

Fabrication and characterization of mini alumina ceramic turbine rotor using a tailored gelcasting process

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Abstract

A mini alumina ceramic turbine rotor has been successfully fabricated using a tailored colloidal process based on gelcasting technology. A specialized forming, drying and sintering approach was developed for the complex-shaped component with both large volume (90 mm in diameter and 20 mm in height) and submillimeter geometry (0.42 mm at the blade tip with curvature), to assure a highly dense product without warpage and cracks. The effects of solid content and temperature on the rheological behaviors of the prepared slurry were investigated to identify the best pourability. A novel approach using radius of curvature and overlapped area was adopted to compare the blade contour similarity under different sintering strategies and solid contents. In addition, the different physical and mechanical properties between main body and blade regions were discussed and their microstructures were analyzed. The preparation route for highly dense alumina rotor with minimum contour distortion was finally summarized.

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Keywords: C. Mechanical properties; Alumina turbine rotor; Gelcasting; Contour similarity; Microstructure

1. Introduction

Superalloys have been historically employed as the leading rotor materials since gas turbine was first introduced. Conventionally, the representative polycrystalline Ni, Co, Ni–Fe based alloys and directionally solidified single crystal alloys must possess excellent high temperature performances desired for turbine rotor applications [1–3]. However, the increasing demands on engine durability, energy savings and emission reductions in the aircraft engines drive the exploration of novel material candidates [3]. It is well-known that ceramics have prominent mechanical performances, excellent thermal and chemical resistance at elevated temperatures, which make them the promising materials for the gas turbine engine components working in the high temperature, corrosive, and mechanically demanding environments [1,4].

However, to form workable complex-shaped rotor is an open issue for many years. As a colloidal forming technique, gelcasting has attracted considerable attentions and exhibited many advantages over the conventional ceramic forming methods such as dry pressing, slip casting and injection molding [5,6]. Apart from the prominent capability to produce complex-shaped ceramics, principal advantages include the near-net-shape forming, better green performance, and low organic levels in the dried green ceramics. It dramatically decreases the binder removal cost and the product lead time [6,7]. Generally, there are two types of slurries in the gelcasting technique based on the solvent species, i.e. aqueous and non-aqueous slurries. The former is mainly adopted nowadays owing to its convenience and economy. Typical gelcasting process employs the in-situ polymerization reaction between the added monomers to transform the homogeneous ceramic slurry into the solidified green part. Preparing the high solid content suspensions with low viscosity plays a crucial part in the gelcasting process since this colloidal forming technique is only limited by the mold design. Moreover, the

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green components prepared by gelcasting have homogeneous microstructures like the suspensions, so that the structural homogeneity and the reliability of ceramics are improved. Further green machining can be carried out according to the specific applications since the green part has relatively high strength after drying [8–14]. In fact, gelcasting was originally developed to make geometrically complex ceramics, such as the turbine components in automotive and aeroengines [6,15,16]. Although a wealth of researches have been dedicated to optimize the constituents to enhance the solid content, develop an economic and environmental gelation system, and extend this colloidal forming to the metal domain [10–14,17–33], literatures covering the fabrication and characterizations of the ceramic turbine engine are fairly scarce up to date [34–36]. The present research involves significant efforts to investigate the entire process of fabricating alumina turbine rotor based on a tailored gelcasting approach. Critical issues and details involved in the rotor fabrication and the subsequent characterizations are systematically investigated and analyzed.

2. Experimental procedure

2.1. Materials and reagents

Commercially available alumina powders (MR70, 99.8%, Martinswerk, Germany) with the average particle size of $0.65\ \mu\text{m}$ were adopted as the raw material. The details concerning the size distribution and constituents of the alumina powders are shown in Table 1. In this gelation system, methacrylamide (MAM, $\text{C}_4\text{H}_7\text{NO}$, Sigma Aldrich, Singapore) and $\text{N,N}'$ -methylenebisacrylamide (MBAM, $\text{C}_7\text{H}_{10}\text{N}_2\text{O}_2$, Sigma Aldrich, Singapore), were used as the polymerization monomers. Poly (methacrylic acid) ammonium salt (PMAA, 30% solution in water) was chosen as the dispersant. Ammonium persulfate (APS, Sigma Aldrich, Singapore) and $\text{N,N,N}',\text{N}'$ -tetramethylethylenediamine (TEMED, Sigma Aldrich, Singapore), were used as the initiator and catalyst, respectively.

Table 1
Characteristics of the starting alumina powder.

Powder	BET (m^2/g)	d_{10} (μm)	d_{50} (μm)	d_{90} (μm)	α -phase (%)	Na_2O (%)	SiO_2 (%)	CaO (%)	MgO (%)	Fe_2O_3 (%)
Al_2O_3	8	0.25	0.65	2.25	≥ 95	0.1	0.08	0.02	0.06	0.02

All the materials and chemicals in this study were used without further purification unless otherwise specified.

2.2. Procedures

As shown in Fig. 1(a), the turbine rotor with the diameter of 90 mm and thickness of 20 mm used for the mini jet engine was originally designed as the metal-based (Ni-based superalloy) component, owing to its excellent performances at elevated temperature and harsh environment. Fig. 1(b) illustrates the separable aluminum mold for the gelcasting of alumina rotor, which was fabricated by CNC machine. The mold size was scaled up by a factor of 1.2 on the basis of the original rotor dimensions, considering the shrinkage caused by the sintering. As known, the mold surface is an important prerequisite for the surface quality of the final sintered turbine rotor, and in this case, this CNC-made mold has considerably low surface roughness of $0.38\ \mu\text{m}$, as shown in Fig. 1(c). Firstly, the monomers MAM, MBAM (4:1, by weight) and the dispersant PMAA (1.25 g/100 g alumina) [5,7] were mixed in the deionized water with the prescribed amount to form a homogeneous solution. Magnetic stirring was used to facilitate the dissolution of each ingredient. After stirring for 4 h, the alumina powder was mixed with the solution by manual stirring after adjusting the PH value to 9.5. This process was followed by the ball milling for 24 h to obtain the highly homogeneous alumina slurry. The degassing step was carried out in a vacuum oven until no further bubbles were observed. Then the slurry was heated up to $50\ ^\circ\text{C}$ after adding the initiator, 5% APS in DI water and the catalyst TEMED successively. Their amount should be controlled carefully to assure a complete gelation reaction and the adequate fluidity of the slurry for the mold casting. Since the complex geometry would add to the difficulty in complete gas removal, further degassing was needed after the mold casting. In this case, another 3-min degassing was necessary to eliminate the residual pores entrapped after the casting step. Then the

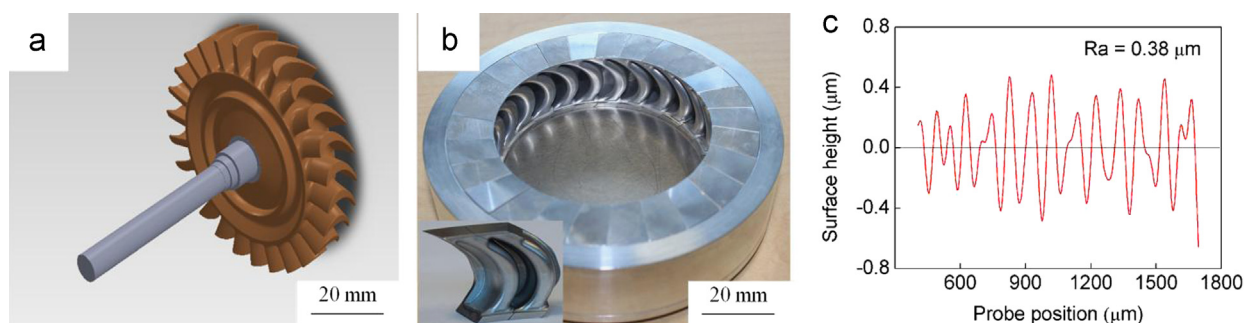


Fig. 1. (a) 3-D geometry of the original turbine rotor. (b) Separable aluminum mold of the rotor for gelcasting. (c) Surface roughness of the aluminum mold.

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