Effect of CaO and SiO₂ on the properties of Y₂O₃-based ceramic core materials

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ABSTRACT

Nb-Si alloy is an important candidate material to produce hollow turbine blades in the aerospace industry. However, the ultra-high melting temperature of Nb-Si alloy (≥1750°C) makes the traditional ceramic core made of Al₂O₃ (poor leachability) or SiO₂ (melting temperature invalid in the production of Nb-Si hollow turbine blades. In this study, Y₂O₃ were used as the ceramic core matrix due to its high melting points, high strength, and low interfacial reactivity. CaO and SiO₂ were added in Y₂O₃ matrix to improve the leachability and high temperature flexural strength (1500°C) of ceramic cores. The other properties such as porosity, shrinkage and bulk density were investigated as well. The results showed that the introduction of CaO in Y₂O₃-based ceramic cores improved the leachability. The addition of SiO₂ in the Y₂O₃-CaO matrix could greatly improve the high temperature flexural strength, and keep a good leachability at the same time. The best comprehensive properties of Y₂O₃-based ceramic cores were obtained when it contained 12 wt% CaO and 4 wt% SiO₂. The new developed Y₂O₃-based ceramic cores with the addition of CaO and SiO₂ has the potential to meet the extreme requirements in the casting of Nb-Si alloy hollow turbine blades.

1. Introduction

To develop a gas turbine with a high thrust-to-weight ratio is always the target in the development of the aerospace industry. Since the 1950s, the thrust to weight ratio of gas turbine has increased averaged by 16% every decade, and the temperature in front of gas turbine has increased at the rate of 20–25°C every year. As the temperature in front of gas turbine blade continuously increases, the requirement for the high temperature bearing capacity of the blade is urgent [1–5]. Manufacturing a hollow gas turbine blade is one of the key technologies to improve the temperature bearing capacity of the blade by introducing cooling-air flow inside of the blade [4,5]. Ceramic cores are mainly used to cast the hollow gas turbine blade with complex inner structure [6,7]. The excellent properties of ceramic cores are critically important for the preparation of hollow gas turbine blade.

The Nb-Si superalloy has become a candidate material for manufacturing turbine blades in the aviation field because of its excellent properties, such as excellent fracture toughness at room temperature, low density, high temperature strength, etc. However, due to the high melting point (≥1750°C) of Nb-Si superalloy, traditional silica-based ceramic cores cannot meet the casting temperature requirements (higher than its melting point, 1713°C) and easily reacts with alloy elements [8,9]. Alumina-based ceramic cores are not used to casting the Nb-Si super-alloy owing to the poor leachability and react with alloy elements at high temperature. Therefore, it is an primary task to develop a more appropriate ceramic core before the extending application of Nb-Si super-alloy in manufacturing hollow turbine blades.

As is known, Y₂O₃ is a promising material for high temperature application field owing to its outstanding refractoriness and excellent chemical stability [10]. It can serve as the mold coating in the casting of TiAl alloy [11], and the crucible or mold shell in the directional solidification casting of Nb-Si alloy with low pollution to the melt [12–15]. Compared with conventional ceramics such as alumina (Al₂O₃) and silica [16,17], it is concluded that Y₂O₃ with excellent properties has a potential for preparing the ceramic cores applying in the casting of Nb-Si super-alloy. However, the poor leachability of Y₂O₃ confines its application in the production of ceramic cores. Additionally, CaO ceramic is also an attractive material in the ceramic core field for the casting of alloy owing to its some advantages such as a high melting temperature, excellent thermodynamic stability properties and high leachability properties. But the easy hydration of CaO could affect the dimensional accuracy [18], and many methods have been carried out to solve this problem such as by depositing the nano-zirconia particles and...
calcium zirconate on the surfaces of CaO particles [19–21]. Both Y₂O₃ and CaO are excellent materials for producing crucibles of Nb-Si alloy. It is reported that Y₂O₃ and CaO are no reaction with Nb, Si, Ti, Hf in the temperature range between 1300 K and 2300 K, among the tests of Al₂O₃, MgO, BeO, Ce₂O₃, ZrO₂, CaO and Y₂O₃, their chemical compatibility with Nb-Si superalloy is superior to other crucible materials [22]. Neither of them is individually appropriate to produce ceramic core, but they might have functional complementation when mixed based on their own performances. In addition, during the heating process, the crystalline transformation of SiO₂ will lead to volume expansion, which may make up for the sintering shrinkage of ceramic cores [23]. Meanwhile, silicate formed by the reaction of SiO₂ and CaO at high temperature is the main provider of concrete strength [24]. Thus, in this study, Y₂O₃ was used as the ceramic core matrix material, and the CaO will be introduced into the Y₂O₃ ceramic cores, aiming to improving the leachability of Y₂O₃ ceramic cores, which ensures that ceramic cores can be quickly leached from the complex alloy cavity without damaging the cavity structure. 

SiO₂ was introduced to try to enhance the high temperature flexural strength of ceramic cores, which ensures that ceramic cores can withstand the thermal shock of molten metal during the casting process.

2. Experimental procedure

Commercially available fused Y₂O₃ powders (Zhengzhou Zhenzhong Electrofusion New Material Co., Ltd) were employed as matrix materials. The composition parameter of Y₂O₃ is shown in Table 1, and the particle size information is shown in Figure 1. Among, the addition of CaO (Taihe New Materials Co., Ltd) content was 4 wt%, 8 wt% and 12 wt%, respectively (relative to weight percent of the total raw materials). And the addition SiO₂(Zhongkai Electronic Materials Co., Ltd.) was 1 wt%, 2 wt%, 3 wt% and 4 wt%, respectively. The mixtures of fused Y₂O₃ (the weight ratio of particle I to particle II is 2:1), CaO and SiO₂ powders were ball-milled for 12 h in a plastic jar with ZrO₂ balls, in which PVB-ethanol solution was used as the wet grinding medium.

Table 2 summarizes the main components of the mixed raw materials with a mass of 100 g. After sieving and drying, the mixed powders were pressed by stainless steel mold with 41 x 6 x 5 mm under 20MPa pressure for 2.5 min. The pressed ceramic cores were sintered at 1600°C for 2 h at a rate of 5°C/min. The linear shrinkage of composite ceramic cores before and after sintering was calculated through measuring the size of bar samples, the equation shown in Eq. (1):

\[
L = \frac{l_1 - l_2}{l_1} \times 100\%
\]

Figure 1. Particle size distribution: (a) Particle I; (b) Particle II.

Table 2. The main components of the mixed raw material with mass of 100 g.

| Sample | Binder composition (10%PVB(g)) | Solid composition (g) | CaO (g) | SiO₂ (g) | CaO mass fraction (C/ (Y + C))(%) | SiO₂ mass fraction (S/ (Y + C + S)) (%) |
|--------|-------------------------------|-----------------------|---------|----------|---------------------------------|----------------------------------------|
| 1      | 5                             | Y₂O₃                  | 95      | 0        | 0                               | 0                                      |
| 2      | 5                             | CaO                   | 91.2    | 3.8      | 0                               | 0                                      |
| 3      | 5                             | SiO₂                  | 87.4    | 7.6      | 0                               | 0                                      |
| 4      | 5                             | CaO                   | 83.6    | 11.2     | 0                               | 0                                      |
| 5      | 5                             | SiO₂                  | 82.65   | 11.2     | 0.95                            | 12                                     |
| 6      | 5                             | CaO                   | 81.7    | 11.2     | 1.9                             | 12                                     |
| 7      | 5                             | SiO₂                  | 80.75   | 11.2     | 2.85                            | 12                                     |
| 8      | 5                             | CaO                   | 79.8    | 11.2     | 3.8                             | 12                                     |
| 9      | 5                             | SiO₂                  | 78.9    | 11.2     | 3.8                             | 12                                     |
| 10     | 5                             | CaO                   | 78.9    | 11.2     | 3.8                             | 12                                     |

The apparent porosity and density of ceramic cores were determined based on the Archimedes’ method, the equations shown in Eqs. (2) and (3), respectively:
\[ P = \frac{M_3 - M_1}{M_3 - M_2} \times 100\% \quad (2) \]

\[ D = \frac{M_1}{M_3 - M_2} \times \rho_1 \quad (3) \]

where \( P \) is the open porosity of ceramic core, \( D \) is the volume density, \( \rho_1 \) is the density of alcohol (0.79 g/ml), \( M_1 \) is the weight of dry samples, and \( M_2 \) and \( M_3 \) are the weight of alcohol-saturated sample alcohol and air, respectively.

The bar samples were used for the flexural strength test by using three-point flexural measurement equipment (WDW300, Changchun Kexin Test Instrument Co., Ltd, China). The flexural strength was measured at 25°C and 1500°C. The flexural strength of samples was calculated with the equation shown in Eq. (4):

\[ \sigma_w = \frac{3 \times FL}{2 \times bh^2} \quad (4) \]

where \( \sigma_w \) is the flexural strength of ceramic core, \( F \) is the stress force, \( L \) is the span, \( b \) and \( h \) are the width and height of fracture section, respectively.

The leachability properties of the ceramic cores was measured as follows: the sample was placed in boiling solution with 40 wt% acetic acid (AR, China Pharmaceutical Group) after accurate weighting using an analytical balance. When soaked in the solution for 60 min, the sample was weighted after pulling out and cleaning up. The weight loss of samples was calculated with the equation shown in Eq. (5):

\[ W = \frac{W_1 - W_2}{W_1} \times 100\% \quad (5) \]

where \( W \) is the weight loss, \( W_1 \) is the original weight and \( W_2 \) is the final weight after corrosion.

Each of the above value was the average of five samples. The thermal expansion coefficient of 4 wt\%SiO\(_2\) ceramic cores was tested by thermal expansion coefficient tester (403 F3, TMA, NETZSCH). The phase compositions of ceramic cores were characterized by X-ray diffractometry (D8 Advance, AXS, Germany). The microstructures of ceramic cores were analyzed by SEM/EDS (FEI-Quanta 450, FEI, U.S.A). In order to prevent the hydration of the sintered ceramic core in the air, ceramic cores after sintering were immersed in the liquid resin for a period of time, which could not only isolate the steam but also strengthen the ceramic core.

3. Results

3.1. Physical properties

3.1.1. The bulk density, the apparent porosity and the linear shrinkage

3.1.1.1. \( Y_2O_3 \) ceramic cores with different CaO contents. In Figure 2(a), the bulk density of ceramic cores was increased from 3.91 g/cm\(^3\) to 4.19 g/cm\(^3\) and the apparent porosity ceramic cores was decreased from 20.20% to 9.01% with the CaO content increasing from 0 wt% to 4 wt%. Then, the bulk density of ceramic cores was decreased from 4.19 g/cm\(^3\) to 4.10 g/cm\(^3\) and the apparent porosity of ceramic cores was maintained to be about 9.00% with the CaO content increasing from 4 wt% to 12 wt%.

In Figure 2(b), the linear shrinkage of ceramic cores was increased from 2% to 5.15% with CaO content increasing from 0 wt% to 4 wt%. Then the linear shrinkage of ceramic cores was increased slightly to 5.5% with the increase CaO content to 12 wt%.

3.1.1.2. \( Y_2O_3/CaO(12 \text{ wt}\%) \) ceramic cores with different SiO\(_2\) contents. When the CaO content was constant at 12 wt%, in Figure 3(a), the bulk density was decreased from about 4.10 g/cm\(^3\) to 3.1 g/cm\(^3\) and the apparent porosity was increased from about 8.93% to 33.57% with SiO\(_2\) content increasing from 0 wt% to 4 wt%. In Figure 3 (b), the linear shrinkage of ceramic cores decreased with the increase of SiO\(_2\) added content.

3.1.2. The flexural strength at 25°C and 1500°C

In Figure 4(a), the flexural strength at 25°C first increased and then slight decreased with the increase of CaO content. The flexural strength at 1500°C first increased and then tended to be stable value with the increase of CaO content. Specifically, the flexural strength at 25°C was increased significantly from 25.68MPa to 46.31MPa and the flexural strength at 1500°C was decreased significantly from 18.60MPa to 5.68MPa with CaO content increasing from 0 wt% to 4 wt%. Then the flexural strength at 25°C was decreased significantly to 35.71MPa and the flexural strength at 1500°C was maintained to be about 5MPa with the increase of CaO to 12 wt%.

When the CaO content was constant at 12 wt%, in Figure 4(b), the flexural strength at 25°C of the samples was decreased from 35.71MPa to 17.47MPa with SiO\(_2\) content increasing from 0 wt% to 4 wt%. The flexural strength at 1500°C was increased from 4.90MPa to 21.06MPa with the SiO\(_2\) content increasing from 0 wt % to 4 wt%.

3.1.3. The thermal expansion coefficient

In Figure 5, SiO\(_2\) content was 4 wt%, with the temperature increases from 50°C to 1400°C, the thermal expansion coefficient of \( Y_2O_3/CaO(12 \text{ wt}\%) \) ceramics varies from \( 6 \times 10^{-6} \text{K}^{-1} \) to \( 9 \times 10^{-6} \text{K}^{-1} \). This is close to the coefficient of thermal expansion of niobium alloy [25].
3.2. Chemical properties

3.2.1. The leachability

According to previous studies [26–28], niobium is appreciably attacked in extremely corrosive media, like concentrated acids or at high temperatures. In order to avoid the corrosion of grain boundary of Nb-Si superalloy caused by strong acid, weak acid was selected to remove ceramic cores. Figure 6(a) and (b) shows the weight loss of Y$_2$O$_3$ ceramic cores with different content CaO and Y$_2$O$_3$/CaO (12 wt%) ceramic cores with different SiO$_2$ content after a leaching test at 80°C for 1 h in 40 wt% acetic acid solution, respectively.

In Figure 6(a), it is found that with the increase of CaO content, the leachability of ceramic cores was improved. Ceramic cores with 12 wt% CaO were completely leached within 15 min and ceramic cores without CaO had almost no leachability within 60 min. In Figure 6(b), when the CaO content was constant at 12 wt%, the leachability of the Y$_2$O$_3$/CaO(12 wt%) ceramic cores became worse gradually with the increase of SiO$_2$ content. However, all the ceramic cores are leached within 60 min.

4. Discussion

4.1. Comprehensive analysis of physical properties

4.1.1. Y$_2$O$_3$ ceramic cores with different CaO contents

For Y$_2$O$_3$ ceramic cores with different CaO contents, combined with the changing trend of the apparent porosity, it can be inferred that the addition of 4 wt% CaO promoted the sintering reaction and made the sintering reaction reach a full state, so with CaO content increasing from 4 wt% to 12 wt%, the apparent porosity of ceramic cores tend to be stable. With the increase of CaO/Y$_2$O$_3$ mass ratio, the relative amount of CaO was increased, the relative amount of Y$_2$O$_3$ added was decreased, and the linear shrinkage of Y$_2$O$_3$ ceramic cores was increased. The main reason is that the linear shrinkage of CaO is greater than that of Y$_2$O$_3$ at
Figure 4. (a) The flexural strength at 25°C, 1500°C of Y$_2$O$_3$ ceramic cores with different CaO contents; (b) The flexural strength at 25°C, 1500°C of Y$_2$O$_3$/CaO(12 wt%) ceramic cores with different SiO$_2$ contents.

Figure 5. The thermal expansion coefficient of Y$_2$O$_3$/CaO(12 wt%) ceramic core with 4 wt%SiO$_2$ content.

Figure 6. (a) Leachability of Y$_2$O$_3$ ceramic cores with different CaO contents; (b) Leachability of Y$_2$O$_3$/CaO(12 wt%) ceramic cores with different SiO$_2$ contents.

Figure 7. The linear shrinkage of pure Y$_2$O$_3$ and pure CaO with different sintering temperature.
the same temperature. In order to prove this point, the linear shrinkage of pure CaO and pure Y$_2$O$_3$ at different temperatures is studied, the result is shown in Figure 7.

The density is calculated from the rules of composites, the bulk density was decreased with CaO content increasing from 4 wt% to 12 wt% due to the lower density of CaO (3.250 g/cm$^3$) compared with that of Y$_2$O$_3$ (5.01 g/cm$^3$). In this process, the linear shrinkage slightly increased is not enough to compensate for the decreased of the bulk density decreased. The flexural strength of ceramic cores is closely related to its structure, the changed porosity and linear shrinkage might lead to the change of the connection and contact area between particles, then lead to the change of the flexural strength. The minimum solid area models demonstrating the strength-porosity dependence can be approximated as follows [29]:

$$\sigma = \sigma_0 \exp(-bP)$$

(6)

Here, $\sigma$ is the flexural strength of porous sample, $\sigma_0$ is the flexural strength of corresponding nonporous sample at the same composition, $P$ is the porosity of porous sample, and $b$ is a parameter determined by pore characteristics.

As shown in Figure 8(a) and Figure 8(b), combined with Figure 2(a) and Figure 4(a), with CaO content increasing from 0 wt% to 4 wt%, the apparent porosity of the ceramic cores was decreased significantly, large Y$_2$O$_3$ particles with point connection was decreased and small single particles bonded together by the sintering necks to form complete larger particles, the flexural strength at 25°C of the ceramic cores was increased significantly. However, in Figure 8(c)–(d), with CaO content increasing from 8 wt% to 12 wt%, although the apparent porosity of ceramic cores maintained relatively stable, CaO beyonds the solid solution limit of the Y$_2$O$_3$ matrix, resulting in solid solution uneven, causing to the large number of internal small pores are appeared [30], the whole porosity was increased, thus it can be known from Eq(6) that the flexural strength at 25°C was decreased gradually. Additionally, compared Figure 8(a) with Figure 8(b)–(d), it can be observed that from the morphology in Figure 8(a), each particle is relatively complete, the fracture of the ceramic cores was along the particle surface, the fracture mode was intergranular fracture. And from the morphology in Figure 8(b)–(d), the cleavage plane appeared obviously at grain fracture surface, which was a typical transgranular fracture mode. Therefore, for ceramic cores without CaO, the flexural strength at 25°C of ceramic cores containing CaO was increased.

The high temperature properties of ceramic cores are affected by the high temperature properties of raw materials. Combined with Figure 4(a), the flexural strength at 1500°C first increased and then tended to a stable value with the increase of CaO content. The main reason is CaO with high temperature creep induces deformation when the force is applied to the ceramic core, reducing the mechanical properties of ceramic cores. The creep process of CaO is shown by the stress-strain curve in Figure 9.

4.1.2. Y$_2$O$_3$/CaO(12 wt%) ceramic cores with different SiO$_2$ contents

For Y$_2$O$_3$ ceramic cores with different SiO$_2$ contents when the CaO content was constant at 12 wt%. There are two reasons influencing the linear shrinkage of Y$_2$O$_3$...
O$_2$/CaO(12 wt%) ceramic cores during sintering process, one is that the densification process of ceramic cores sintering, other is that the volume expansion caused by SiO$_2$ crystalline transformation [31–33]. And it is all known that the phase transformation of cristobalite accompanies with the volume shrinkage by 2.8% during cooling [34]. Therefore, combined with Figure 3(a) and Figure 3(b), it can be inferred that in the process of heating, the SiO$_2$ crystalline transformation resulted in volume expansion, then SiO$_2$ participated in the sintering reaction and was consumed, under the effect of sintering densification, ceramic cores with a certain the linear shrinkage were finally formed. For example, the linear shrinkage of ceramic cores is decreased but always positive with SiO$_2$ content increasing from 0% to 3 wt%, and linear shrinkage from positive converted into negative with 4 wt% SiO$_2$ content. According to the principle of the volume expansion caused by the SiO$_2$ crystalline transformation, which compensates for some shrinkage during the sintering process [20], the final size of ceramic cores can be adjusted by changing the content of added SiO$_2$.

As shown in Figure 10(a), the particles are bonded together and the pores are not obvious in the matrix. In Figure 10(b), the connection between particles was not so tight, small amounts of pores and single particles began to appear, and the long and narrow channels were generated. In Figure 10(c) and Figure 10(d), the particles formed were fine and distributed uniformly in the matrix. Combined with Eq(6), with the increase of SiO$_2$ content, the apparent porosity of the ceramic cores was increased significantly and the amounts of pores tended to increase (consistent with Figure 3(a)). The local magnification of the microstructure in Fig. 10(d) is shown in Figure 12(a), it has been observed that the fracture planes at fine sintering neck and confirmed that the sintering neck is refined when SiO$_2$ is added. When the stress is applied, fine sintering neck is more likely to fracture, which also can explain the phenomenon that the flexural strength at 25°C of the ceramic cores was decreased (consistent with Figure 4(b)). Additionally, with the increase of SiO$_2$ content, the sintering neck is refined gradually and resulted in the cleavage plane disappeared at grain fracture.

![Figure 9](image_url)  
Figure 9. The stress-strain curve of Y$_2$O$_3$ ceramic core with 12 wt% CaO content.

![Figure 10](image_url)  
Figure 10. Microstructures of Y$_2$O$_3$/CaO(12 wt%) ceramic cores with various SiO$_2$ contents: (a) 1 wt%; (b) 2 wt%; (c) 3 wt%; (d) 4 wt %.
surface, the fracture surface of ceramic core was transferred from the cleavage plane to the surface along the grain, the main fracture mode changed from transgranular fracture to intergranular fracture. Therefore, the change of fracture mode was also an important factor for the decrease of the flexural strength at 25°C.

Combined with Figure 4(b), the flexural strength at 1500°C increased with the increase of SiO2 content. At 1500°C, the ceramic cores may be induced to creep when the flexural strength of the ceramic cores reaches to the ultimate the flexural strength (such as more than 20MPa) when it is subjected to the ultimate fracture stress. When Y2O3/CaO(12 wt%) ceramic cores are subjected to extreme stress at high temperatures, it does not brittle fracture instantaneously and maintains the high strength, which is different from ordinary ceramic cores and met the requirement of investment casting [35]. The stress-strain curve of Y2O3/CaO(12 wt%) ceramic cores in Figure 11.

Compared the change trend of flexural strength at 1500°C in Figure 4(a) and Figure 4(b), it could be concluded that when SiO2 was added into the ceramic cores, sintered products play a positive role in improving the flexural strength at 1500°C of the ceramic cores. Considering previous studies [29,35,36], the new products may be mainly Ca2SiO4 or similar silicates, in order to verify the authenticity of formation of products at fine sintering necks, select the local magnification microstructure of ceramic cores with 4 wt% SiO2 shown in Figure 12(a). The corresponding EDS mapping is shown in Figure 12(b), which shows element content and its composition distribution in the matrix, it can be seen that distribution of element content is generally consistent with raw materials, and the main distribution area of Si is coincided with the distribution area of Ca, based on the EDS point scanning results of the distribution region of Si and Ca in Figure 12(c), the relative proportion of Si and Ca elements is obtained. Therefore, the comprehensive results show that the SiO2 mainly reacts with the CaO in the ceramic cores to form the Ca2SiO4 or similar silicates, and led to the flexural strength at 1500°C of the ceramic cores was increased [20,36].

4.2. Analysis of chemical properties

According to previously established knowledge [30], Y2O3 has a certain solution ability for CaO, and the EDS mapping on Y2O3/CaO(12 wt%) ceramic cores was carried out, the result is shown in Figure 13.
4.3. Phase analysis

X-ray diffraction patterns of Y$_2$O$_3$ ceramic cores with different content CaO are shown in Figure 14(a). It is seen that the ceramic cores without CaO content shows only Y$_2$O$_3$ diffraction peaks (corresponding to JCPDS 41–1105). When CaO content was 4 wt%, there was no detection of CaO peaks in the XRD patterns. However, CaO peaks (corresponding to JCPDS 48–1467) were observed in the XRD patterns until the ceramic cores contained more than 8 wt%CaO content. With CaO content increasing from to 12 wt%, the intensity of CaO peaks was increased gradually. However, it is found that CaO peaks are always weak in the XRD patterns. In order to show clearly the occurrence of CaO peaks in Figure 14(a), the intensity ratio of CaO peaks to Y$_2$O$_3$ peaks with different CaO contents are shown in Table 3. As is known, Y$_2$O$_3$ has a certain solution ability for CaO and its products formed by sintering reaction. Additionally, the intensity was slight maybe also the RIR values of CaO(4.45) under half of RIR values of Y$_2$O$_3$(9.10) [30,38]. With the increase of CaO content, it can be seen that Y$_2$O$_3$ peaks was decreased gradually, combined with above two reasons, which is attributed to that the
addition of CaO can interfere with the expression of $Y_2O_3$ peak.

For $Y_2O_3$ ceramic cores with different SiO$_2$ contents when the CaO content was constant at 12 wt %, the XRD patterns are shown in Figure 14(b). It is significant that CaO peaks of the ceramic cores without SiO$_2$ can be observed, which is consistent with Figure 14(a). When SiO$_2$ content was 1 wt%, CaO peaks disappeared. With the SiO$_2$ content increasing from 2 wt% to 4 wt%, the peaks of SiO$_2$ and its products were also not shown and only $Y_2O_3$ peaks can be exhibited. It can be inferred that when SiO$_2$ is added, the reaction between CaO and SiO$_2$, leading to the disappearance of CaO peaks and SiO$_2$ peaks and its product peaks are hard to be detected because only small content is generated in the samples, and impurities in the raw materials, such as Al$_2$O$_3$ can also disturb the expression of peak when content of product is less than matrix (as shown in Table 1) [31]. Meanwhile, $Y_2O_3$ peaks increased slightly with the increase of SiO$_2$ content, and the variation trend is contrary to that from Figure 14(a). It is indicated that the expression negative effects of $Y_2O_3$ peaks has been weakened due to the decrease of CaO content when SiO$_2$ is added.

5. Conclusions

$Y_2O_3$ ceramic cores with the addition of CaO and SiO$_2$ were successfully prepared by traditionally dry-pressing assisted of pressureless sintering method. The effect of CaO and SiO$_2$ on the properties, including porosity, bulk density, shrinkage, flexural strength and leachability of $Y_2O_3$-based ceramic cores were investigated. The results showed that the introduction of CaO increased the leachability of $Y_2O_3$ ceramic cores while the flexural strength at 1500°C showed a decreasing trend. However, the addition of SiO$_2$ improved the flexural strength at 1500°C without impairing the leachability.

The ingredient to get the best comprehensive performance of $Y_2O_3$ ceramic cores derived from this study is the addition of 12 wt%CaO and 4 wt%SiO$_2$ possessed excellent comprehensive performance. The bulk-density, apparent porosity, linear shrinkage and flexural strength at 25°C and 1500°C were 3.1 g/cm$^3$, 33.57%, −0.6%, 17.47MPa and 21.06MPa, respectively.

$Y_2O_3$ ceramic cores can resist the impact of instantaneous extreme force during casting of superalloys, which is superior to the conventional ceramic cores of SiO$_2$ and Al$_2$O$_3$. That means the addition of both CaO and SiO$_2$ in the $Y_2O_3$ matrix is a promising methodology to produce high quality $Y_2O_3$ ceramic cores with the potential application in the production of hollow Ni-Si superalloy turbine blades.

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Disclosure Statement

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