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Optimization and evaluation of metal injection molding by using X-ray tomography

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ABSTRACT

6061 aluminum alloy and 316L stainless steel green bodies were obtained by using different injection parameters (injection pressure, speed and temperature). After injection process, the green bodies were scanned by X-ray tomography. The projection and reconstruction images show the different kinds of defects obtained by the improper injection parameters. Then, 3D rendering of the Al alloy green bodies was used to demonstrate the spatial morphology characteristics of the serious defects. Based on the scanned and calculated results, it is convenient to obtain the proper injection parameters for the Al alloy. Then, reasons of the defect formation were discussed. During mold filling, the serious defects mainly formed in the case of low injection temperature and high injection speed. According to the gray value distribution of projection image, a threshold gray value was obtained to evaluate whether the quality of green body can meet the desired standard. The proper injection parameters of 316L stainless steel can be obtained efficiently by using the method of analyzing the Al alloy injection.

1. Introduction

Powder injection molding (PIM) is a relatively new near-net-shape materials processing technology which is useful to produce small and intricate products in large quantities [1,2]. This technology includes four steps consisting of feedstock mixing, mold filling, binder removal and sintering. Quality of mold filling is influenced by many parameters such as injection pressure, speed and temperature. Improper injection parameters lead to the formation of defects in green body [3]. Influences of the defects cannot be eliminated and on the contrary certainly amplified in the subsequent debinding and sintering process [4]. In the past, sample inspection was used. The checked samples were cut or broken into many parts to detect the existence of defects. Another method is to test the properties of the final sintered samples [5,6]. The results tested by the two methods cannot feed back to the injection parameters quickly and directly. Therefore, these methods are both time consuming and economic waste.

For the conventional observation techniques (scanning electron microscope and optical microscope), sample preparations, such as cutting and polishing, are required. Many artificial defects altering the original structure of the sample may emerge [7]. For the preparation of injected green body, powder particles may be pulled out and binder may smear onto the surface easily. Therefore the conventional observation techniques are not appropriate to perform the detection and analysis of defects in the green body. Nowadays, X-ray tomography has been applied to many fields of materials science and it can nondestructively characterize the inner structure of materials at high resolution [8–12]. In the research field of injection process, Weber and Heldele analyzed the powder particle size and content distribution in the green body [13,14], and Fang verified the simulation results by using the X-ray tomography scanned data [15]. In this study, the green bodies were firstly scanned by X-ray tomography. Then, the detailed analysis of defect formation was performed. Based on the analyzed results of Al alloy injection, the proper injection parameters for the stainless steel can be obtained easily and it can verify the practicability of the tested method proposed by this paper. For the rapid X-ray tomography detection, the gray value distributions of green bodies were used to evaluate the quality of the injection process and extract the defects from the projection images.

2. Experiment

2.1. Sample preparation

The feedstock for this experiment was prepared by mixing 6061 Al alloy powder/316L stainless steel powder (producer: Beijing Gaoye Science and Technology Co. Ltd, commercial number: GB/T 9258.3-2000) and paraffin wax + polyethylene + stearic acid binder system (the mass ratio is 70:29:1). The granularities of Al alloy and stainless steel powder particle are both 500 mesh. The characteristics of binder components are shown in Table 1. The solid loading used in this study was 65 vol.% (Al alloy) and 60 vol.% (stainless steel). The binder components were first put in the NH-1 mixer and allowed to melt completely.

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Table 1
Characteristics of the binder components.

Binder components	Density (g/cm3)	Melting point (°C)	Producer	Commercial number
Paraffin wax	0.912	70	SINOPEC Beijing Yanshan branch	GB254
Polyethylene	0.903	169	SINOPEC Beijing Yanshan branch	Q/SHYS.02.007-2000
Stearic acid	0.962	72	Beijing Dongfang Petrochemical Co., Ltd	Q/HB 3410-2003

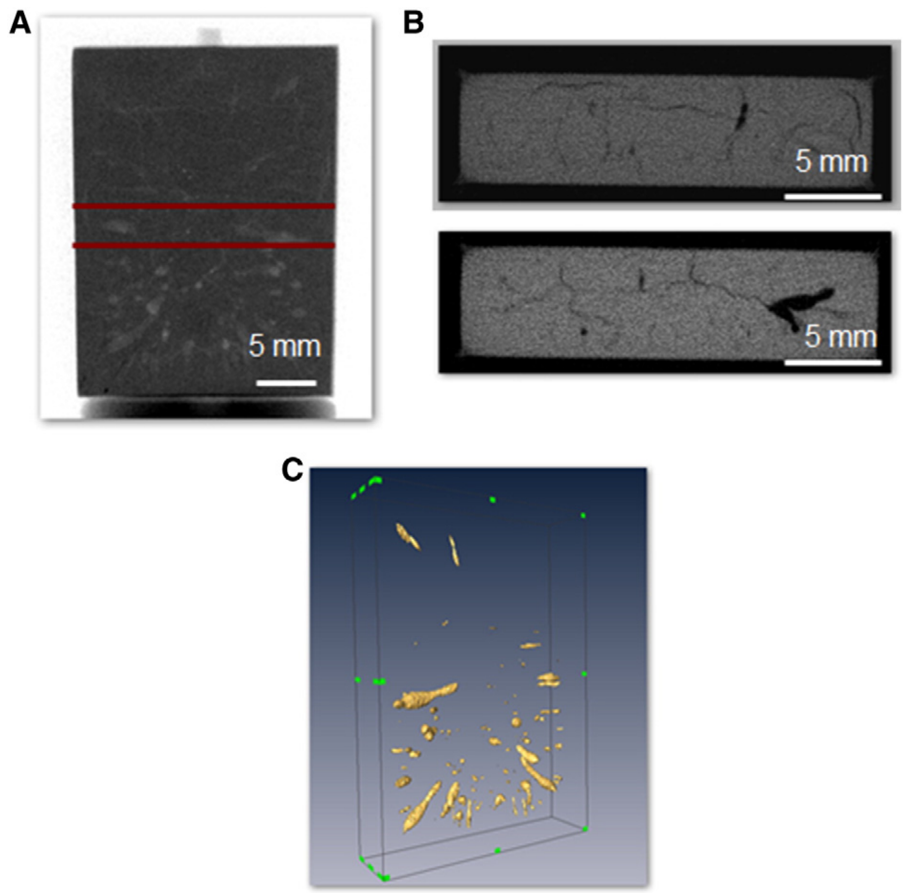

Fig. 1. A, Projection image of A100-50-165 green body. B, Reconstruction images of the corresponding slices. C, 3D vision of the big pores in A100-50-145 green body.

Then the metal powders were added to achieve the desired powder-loading and mixed at a rotation rate of 80 r/min at 160 °C for 120 min. After mixing, the material was extruded into granules. Then, the feed-stock was injected into a cuboid cavity with different initial injection pressures, speeds and temperatures. The size of the cuboid mold is demonstrated in reference [16]. The obtained green bodies were denoted as the corresponding injection parameters. For example, A/S100-50-165 green body means that the Al alloy/stainless steel green body was obtained by using an injection pressure of 100 MPa, a speed of 50 cm^3/s and a temperature of 165 °C. For each experimental condition, 8 samples were obtained to perform the X-ray tomographic scan. Images of a green body among the 8 samples were used to show their main common characteristics, and each data represents the average tested value of the corresponding 8 samples.

2.2. X-ray tomography scan

After the injection process, the green bodies were scanned by X-ray tomography with a voltage of 130 kV and an electric current of 200 μA. During scanning, the samples were rotated through 360° with angular increments of 0.9°, and a scan image was taken at each position. After scanning, the CT datasets were used to produce a series of original reconstructed slice images by means of back projection algorithm. Then, a Median filter was used to perform the noise removal operation.

3. Results and discussion

3.1. Defects detection and process parameter optimization for Al alloy injection

Fig. 1A shows the filtered projection image of A100-50-145 green body. It can be seen that many defects emerged in the edge and central

Table 2
Average volume and amount of the big pores (volume is larger than 10,000 pixels) in the green bodies.

Green body	Amount of pores (volume > 10,000 pixels)	Average volume of pores (volume > 10,000 pixels) (pixels)
100-50-145	14	24,821
120-50-145	11	23,983
100-70-145	9	22,995
100-50-155	7	18,832
100-80-175	6	15,537