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Research on selective laser sintering of Kaolin–epoxy resin ceramic powders combined with cold isostatic pressing and sintering

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ABSTRACT

In order to fabricate traditional products with complex shapes consisting of Kaolin ceramic, selective laser sintering (SLS) combined with cold isostatic pressing (CIP) process was used to consolidate Kaolin powder with additive of epoxy resin E06. To begin preparing the material, epoxy resin (10 wt%) and Kaolin were combined through mechanical mixing, which provided a good fluidity for SLS. Investigations on the shrinkage and micro topography of Kaolin–epoxy resin SLS samples were conducted to optimize the laser sintering parameters. It was found that SLS samples represented acceptable shrinkage and high density when laser energy density was 0.3300–0.3763 J/mm^2. Then the SLS samples were processed by CIP to eliminate the pores in green ceramics. Finally, the optimized SLS/CIP Kaolin samples were debinded and sintered to produce crack-free Kaolin ceramics. The "Yellow Duck" Kaolin ceramic product was fabricated by combining SLS/CIP with colored glazing. The study shows a novel and promising approach to fabricate complex traditional ceramic products via SLS combined with CIP and sintering.

1. Introduction

Traditional ceramics are the predecessor of modern advanced ceramics, which mainly refer to pottery and porcelain. China is one of the earliest countries in the world that invented pottery. The history of making pottery could be dated back to nearly ten thousand years ago. It has been over two thousand years since porcelain was invented in Eastern Han Dynasty. It is not only the crystallization of science and technology, but also an achievement for arts and culture [1]. Kaolin is a kind of pottery clay, like raw materials of traditional ceramics, which is made into different utensils after forming, drying and sintering processes [2]. Traditional ceramic products are usually formed by rotary manual forming [3] and slip casting [4]. But their shape and structure are limited. Rotary manual forming is only suitable for symmetrical rotary billet and slip casting is restricted by the mold, so both of them have limitations in fabricating complex ceramic products [5]. In recent years, requirements for personalization of traditional ceramics are increasing rapidly. It is urgent for traditional ceramics manufacturers to innovate new forming methods [6].

As one of the additive manufacturing (AM) technologies, selective laser sintering (SLS) has been applied to fabricate net-shaped parts. The SLS working process can be indicated in Fig. 1. It can fabricate three-dimensional complex ceramic products with arbitrary shapes from CAD models without molds [7]. The primary advantage of the SLS process is the flexibility in the selection of ceramic material systems [8], compared to other AM techniques [9,10]. Therefore, SLS can be employed to fabricate traditional Kaolin ceramic products with complex structures.

The initial powder in SLS should have a good fluidity, requiring a particle size distribution on micron level [11]. On the other hand, it requires submicrometer-sized starting powder to produce dense ceramic parts via solid-state sintering [12]. To achieve high fluidity, fine ceramic powder could be prilled to produce spherical granules. In recent years, many scholars have researched SLS forming materials such as earth, stone and other related materials. Jain [13] showed that clay-reinforced polyamide fabricated by SLS was superior to polyamide in mechanical properties. Yan [14] prepared PA12/rectorite composite powders to improve the performance of the parts by modifying PA12 polymer. However, the base material of the above researches was organic polymers, while other substances were used only as small amounts of additives for the enhancement. As a result, it still could not provide a reference for SLS to form complex traditional ceramics. As reference, some researchers had attempted to form ceramic matrix green bodies by

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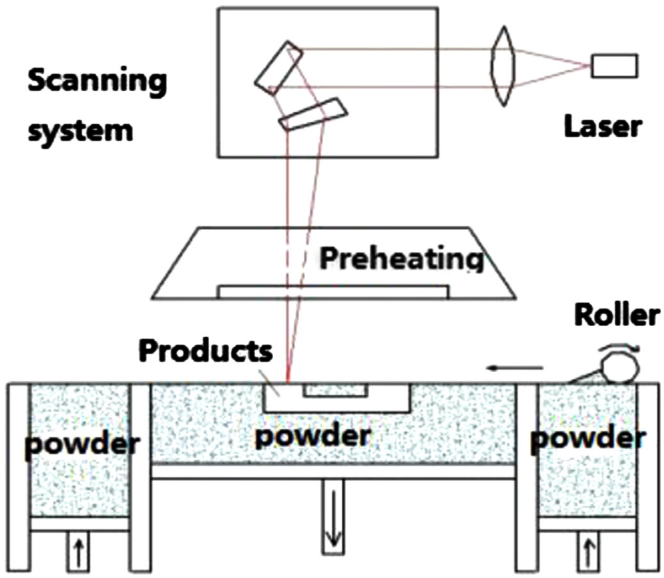

Fig. 1. Schematic of the SLS process.

indirect SLS on ceramic powder with mixing polymer binders. Shahzad et al. [15] prepared alumina-polyamide microspheres with an average diameter of 50 μm by means of phase inversion technique using dimethyl sulfoxide as solvent. The processes including SLS, debinding and sintering on ceramic-polymer microspheres for ceramics proved to be feasible and promising. However, the sintered relative density for above ceramic samples only reached 50%. These defects were due to lots of pores and polymer binders that existed in SLS parts, which had some bad effects on post processing.

Therefore, this paper aims at developing a new process combining SLS and cold isostatic pressing (CIP) [16] to fabricate personalized traditional Kaolin ceramic products with fewer pores. The compound technology is advantageous in forming complex green ceramics and the densification of ceramic powder. In order to simplify the preparation process of SLS powder, a mechanical mixing method was adopted to add epoxy resin E06 into Kaolin. Parameters of each step in SLS/CIP/Sintering process were investigated to improve the final performance of the products. Fig. 2 shows the fabrication process of Kaolin ceramics using SLS, CIP, debinding (glazing) and sintering. It might provide a new and reliable method for fabricating traditional ceramic products. The composition of Kaolin powder is shown in Table 1.

2. Experimental procedure

2.1. Powder preparation

The ceramic material in this experiment is Kaolin powder which is one of the traditional ceramic materials provided by Hunan New Century Ceramic Co., Ltd. The main composition of Kaolin powder is as the follows:

The micro topography of the powder was analyzed by SEM. The spherical particles in Fig. 3(a) are Kaolin particles after granulation. Fig. 3(b) and (c) show the particle size distribution for the Kaolin powder and the epoxy resin E06 powder. The size of most Kaolin powder particle is 100–120 μm and the size of more than 30 vol% of the epoxy resin powder size is 20–28 μm. The Kaolin spherical particles were mixed uniformly with epoxy resin E06 powder in a 3D blending machine for 24 h and the mass ratio was 9:1. The powder has good fluidity, and it is very suitable for SLS. This

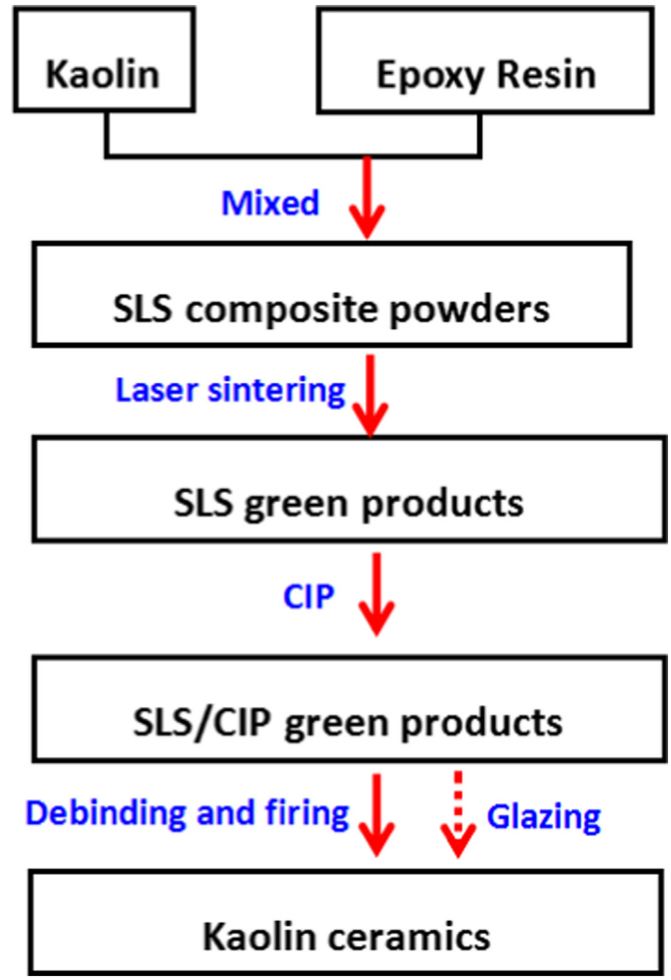

Fig. 2. Fabrication process of Kaolin ceramics using SLS, CIP, debinding (glazing) and sintering.

Table 1
Mass ratio of each composition of Kaolin powder.

Composition	SiO_2	Al_2O_3	H_2O	Others
Content (wt%)	60	35	2	3

method is convenient and suitable for the application and development of forming traditional ceramic products by SLS in future.

2.2. SLS/CIP forming

In order to obtain complex personalized traditional ceramics with high density and high precision, it is necessary for Kaolin–epoxy resin composite powder to be researched systematically in SLS, CIP and sintering processes. On the basis of what has been mentioned above, painted pottery products can be painted glaze on the SLS/CIP bodies of Kaolin before sintering.

In SLS, the laser energy density was the core factor affecting the forming quality. The design of the 8 groups of different laser energy densities is presented in Table 2. The scan spacing of these 8 groups was 0.13 mm and the preheating temperature was 55 °C. From the aspect of forming quality, it was regarded that SLS forming can be completed when the laser energy densities are between 0.2750 and 0.4125 J/mm^2. When the laser energy density was too low, for example e=0.2450 J/mm^2, the body did not change when laser was scanning. The energy of the laser could not even melt epoxy resin, so it could not bond Kaolin particles. When