Modelling Powder-binder Segregation in Powder Injection Moulding

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1.Introduction

Powder Injection Moulding (PIM) is a manufacturing process that allows low cost production of complex and net-shape parts in a variety of metal and ceramic material. It is a shape forming technology that combines the design flexibility and productivity of plastic injection moulding and excellent material properties of metal or ceramic. The use of PIM method in manufacturing of ceramic components is known as Ceramic Injection Moulding (CIM).

There are mainly four stages involved in CIM process. In the first stage of CIM, ceramic powders are compounded at elevated temperatures with a binder system and sintering aids into granulates or pelletized shapes which is known as feedstock. The binder system provides plasticity, viscous flow, to the feedstock to aid the forming process. Conventional plastic injection moulding machine is used for the shape forming process to inject ceramic green parts. Next, the binder system is removed from the green parts through solvent and thermal debinding process resulting in brown parts. Lastly, the brown parts are sintered to achieve desired density, dimensions, mechanical properties and microstructures.

2.Motivation

The segregation between powder and binder is a common occurrence during PIM which leads to the inhomogeneity in the green bodies. David *(2005)* states that defects from imperfect injection moulding process are not repairable in the latter process of debinding and sintering therefore it is important to have good injection moulding parameters to minimize defects and inhomogeneity within the body. Fang, et al *(2014)* states the evolution of powder–binder separation during injection moulding is difficult to be observed using experimental method, especially, in the early stages of moulding. Numerical models can be developed to provide understanding to the evolution of filling material during injection moulding process, Fang, et al *(2014)*. The schematic diagram of the injection moulding system is as shown in Figure 1.

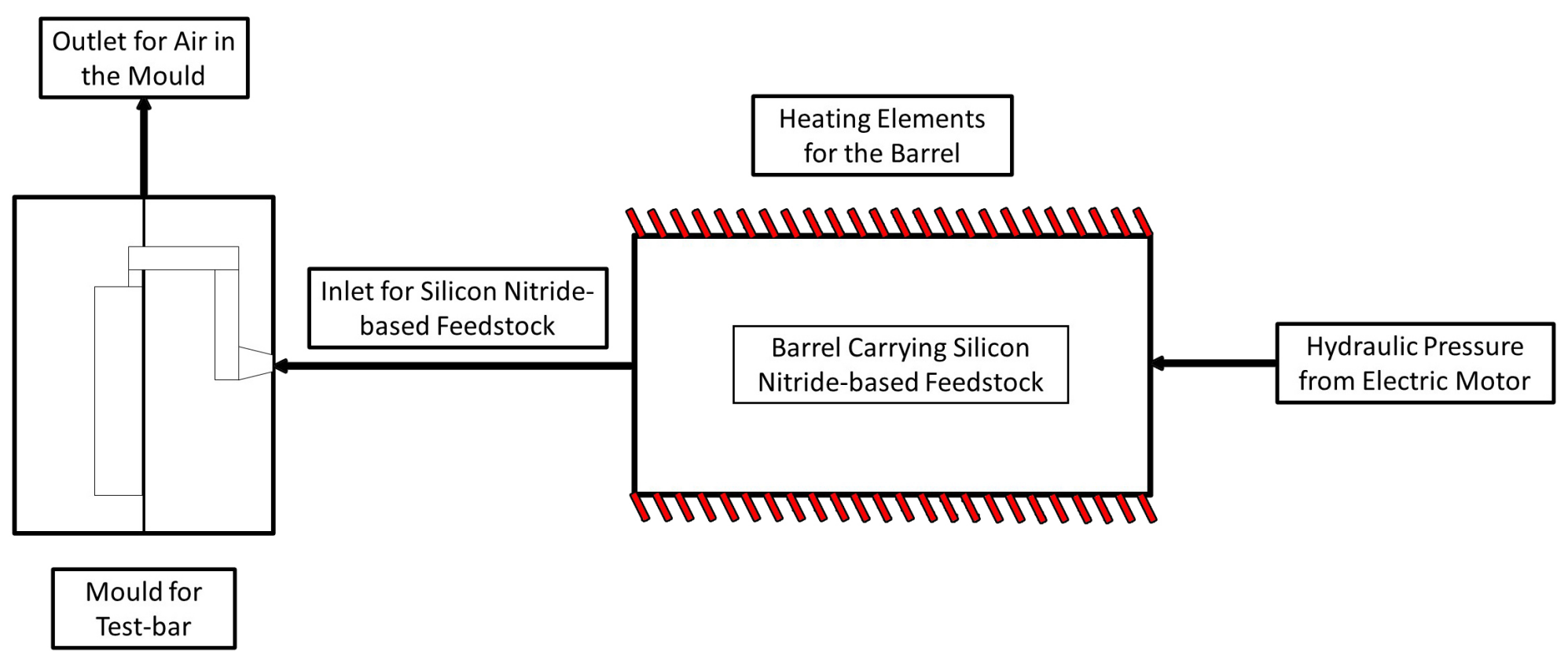

Figure 1: Schematic diagram of injection moulding system

3.Methodologies

A multiphase flow numerical model has been developed in ANSYS CFX using a Eulerian approach to simulate the segregation during mould filling of silicon nitride-based feedstock. The numerical model considers a two-phase free surface inhomogeneous model. The two phase are air and silicon nitride-based feedstock with free surface model to separate the two phases. The inhomogeneous relationship between the silicon nitride-based feedstock and air would define that each phase has its own flow field. Variable composition mixture model is used to represent the silicon nitride-based feedstock allowing the compoments in the mixture, silicon nitride powder and binder system to have its own density and volume fraction. The schematic diagram of the numerical model is as shown in Figure 2.

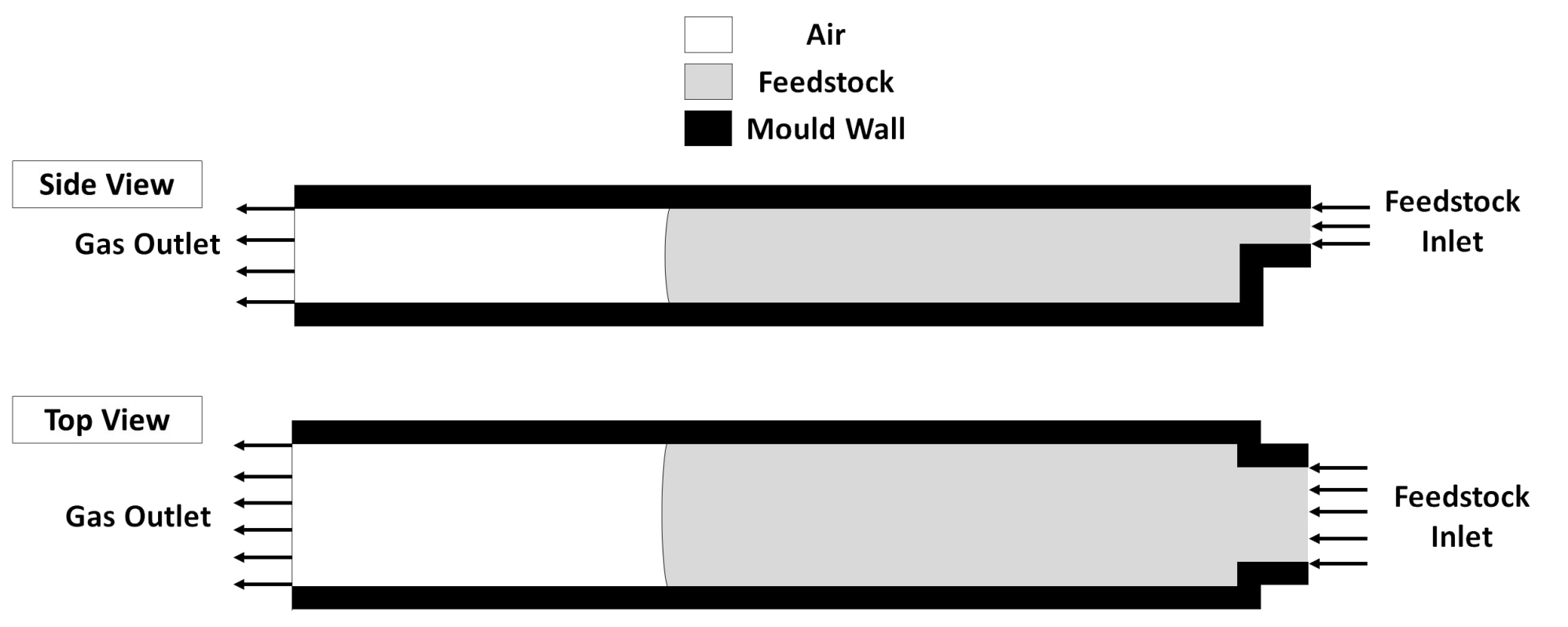

Figure 2: Schematic diagram of the numerical model

4.Experimental Procedure

The viscosity model used to represent the silicon nitride-based feedstock is based on the Power-Law model, Equation 1. The Power-Law model was used to curve fitted with the experimental data to achieve the K and n coefficients. The viscosity of prepared feedstock was measured in the Yasuda capillary rheometer within a range of shear rate from 116.7 to 5,836.8 s−1 at 423K, 433K, 443K, 453K and 463 K, respectively. The R-square for each fitted curve in temperatures ranging from 423K to 463K are 0.9988, 0.9972, 0.9961, 0.996 and 0.9958 respectively. The fitted curves and experimental data are shown in comparison in Figure 3. The comparison shows that the fitted curves are in good agreement with the experimental data.

$$\eta_f = K\dot{\gamma}^{n-1} \qquad (1)$$

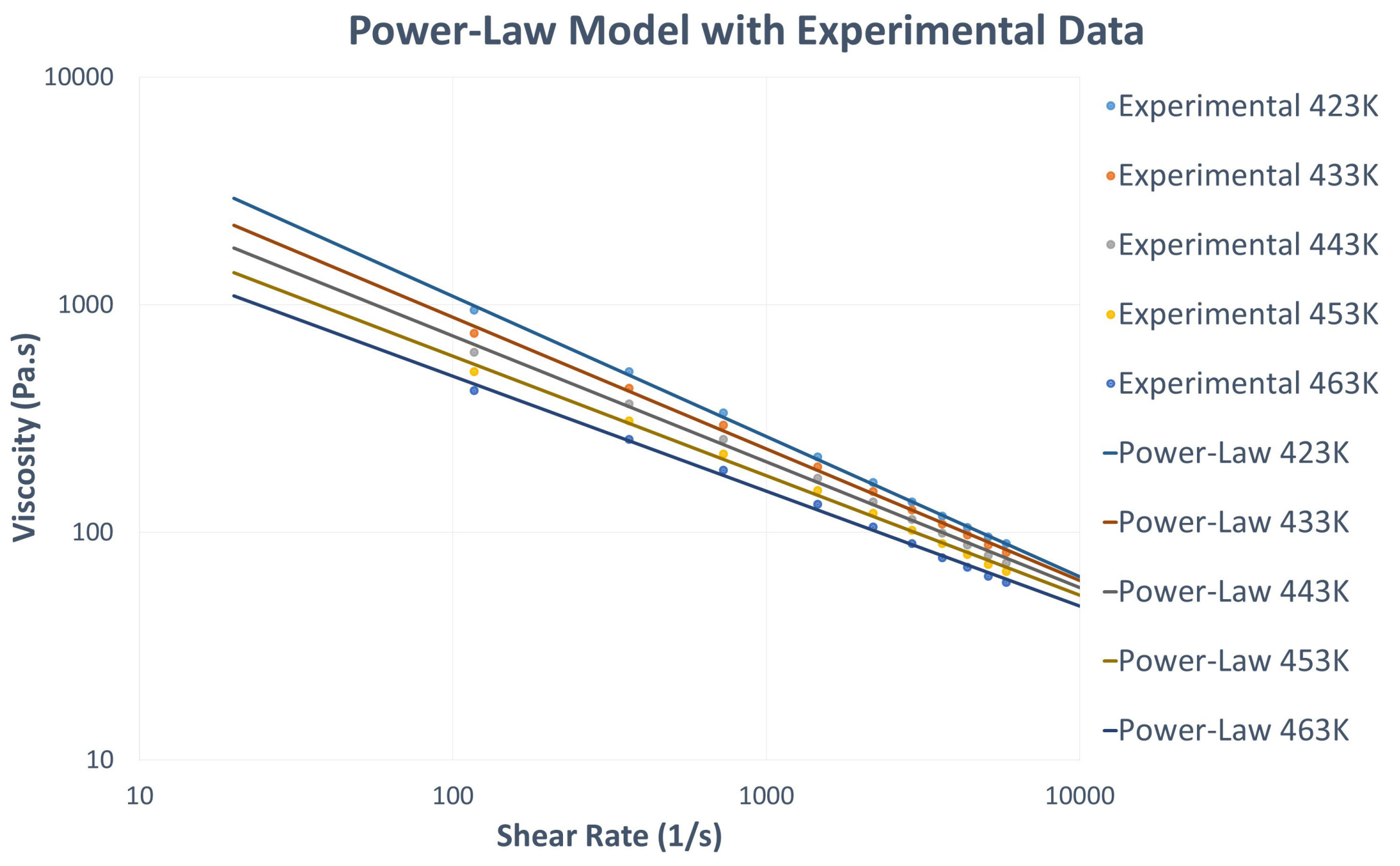

Figure 3: Comparison between Power-Law model and experimental data

The theoretical density of the feedstock can be predicted based on the composition of the feedstock, density and volume fractions of each component. The density of the feedstock was measured using the AccuPyc II 1340 Gas Pycnometer with mean density determined out of five measurements. The measured mean density (1.9576 g/cm3) is compared with theoretical density (1.9645 g/cm3), as shown in Table 2. The difference between theoretical density and measured density approximately 0.35%.

5.Numerical Simulation

The geometric shape, dimensions and boundary conditions of the numerical model are shown in Figure 4(a). The imposed boundary conditions are mass flow rate of 30.89 g/s at the inlet with 453K material temperature. The outlet and mould pressure is set to 1 atm and air ideal gas is used. At the wall boundary, mould temperature was represented by assigning 373K to the wall temperature. The numerical model was meshed with tetrahedron elements and map meshing consisting 4534 nodes and 20572 elements with maximum element size of 1mm and minimum element size of 0.2mm as shown in Figure 4(b). A transient simulation was carried out for a total time of 0.2s with adaptive time steps ranging from 0.0005s to 0.00005s.

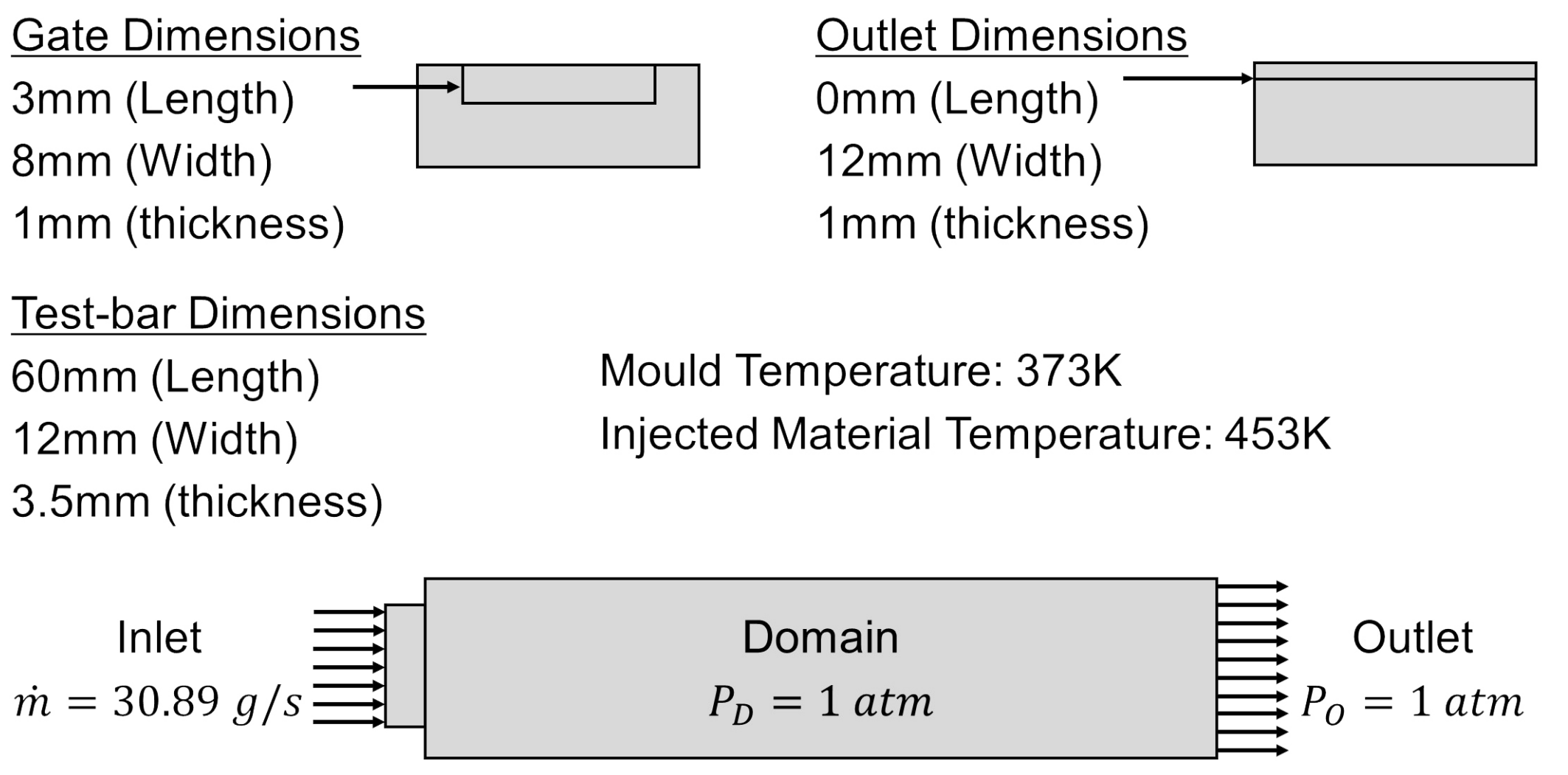

Figure 4: (a) Boundary conditions of the numerical model

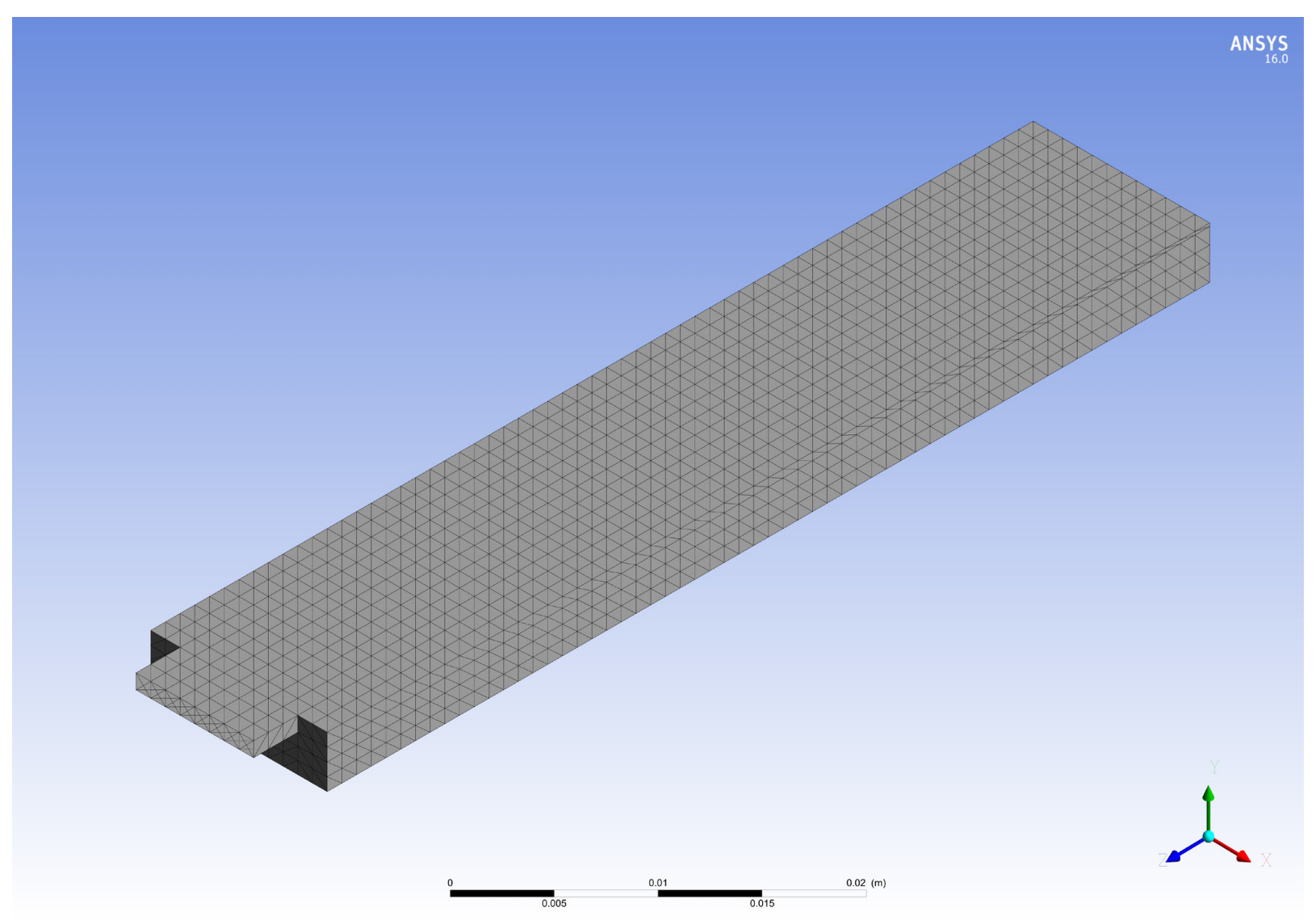

Figure 4: (b) Numerical model mesh and

6.Results

A "short shots" technique is used to depict the sequence of mould filling. The technique involves interrupting the injection moulding process before the cavity is filled. It is compared with the filling sequence from the numerical modelling of the mould filling process with each time interval. Thin streams of mixture are known as "jets" can be seen at the early stage of mould filling, they would pile up to fill the mould. These "jets" can cause knit lines to form where the injected material are unable to fuse together properly during the mould filling process and they cause the region of the part to be weak *(David, 2005)*.The comparison shows that the mould filling patterns between the "short shots"technique match adequately with the numerical model as shown in Figure 5.

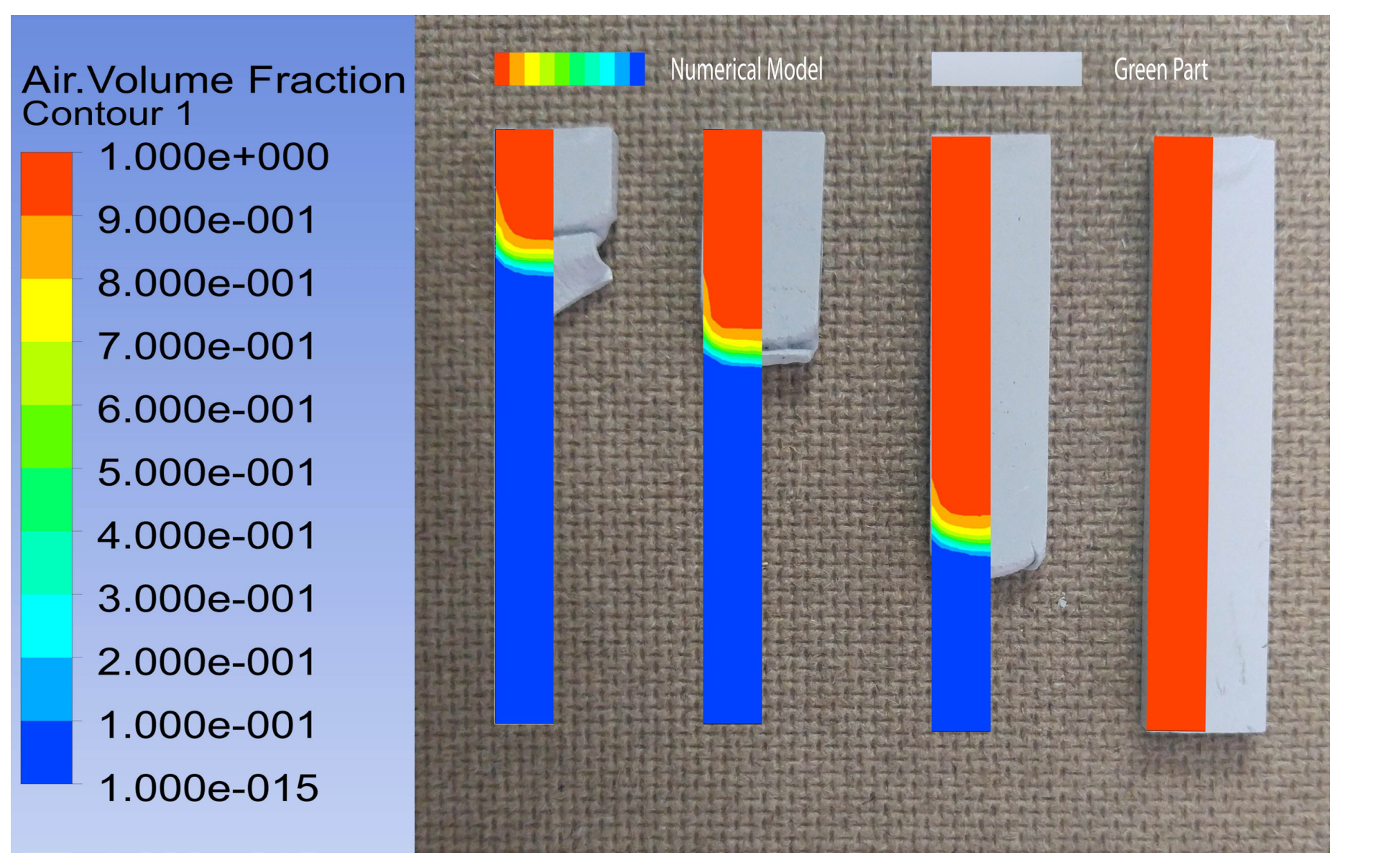

Figure 5: Sequence of "short shots" compared to numerical model

At t=0.175s, the mould is fully filled with silicon nitride-based feedstock. A density contour with 11 contours ranging from 1.940 g/cm3 to 1.964 g/cm3 was used to visualise the density distribution within the green part and it can be seen in Figure 6. The result shows lower densities in the region at the rear of the green part.

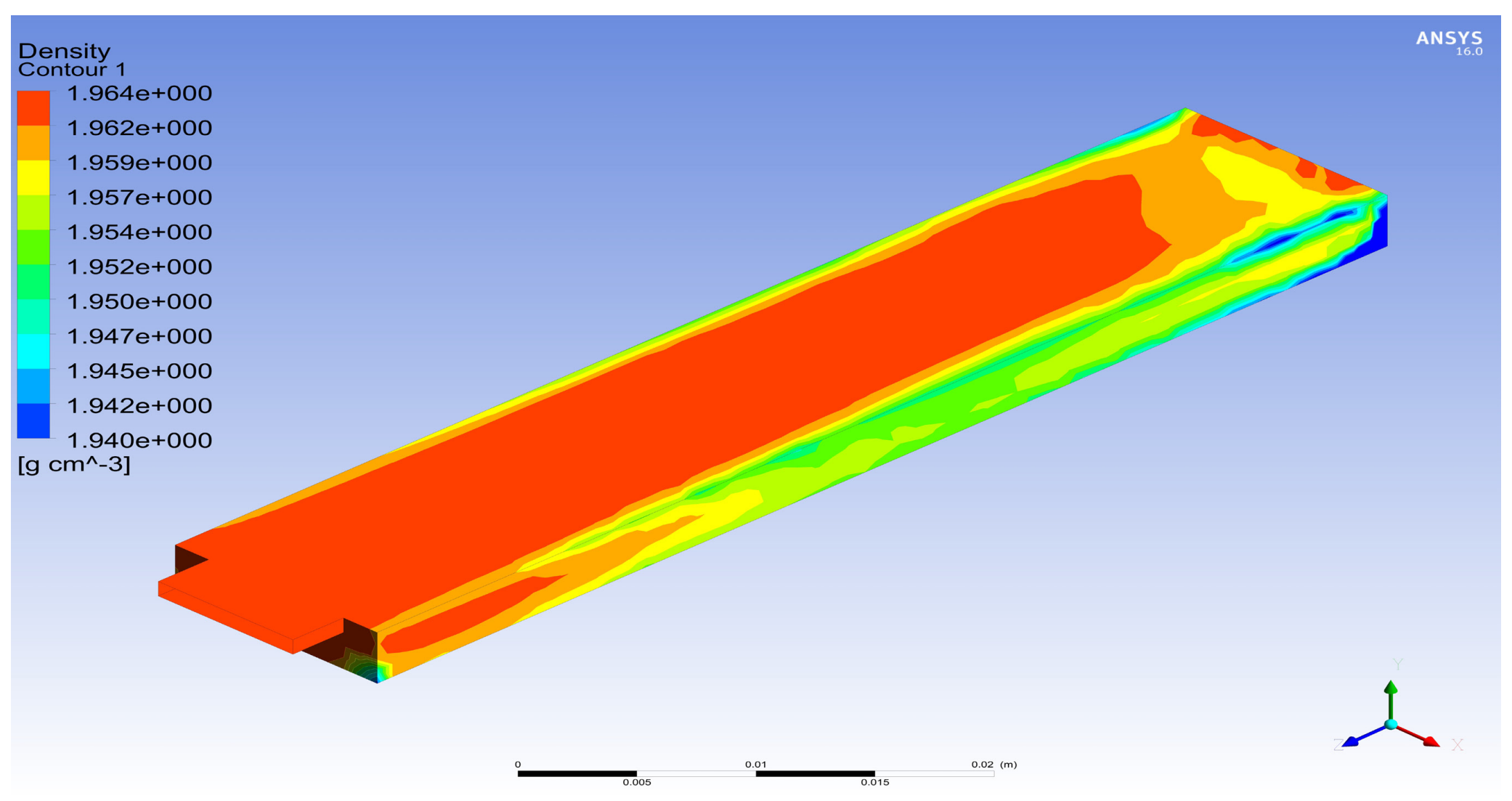

Figure 6: Density distribution of the green part at t=0.175s

An experimental method was used to study the powder distribution within the green part by measuring the density in each section. Densities were measured using the Archimedes' Principle with the AD-1653 Density Determination Kit. Sample are divided into 10 sections and the experimental results can be seen in Figure 7(a). The results of the density distribution within the green part from the numerical model at t=0.175s is as shown in Figure 7(b).

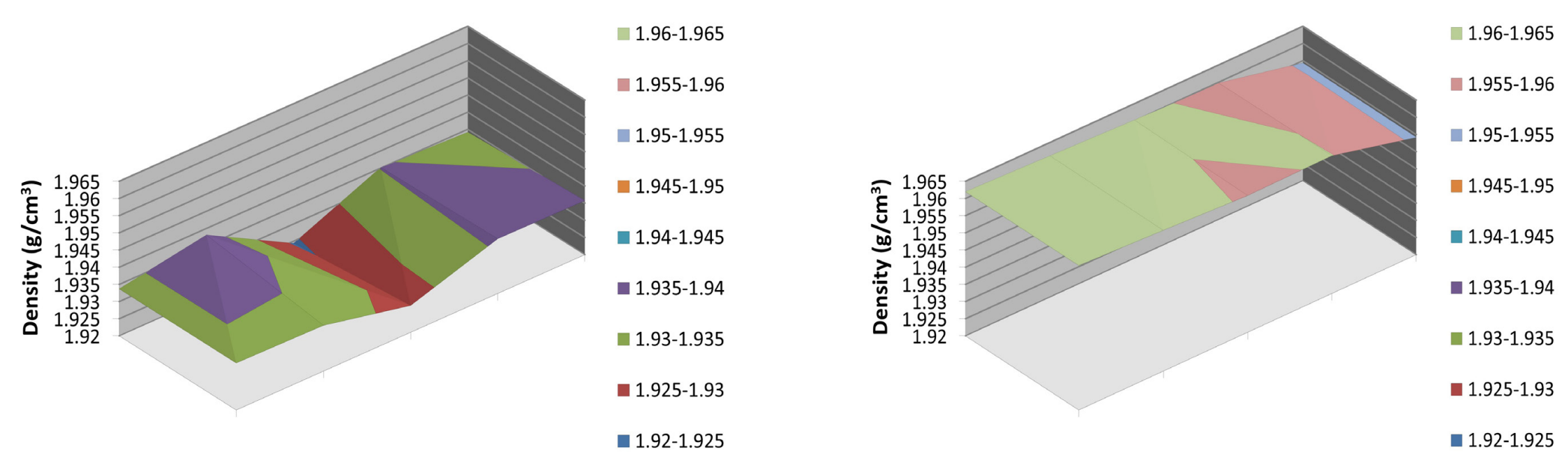

Figure 7: (a) Density distribution from experimental results and (b) Density distribution from numerical results

7.Conclusion

Mould filling patterns in the numerical simulation matches adequately with the real process. Numerical results show density are well distributed from the front to the midsection and dropping slightly in the rear. Whereas, measured densities show the drop in the midsection. Overall numerical results show higher densities than the measured densities of the green part.

Reference

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