, aerospace, aerospace, nuclear chemical and other industries. Such as ceramic cutting tools, power pipes, explosion-proof shielding, aerospace high-temperature protective layer, etc. Al2O3 material has attracted great attention of scientists and technicians from all walks of life in the past few decades, and its development is very

rapid.

Table 1. Main properties of the two ceramic materials

Modification	Strain	Space group	Character constant / nm	Density g/cm3	Refractive index	Product type (normal)	High temperature stability
a-Al2O3	Hexagon	R3c	a=0.5118	3.95-4.02	No=1.767	The sheet / polyhedral	Stable
r-Al2O3	Cube	Fd3m	a=0.773-0.806	3.90-3.42	N=1.69	Octahedron	> 1,200℃ C is unstable

Due to different grain size and purity, Al2O3 has a high melting point, about 2000 ℃ ~ 2500 ℃. There are more than ten kinds of same crystal forms, mainly including two crystal forms, a-Al2O3 and y-al2o3. The other crystal forms are almost completely transformed into a-Al2O3 at a high temperature above 1300℃. A-Al2O3 belongs to hexagonal system and represents a thermodynamically stable crystal form. It is the main crystalline phase of alumina ceramics. Y-al2o3 has face centered cubic lattice, low density and poor high temperature stability, which is not available in nature. Table 1 shows the important physical and chemical properties of the two Al2O3 crystalline phases.



A. Density ratio B. Forming pressure bending resistance

Figure 2. Relationship diagram between forming pressure, relative density of material and compressive strength

Figure 2 shows that the density of the material gradually increases with the increase of forming pressure. When the pressure is 40 MPa, the upward trend of the curve gradually slows down and the pressure continues to increase. The density continues to increase, mainly because the internal pores

or internal particle voids are large under low pressure, and the density increases significantly with the increase of pressure. When the density reaches a certain degree, the internal pores and other grain defects or voids are obviously reduced or eliminated, and the increase of density gradually slows down. It can be seen from the figure that cold isostatic pressing (130 MPa) increases the density of ceramics, but it is very low. Compared with the forming pressure of 40 MPa, the relative density increases by about 0.64%. Therefore, the effect of cold isostatic pressing is not obvious. It can be seen from the figure on the right that the bending strength of nanocomposite ceramics increases with the increase of forming pressure: when the pressure is 40 MPa (the bending strength reaches 421 MPa) and 50 MPa, the increase rate slows down, which is also closely related to the growth trend. When cold isostatic pressing samples are used, the bending strength of materials continues to increase, about 1.08 times that of 40 MPa castings.

In this experiment, the content of nano ceramic material was 18% (weight), the molding pressure was 40 MPa, the sintering temperature was changed to 1600 ℃, 1650 ℃, 1700 ℃ and 1850 ℃, and the time was maintained for 4 hours. The internal microstructure and related properties were studied in 6 hours, 8 hours and 10 hours. See Table 2 for specific preparation plan:

Table 2. Preparation conditions for ceramic materials

variable quantity	Y-ZrO> Addition Amount (wt%)	Forming pressure (MPa)	Sinter point (℃)	Soaking time (h)
			1600	8
			1650	
Sinter point	18	40	1700	
			1850	
				4
				6
Soaking time	18	40	1900	8
				10

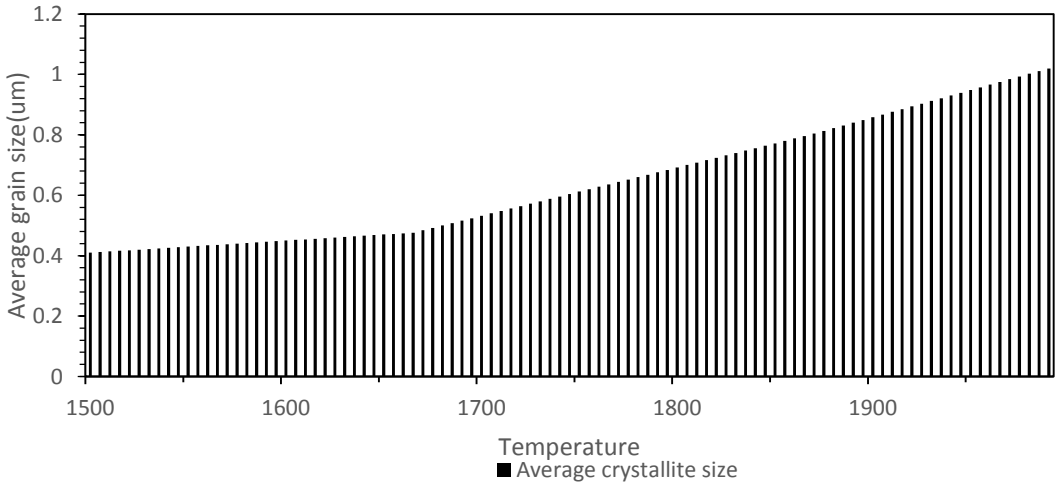


Figure 3. Effects of temperature on the grain size

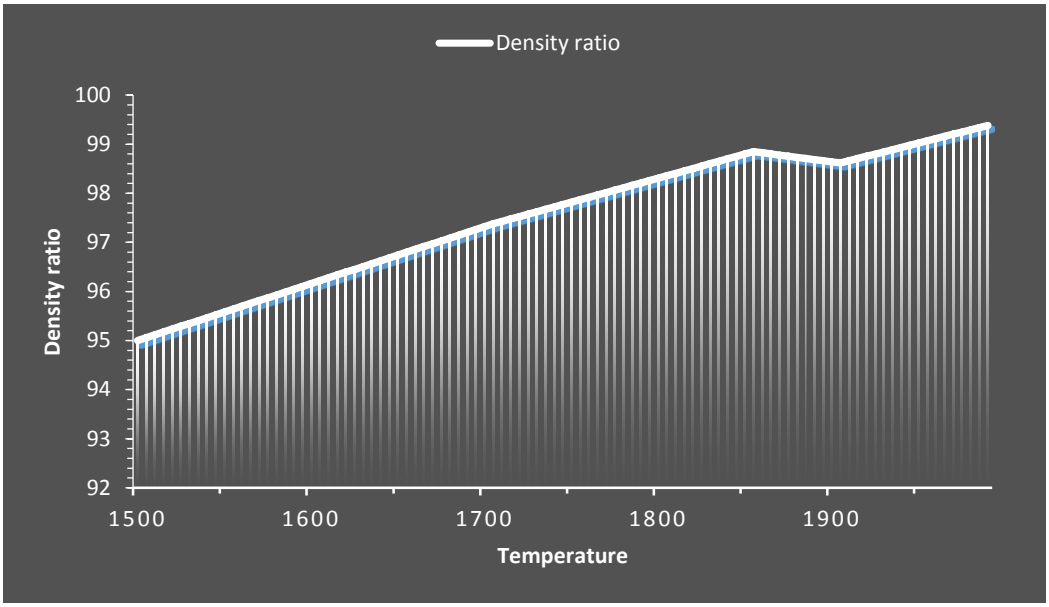


Figure 4. The relation between the temperature and the relative density

Figure 3 and Figure 4 are corresponding specific gravity diagrams. It can be seen from the figure that the density increases gradually with the increase of sintering temperature. Higher relative density can be obtained at the sintering temperature of 1850 ℃, and then the density (98.58%) increases slowly. The reason is that the ceramic forms poorly during low-temperature sintering, and it is difficult to remove pores and internal defects, which affects the overall density of ceramic materials. With the increase of sintering temperature, the particles are relatively easy to migrate and diffuse, so the voids or defects between matrix particles, between matrix and Y-ZrO2 particles or between grains can be further removed, so as to improve the overall density of the material. When the sintering temperature is 1850 ℃, the relative density is 98.69%, which increases by about 0.1%. It shows that the pores and defects in the material are basically discharged or removed at 1900 ℃.

3.2. Load Displacement Curve Analysis

According to Newton's law, in each simulation step, the force on the indenter can be used as the load of the indenter on the substrate. The displacement of the indenter at each step can be determined directly. In this way, the load and displacement in the simulation process form an important characterization of the nanoindentation load displacement curve data. Load displacement curve is the most important data of nano indentation (including experiment and molecular simulation). In molecular simulation, the charge displacement curve combined with the molecular configuration of the simulated output can be used to evaluate the zero contact between the indenter and the matrix, and obtain the real indentation depth, indentation area and hardness. The load displacement curve obtained in our simulation is shown in Figure 5.

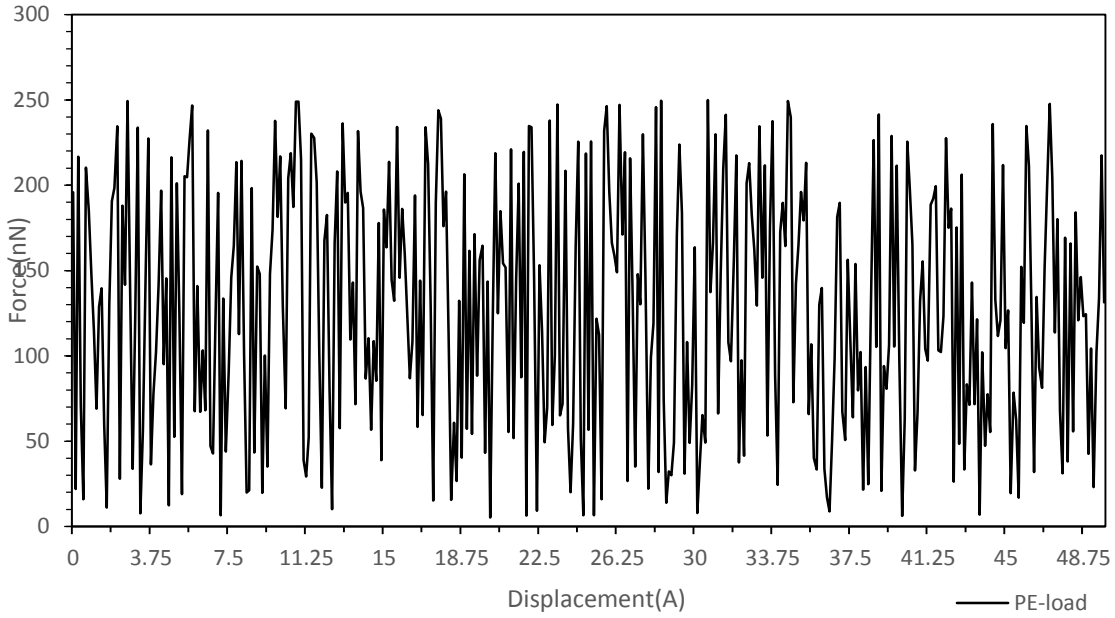


Figure 5. Load-displacement curve for the loading process

Figure 5, the load displacement curve corresponding to the PE model shows a slight downward trend from the beginning of charging to about 5a, and the load at this load level is completely lower than zero. This also happens in PVAC loading. This shows that the atom at the tip of the indenter and the matrix atom closest to the tip of the indenter are in an attractive state, and there is still a certain distance between them according to van der Waals principle and electrostatic interaction. This is normal. Although we placed the indenter near the top surface of the substrate before formal loading, we did not fully contact the top surface. At the beginning of formal loading, the indenter did not contact the substrate. Therefore, we need to combine the output analog image to accurately determine when the indenter is in formal contact with the substrate, that is, when the indenter is in formal contact with the substrate.

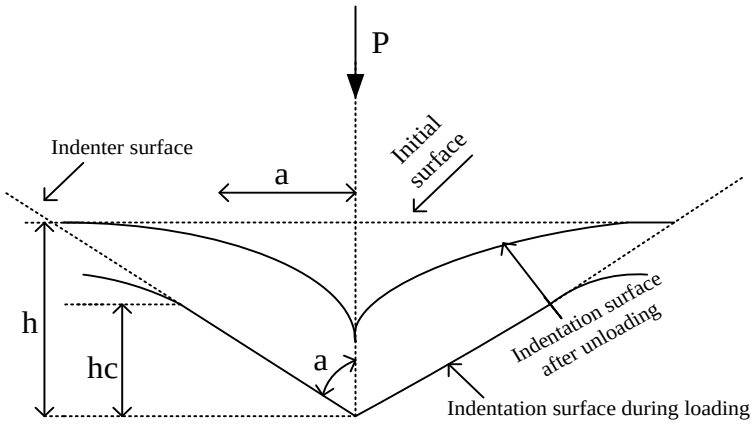


Figure 6. Schematic diagram of the indentation profile

In the process of nano indentation test, after the indenter is driven into the sample at a certain speed in the loading stage, the area in contact with the indenter and its environment begins to show elastic deformation, the depth increases, and then plastic deformation occurs. When the tax load or offset reaches the maximum value, keep it under the load for a period of time, which is the step of maintaining the load. In the load maintenance stage, the load at this time is Pmax, and the penetration depth of the penetrator from the initial surface is Hmax. The O-P method assumes that the contact area between the indenter H (indentation) and the indenter sinks, just as when a rigid punch of simple geometry is driven into an elastic half space. Due to the existence of the groove, the actual contact depth between the indenter and the substrate is hc and the contact surface is AP. The unloading starts at the end of the holding load, and then the elastic deformation is restored. Unloading, but the performance at this stage is no longer the elastic performance at the initial pressing, but the elastic recovery after plastic deformation. After unloading, the remaining depth of the groove is hf. Figure 6 is a schematic diagram of the groove contour.

Figure7 is an indentation scale test diagram of ceramic nano materials.

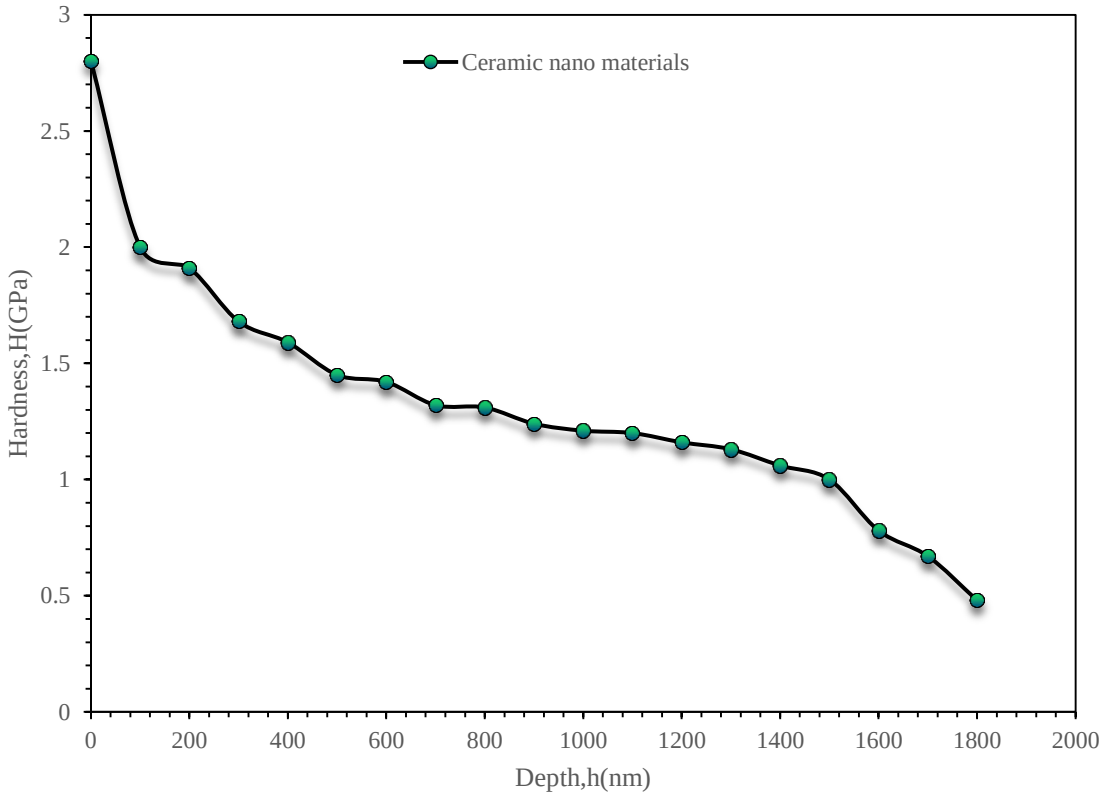


Figure 7. Scaling effects in the indentation of ceramic nanomaterials

As can be seen from Figure 7, the hardness values obtained at different penetration depths are different. With the gradual decrease of penetration depth, the stability value also increases rapidly, which is the maximum scaling effect of nano indentation. In addition, when the indentation depth is more than 1000 nm or less, the effect of scaling treatment in the figure is not significant, while when the indentation depth is less than 300 nm, the stability increases sharply or even increases exponentially, especially the effect of scaling treatment.

Table 3. Hardness model of the composition of ceramic nanomaterials

Simulation matter	Load displacement (nm)	Curve of load (nN)	Area curve (nm2)	Hardness Curve (GPa)
PVAC	h	24.25308	$\pi\left(0.5+\frac{5}{6}h\right)^2$	$\frac{24.25308}{\pi\left(0.5+\frac{5}{6}h\right)^2}$
PE	h	466.578	$\pi\left(0.5+\frac{4}{5}h\right)^2$	$\frac{466.578}{\pi\left(0.5+\frac{4}{5}h\right)^2}$

After adapting to the load displacement curve, the hardness can be measured directly. The hardness at each load displacement is further calculated by dividing the load here by the projected area of the indenter. Since we have fitted the loads at all points on the curve, and the area can also be obtained according to the shape of the indenter, the hardness displacement curve can be obtained by dividing the load displacement curve by the surface curve displacement. Table 3 shows this PE or PVAc process. The load curve is the functional formula applicable to Figure 7, and the area curve is obtained by geometric calculation of the two round table penetrators created by the algorithm.

4. Discussion

Composite ceramics have many excellent properties, such as high hardness, high strength, wear resistance, high temperature resistance, good mechanical properties, corrosion resistance and so on. It can manufacture ceramic materials used in various fields of the national economy. However, as a brittle metal material, ceramics will break quickly without warning, which seriously affects the wide application of composite ceramics, especially in building structural components. Therefore, increasing the brittleness of composite ceramics is essential to further expand the application range of composite ceramics. There are two main ways to increase the brittleness of composite ceramics: on the one hand, reduce the internal defects or reduce the defect area, on the other hand, improve the toughness of the material. The latter method can be achieved by refining the raw material powder. The use of finer nano powder as ceramic sintering raw material makes the ceramic material more compact and reduces internal cracks, so as to further achieve the purpose of microcrack toughness. The second method has relatively few restrictions on equipment and is relatively cheap. Therefore, the method of improving fracture toughness has become one of the most important ways. For decades, researchers have made continuous efforts and achieved remarkable results. Among these toughening methods, adding a second phase to the ceramic matrix to form multiphase ceramics is the main method. At present, ceramics are mainly hardened by whiskers, fibers and second phase particles. At the same time, the added hardening medium should increase the toughness of the ceramic material without damaging its original excellent properties. Therefore, the hardening phase of the ceramic material should also have many excellent properties of the matrix ceramic material, such as high temperature resistance, wear resistance, corrosion resistance, high hardness and good mechanical properties. It is the second phase of the bias means.

Film thickness is one of the most basic parameters that determine the characteristics and properties of films. Due to the further development of modern coating technology, it is particularly huge to accurately measure the film thickness at the nm level (from a few nanometers to hundreds

of nanometers). Among the general mechanical methods and current optical methods, electronic optical measurement method is the most important test method because of its advantages of accuracy, high speed and nondestructive test results. However, due to the progress of Zero Five conductor technology and coating preparation technology, Zero Five conductor radio coating is used in many optical devices, electronic devices and low light electromechanical systems. In many cases, the thickness and optical parameters of the film largely determine the mechanical, electromagnetic, photoelectric and optical properties of the film. Therefore, the accurate measurement of film thickness and optical constants plays a key role in the production and application of thin films.

Nanoindentation is a kind of continuous detection of some form of indenter through a high-resolution instrument. The instrument pushes the material at a certain speed and maintains the load, then unloads and records the displacement of the indenter load. The elastic modulus, hardness and other mechanical properties of the material are calculated according to the relevant theories. As long as the accuracy of measuring stress and displacement at depth is high enough, the dynamic characteristics of materials can be easily obtained even at the penetration depth of nano scale. Compared with traditional thermodynamic measurement methods, nano indentation method has many advantages. Firstly, it has few requirements for the shape and thickness of the test piece, and does not need any special device or mechanical fixation of the sample. It only needs to be fixed on the sample table. This function is very suitable for the identification of polymer films and will hardly damage the sample, so a sample can be tested repeatedly. Nano indentation has become the main method to characterize the mechanical properties of various polymer materials and nanocomposites.

5. Conclusion

Ceramic materials have excellent physical properties in modern industry and are widely used in aerospace, nuclear fusion, military and other fields. However, with the rapid development and progress of science and technology, the demand for energy is increasing. As an advanced numerical calculation method, finite element method can not meet the needs of social production. Thin film thickness measurement technology is the most widely used and mature technology in the world. In this paper, the indentation unloading of ceramic materials is studied and analyzed, the variation laws of mechanical properties and strain characteristics of ceramic materials under different densities are discussed, and the corresponding measures are put forward to improve the comprehensive properties of ceramics.

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Data Availability

Data sharing is not applicable to this article as no new data were created or analysed in this study.

Conflict of Interest

The author states that this article has no conflict of interest.

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