



Design and Selective Laser Sintering of complex porous polyamide mould for pressure slip casting

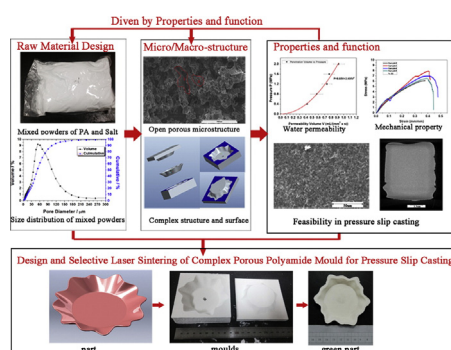
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HIGHLIGHTS

- Selective Laser Sintering was used to make the porous mould for pressure slip casting.
- Rapid fabrication of porous mould with complex structure has been achieved.
- Porous material with controllable microstructure was prepared by raw material design.

GRAPHICAL ABSTRACT



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ABSTRACT

A novel method to prepare porous resin mould for pressure slip casting was proposed by using Selective Laser Sintering (SLS), which is one of Additive Manufacturing (AM) processes. The mixture of polyamide and salt (NaCl) were designed as raw materials, in which polyamide acted as matrix material and NaCl as pore-foaming agent. To investigate the feasibility of the pressure slip casting with the mould, the compressive strength and porosity of the porous specimens were measured. Experiments showed a compressive strength of 7.19 MPa and an elastic modulus of 32.26 MPa were reached. Meanwhile, the porosity of the specimens was 59.75%, and the aperture concentrated in 25–75 μm . The water permeability was verified and the maximum permeability reached to 0.921 $\text{mL}/(\text{mm}^2 \cdot \text{s})$. Pressure slip casting with porcelain slurry was performed using SLS porous specimens as the mould. Results showed the moisture content of the green body was about 23% and the relative density was 68.4%–74.1%. At last, a green body of whiteware with complex surface was prepared by the proposed method to demonstrate the feasibility of pressure slip casting with this mould. This method could be used in porcelain industry to realize rapid development of new products and customized production with further improvements.

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1. Introduction

In the last couple of years, significant progress has been made in the development and application of Additive Manufacturing (AM), which offered advantages of design freedom of structure and a wide choice of materials compared with conventional manufacturing methods [1–3]. Now, AM processes are increasingly used to build engineering

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components with complex geometrical shape, bone scaffolds, complex lattice structures with unique engineering characteristics, functionally graded material with tailored mechanical properties and so on [4–8]. Selective Laser Sintering (SLS) is a powder based layer-wise Additive Manufacturing process. In this process, the part is directly built up from CAD data by selectively sintering powders materials layer by layer as shown in Fig. 1. SLS has shown a number of advantages over other AM techniques. The advantage most cited is that many kinds of materials can be processed with good mechanical properties [9–10]. Among a variety of polymer materials, the research on nylon was carried out by most researchers due to its high mechanical properties with a tensile strength of 52 MPa and an elasticity modulus of 2158 MPa [11–12]. Meanwhile, some researchers also studied on the production of graded porous polyamide via SLS [13–14]. The parts formed by SLS can be used as structural components and moulds.

The development of SLS provides new possibilities to integrate materials design, structure design, and functional design, finally achieve a new strategy of design and fabrication, which is driven by the objective functions. For instance, in the field of bio-fabrication many researchers prepared porous materials by SLS used as scaffold for the human body implants [15], in which the porous structure also provided functional channels for the transportation of nutritive material for the living cells. In conventional ceramic industry, porous materials have also been used as mould for pressure slip casting by absorbing the water in ceramic slurry to form a green body of ceramic product [16]. To achieve the function of water absorption, the porous mould should have high water permeability with an open porous microstructure, a smooth surface favorable for demoulding, high mechanical strength to resist the mould clamping force and casting pressure, good durability and so on. Now, the porous mould is generally made from thermosetting resin by emulsion polymerization firstly, and then NC machining to get the mould cavity. And the most widely used materials are polymethyl methacrylate and epoxy compound [17–19]. It usually took a few weeks, even months to prepare a mould by this way, and was also expensive, especially for the moulds with complex structure and surface features.

To reduce the expense and preparing period of the moulds, SLS have been attempted to prepare porous mould for pressure slip casting. In 1999, Rolf Pfeifer [20] tried to prepare porous Polystyrene by SLS for pressure slip casting by optimizing the building parameters of the SLS to get a component with porous microstructure. The prepared porous materials have an open porosity of about 11% with an average pore diameter of 27 μm , and about 2/3 of the pores are closed due to the uncontrollable pore forming process. Poor water permeability and mechanical strength caused the impracticability of the mould and there are no more research activities after the first trial. Additionally, Prof. Michael J. Cima [21] in MIT exploited the 3DP process for the fabrication of the porous alumina mould for pressure slip casting. However, as a rigid material, the impact force in the process of clamping is apt to cause the destruction of the mould, and finally produced no effective applications.

In the present research, resin mould with controllable porosity and mechanical properties was prepared by SLS process by using a mixed

powder as raw material, in which polyamide acted as matrix material for its good mechanical properties and NaCl acted as pore-foaming agent. To investigate the process feasibility of pressure slip casting with porous resin mould, compressive strength, porosity and permeability of porous resin were measured. And pressure slip casting with porcelain slurry was also performed to study the influences of casting pressure and time on the green body. Then a whiteware with complex surface was produced by pressure slip casting with a prepared porous polyamide mould to demonstrate the process feasibility.

2. Experimental outlines

2.1. Raw material preparation and porous mould fabrication

Polyamide used in the experiment was Nylon12 with an average particle size of 60 μm , supplied by RAPLAS International Ltd. The NaCl was supplied by Tianjin TIANLI Chemical Reagents Ltd. with the particle size between 100–200 μm and crushed to a particle size less than 75 μm by airflow pulverization. These two kinds of powder were mixed by V-mixer (V-20L) for 2 h as the raw materials for SLS process. The volume ratio of polyamide to NaCl was 60:40 in order to get sufficient porosity on the premise of enough strength.

The SLS machine used in the fabrication of porous mould was type SLS 300, developed by Shanxi HengTong Intelligent machines Ltd., China. On the basis of the previous process experiments, the sintering parameters were as follows: XY double scan mode, powder bed temperature of 160 $^{\circ}\text{C}$, scanning speed of 4000 mm/s, scanning interval of 0.12 mm, laser power of 10 W, layer thickness of 0.2 mm. The sintered sample was submerged in water and cleaned in an ultrasonic cleaning machine in room temperature until the mass loss was about 50% when all the NaCl was dissolved in water. Then the samples were moved to a drying oven and dried at 50 $^{\circ}\text{C}$ for 24 h.

2.2. Characterization of the porous mould

The compressive mechanical strength was tested by compression testing machine (PLD-5 kN). Five specimens (10 mm $\times$ 10 mm $\times$ 30 mm) as a group (as shown in Fig. 2) were tested at room temperature under a constant compression speed 1 mm/min.

Scanning Electron Microscopy (SEM, S-3000N, Hitachi) was used to investigate the porous morphology of cross sections in the brittle fractured sample after dipping in liquid nitrogen. The sections parallel to the slicing direction and vertical to the slicing direction were both observed by SEM. The porosity and the pore size distribution of the test samples were measured by mercury intrusion porosimeter (Poremaster60, QuantachromInns) and three samples was prepared as a group with a size of 10 mm $\times$ 10 mm $\times$ 10 mm for mercury intrusion test.

The water permeability of the samples was measured by a custom-made cylindrical permeability device with a diameter of 18 mm and a depth of 20 mm as shown in Fig. 3. After the porous sample with section dimension of 30 mm $\times$ 30 mm was fixed at right position, the water was pumped into the vertically positioned mould by pressurized nitrogen. The volume of water permeated per unit area and time was recorded. The effect of pressure on the permeability of materials was studied. The permeability of the samples with different thickness was also measured to determine the optimal mould thickness.

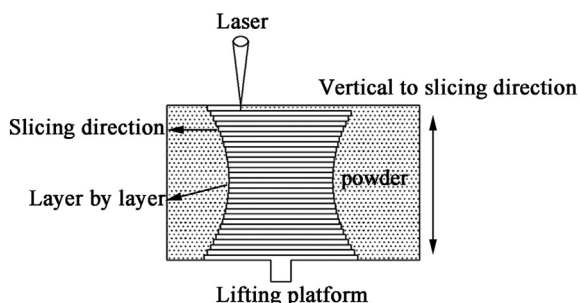


Fig. 1. Schematic overview of SLS process.



Fig. 2. The sample used for compressive test.

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