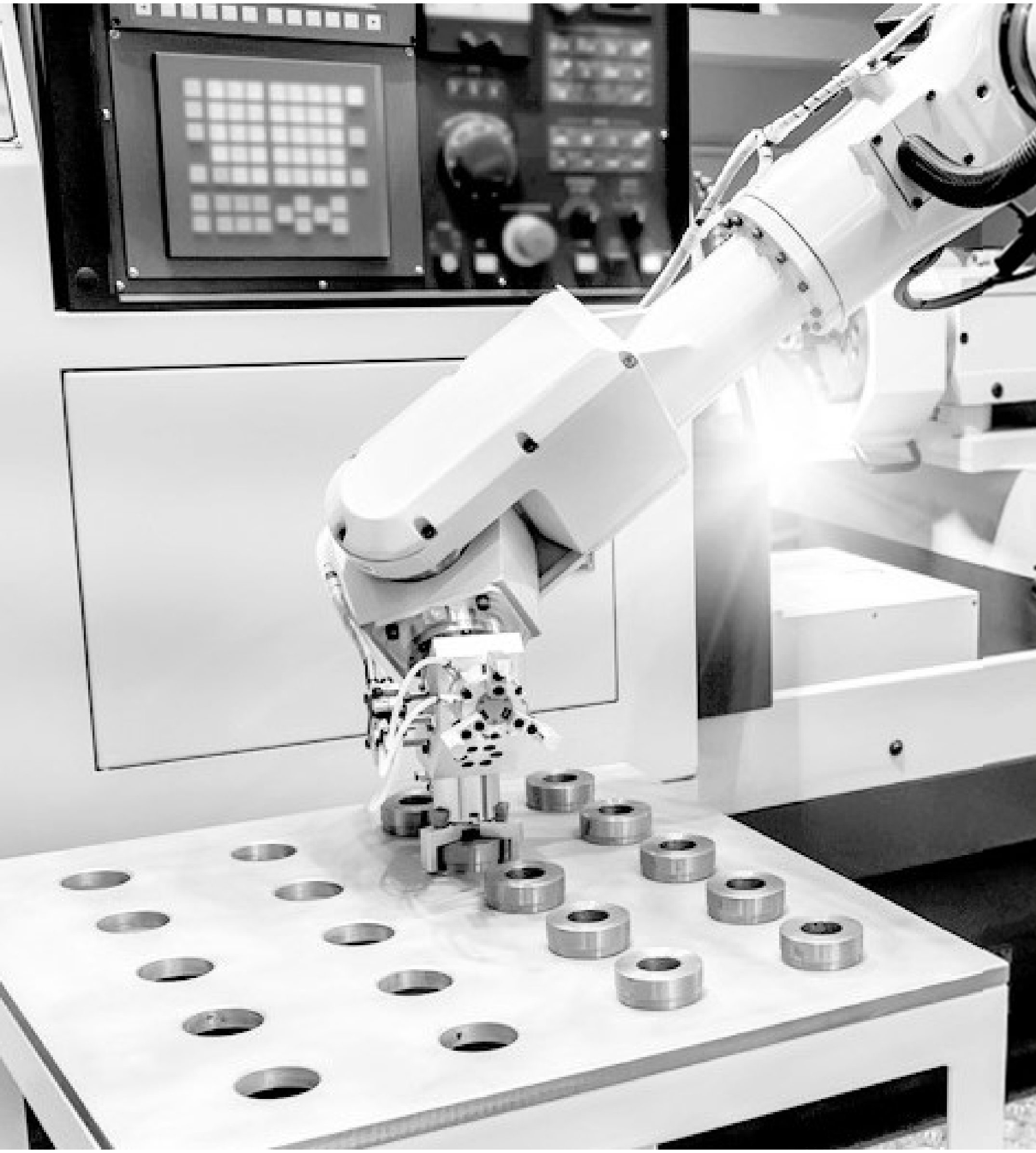

Singapore Institute of Manufacturing Technology

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BINDER JETTING PRINTING OF 316L FINE POROUS CUP MEMBRANES

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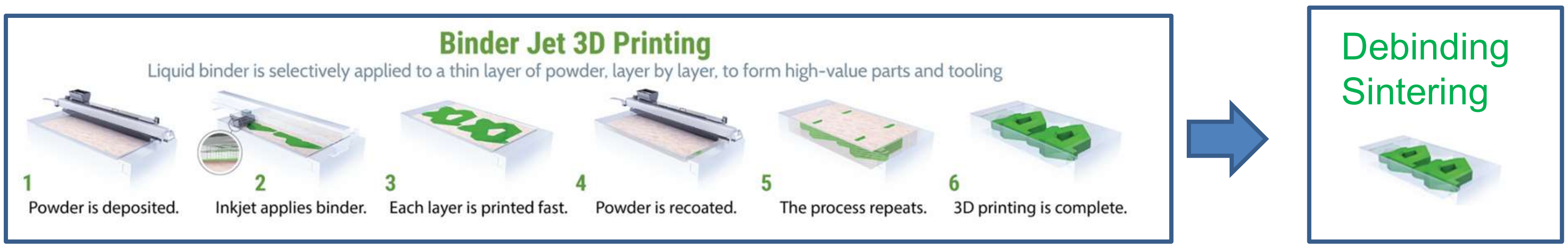
Introduction

- Porous SS316L components are used in filtration, gas venting for molding, lightweight structures, etc..

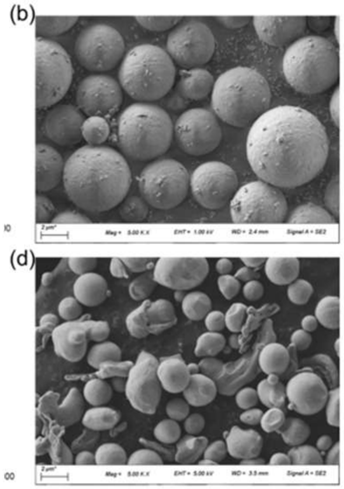
- Powder compaction or powder injection molding process are the most commonly used manufacturing routes
  - *long lead time*
  - *Inflexible for complex geometry design*
  - *Not economical for reproducing obsolescent or old model parts.*

- Binder Jet Printing is an effective way to address the issues.

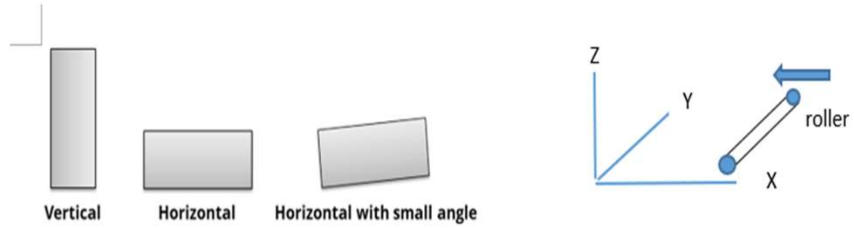


Process flow for 3D Biner Jet Printing process

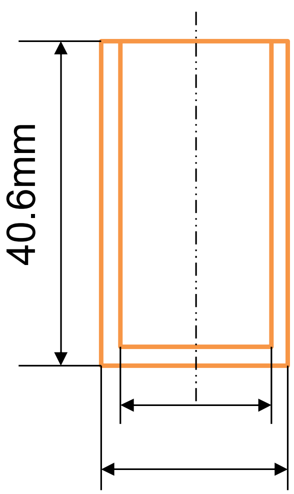
Experimental Set-up



1. Feedstock:
   - 12 wt.% pore former and 88 wt.% of SS316L fine powders
   - Particle size of SS316L powders of D50 = 4 μm and polymeric pore former of D50 = 4.6 μm



Orientation of parts in BJP printing



2. Geometry of Cup

Aspect ratio =length/OD=2.07

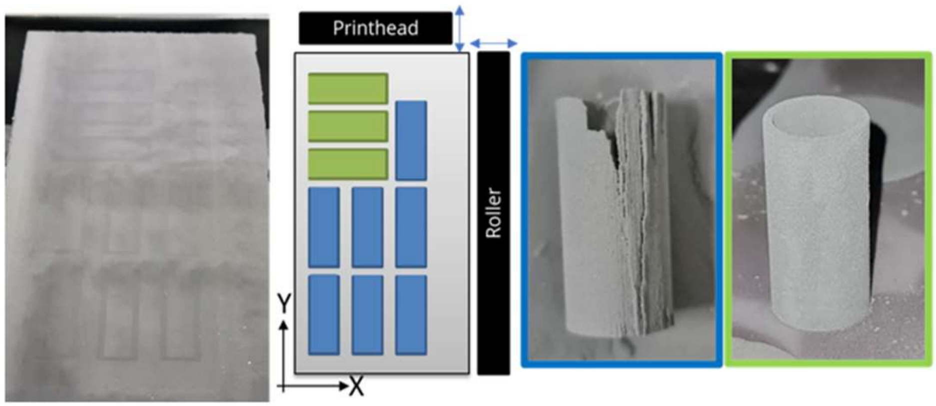
Ø13.6mm to Ø16.6mm (varied wall thickness)

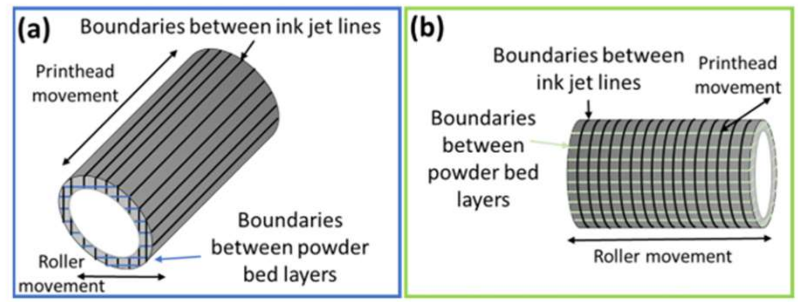
Ø19.6mm

Major BJP processing parameters

Parameters	Values
Layer thickness (μm)	30
Saturation (%)	60
Recoat speed (mm/s)	40-100
Ultrasonic intensity	50-75%
Rough Roller speed (rpm)	250
Fine roller speed (rpm)	350
Roller traverse speed (mm/s)	3
Binder set time (seconds)	30-40
Binder drying time (seconds)	5
Infrared emitter output (%)	90
Drying temperature (°C)	40
Curing Temperature (°C) & holding (hour)	200 & 4 in air
Debinding Temperature (°C) & holding (hour)	600 & 1 in N2
Sintering Temperature (°C) & holding (hour)	1080 & 1in H2

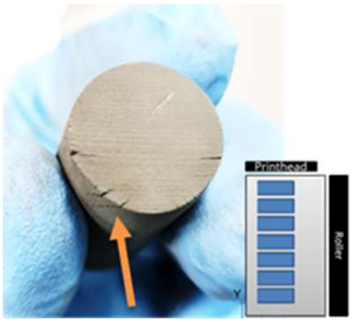
Results and Discussion:
Orientation in horizontal printing (1)





- The building orientation marked with blue leads to very poor green part strength.
- The boundaries between inkjet lines and powder bed layers are normally the weak point of binder jetting printed parts.
- The intersection points of inkjet line boundaries and powder layer boundaries locate on the thin annulus cross-section when the cups are printed parallel to the roller, while the lines formed by these points of intersection are the weakest part in the green parts.
- The cup printed perpendicular to the roller has shorter lines of intersection, thus the parts have relatively higher strength.

Results and Discussion:
Issues with *Orientation in horizontal printing (2)*

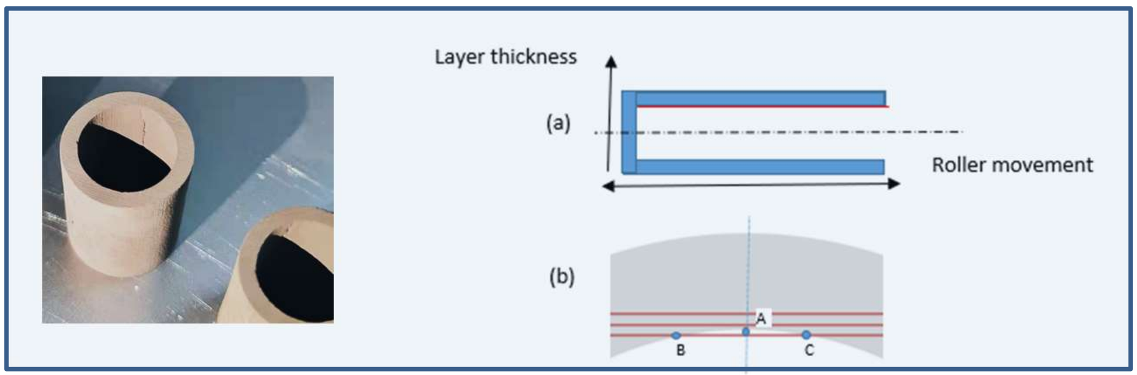


Wall thickness 1.5mm

Cracks in the bottom half and cut through several layers have been detected due to lack of support

To solve this issue

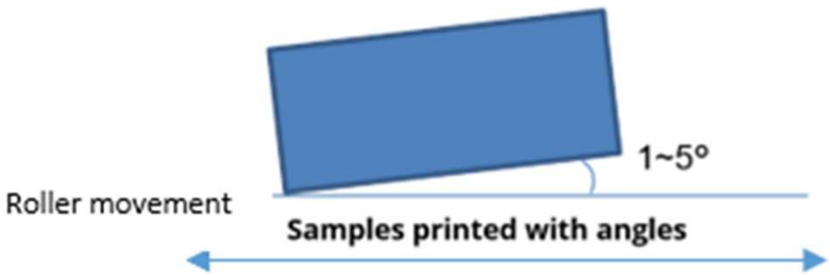
- *The amount of powder spread on the powder bed needs to be sufficient to obtain a dense powder bed*
- *Increase wall thickness*

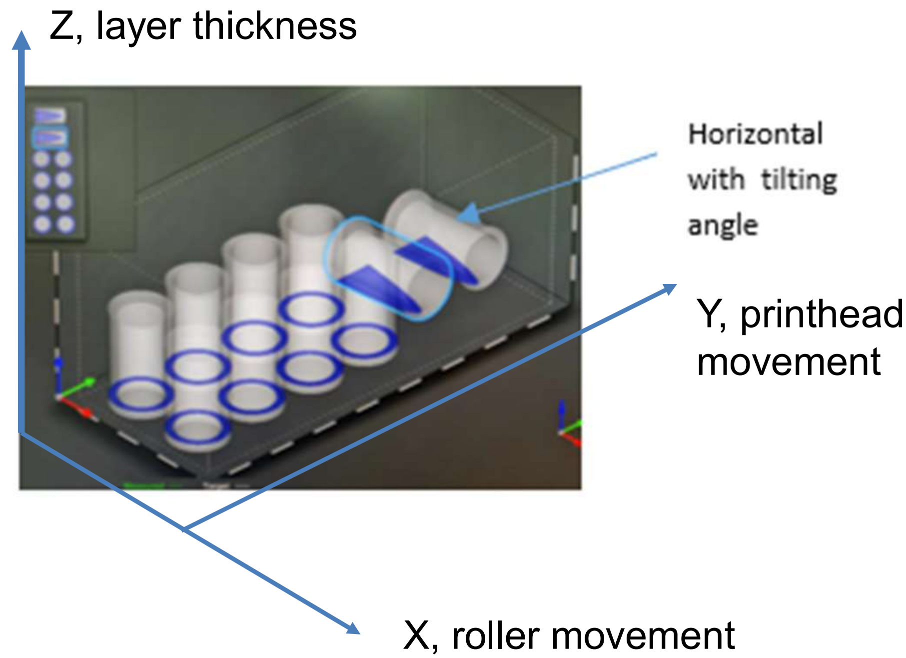


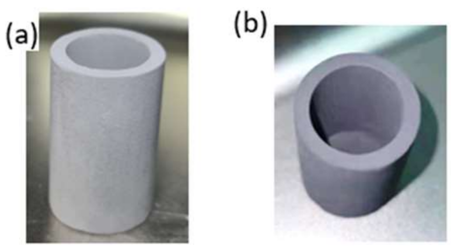
Wall thickness 3.0mm

When the slicing layer is not happened to meet the inner diameter at cup's highest point A, rather than meeting at point B and C, a joining line will appear due to formation of a "gap" in between two sliced layers after printing.

Results and Discussion:
Tilting in horizontal printing (3)







Defect free printed cups

Defect free printed cups,
(a) horizontal printing with tilting angle of 5°
(b) (b) horizontal printing with tilting angle of 1°

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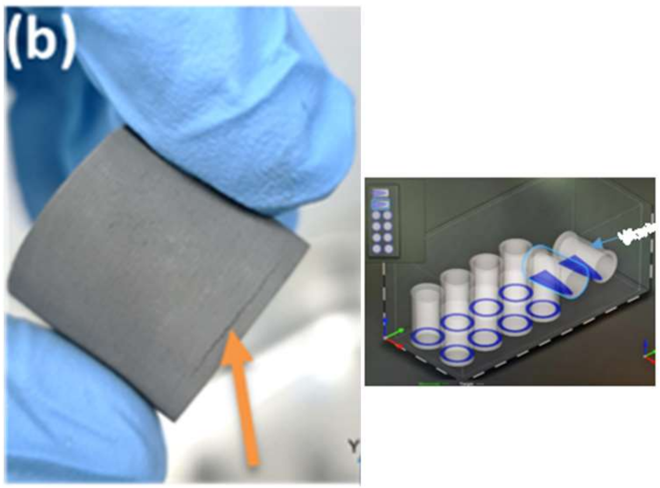
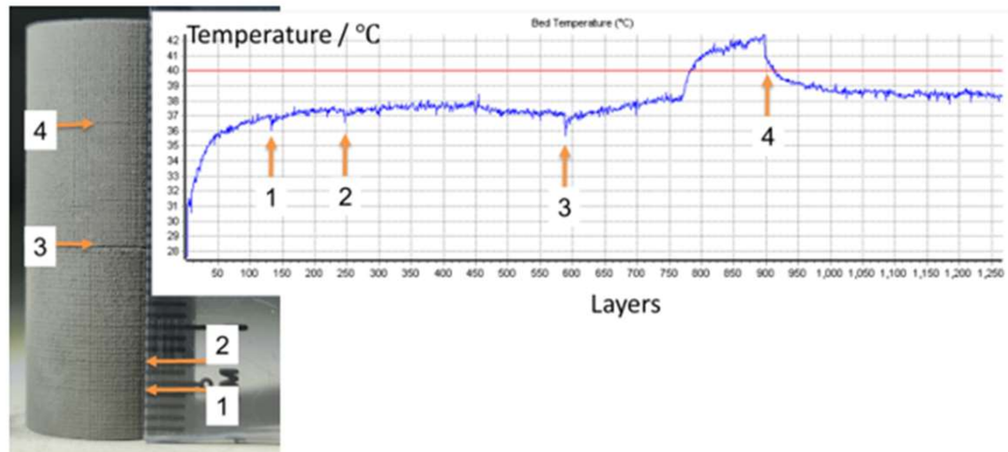
Results and Discussion:

Orientation in vertical printing for part with thin wall (1.5mm)



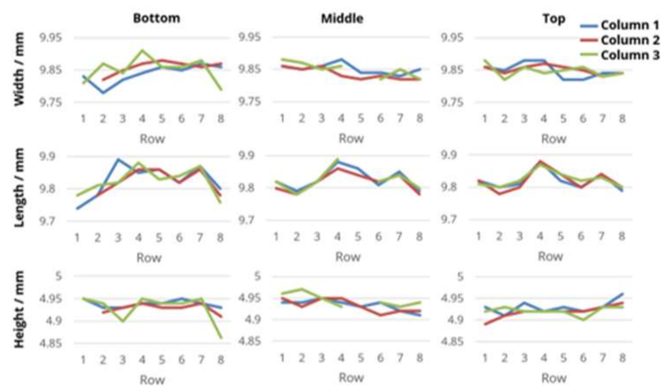
Wall thickness of the cup is too thin to withstand the contraction force of the sidewall and bottom of the cup generated during the curing process.



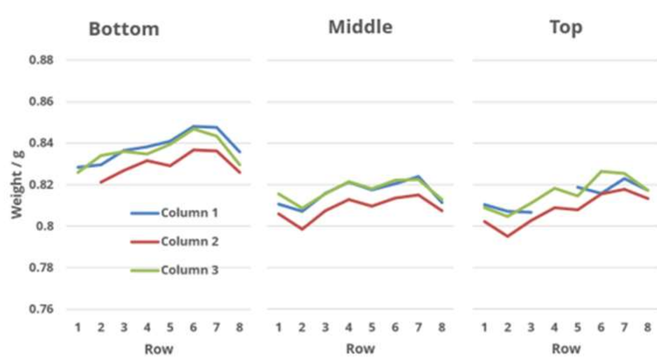
Cracks/marks were generated due to powder bed temperature drop which is caused by temperature variation leading to nonuniform parts shrinkage

Results and Discussion:

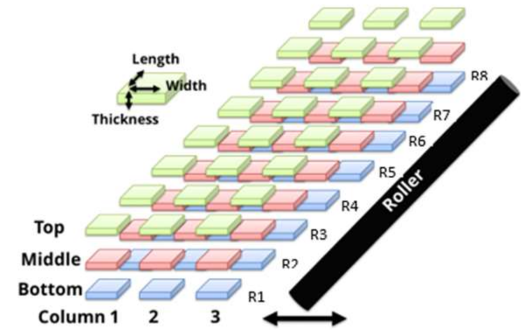
Density variation of printed cubes across the powder bed



Size of printed cubes



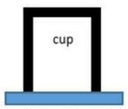
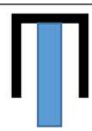
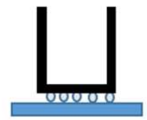
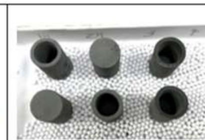
Weight of printed cubes



Cube layout

- Dimension of these cubes is in similar variation range, hence, their printed volume is the same.
- The weight of cubes located in bottom layer is the highest among the three layers, and the weight of cubes in middle and top layers is in similar range.
- All the cubes in the column 2 (in the middle) , irrespective of their layer location, have shown the lightest weight as compared to column 1 and 3.
- The density of cubes is the highest in bottom layer, and the lowest in center location (column2).

Results and Discussion:
Sintering Orientation

Items	Supporting method, Skematic view	Picture of sintered parts	Remarks
1. Upward			Cone shape, with dimension in top open end is slighlty smaller than the bottom one
2. Downward			Bulging on bottom surface which is contacting with sintering plate
3. Horizontal			Part is heavily deformed. The surface contacting with cermaic plate is flattened
4. Support by rod			• Protruding on top surface in contacting area • Center line of the sintered part is tilted
5. Support by rolling beads			• Slightly bulging on the bottom surface contacting with rolling beads • However, there are bead marks on contacting area
6. Support by profiled jig			Heavily deformed - Oval shape

- Parts laid in the 1st upward direction and the 5th on rolling beads, yield the relatively less deformation.
- However, parts in 5th are not stable and easily toppled down when transferring , and dented mark is also noticeable.
- Parts in 1st direction are for mass production

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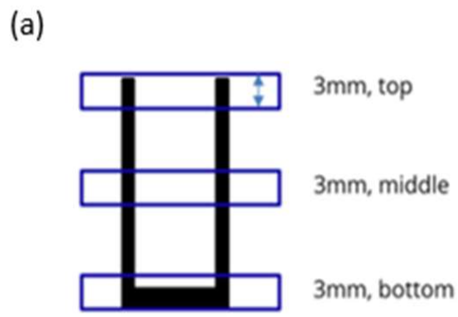
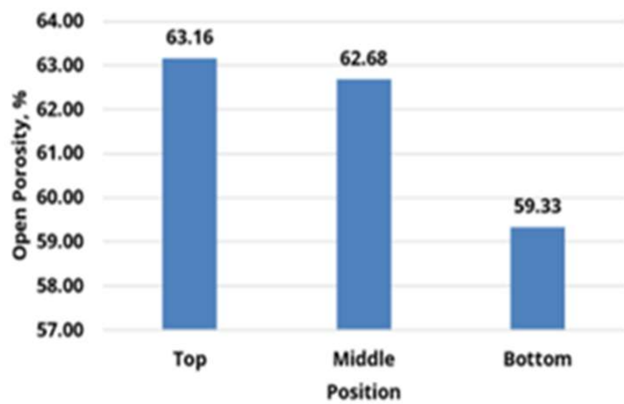
Results and Discussion:

Density variation printed in vertical direction

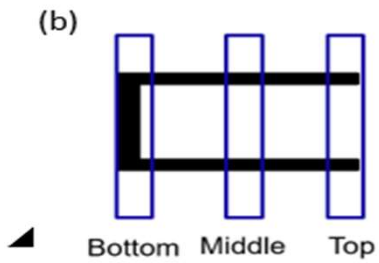


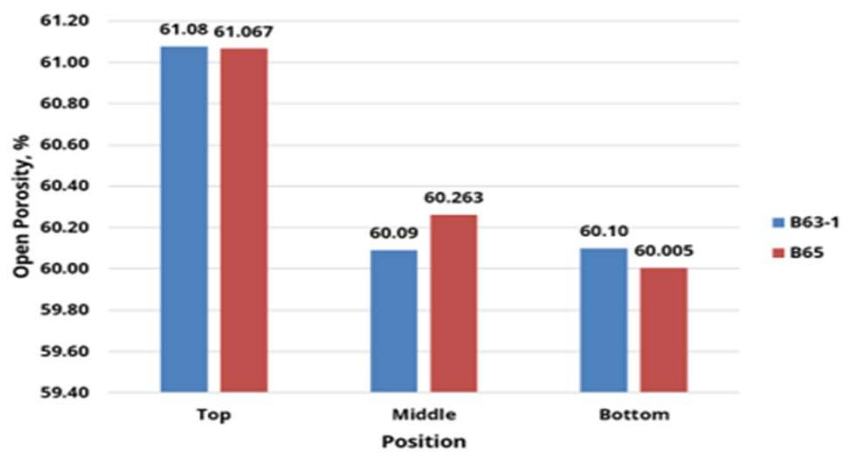


- The top portion in open end has the highest porosity of 63.16%, followed by middle position of 62.68%. The least porous area is in bottom portion with porosity of 59.33%.
- The difference in porosity across the whole sintered cup is 3.83%.
- This finding is in agreement with cube density study, where cubes in the bottom layer has the highest density, hence the least porosity.
- Gravity effect in sintering also intensified this phenomenon.

Results and Discussion:

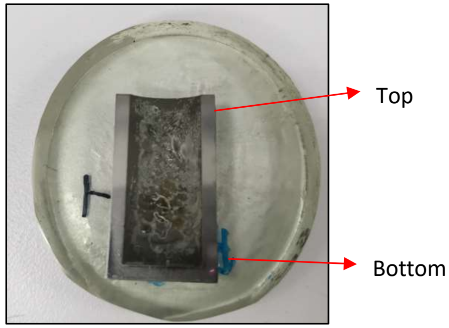
Density variation printed in horizontal direction





- The top portion in open end has slightly higher porosity of 61%, followed by middle and bottom portion.
- The porosity difference of 1% could be attributed to gravity effect in sintering.

Results and Discussion:
Microstructure



Top

Bottom

Conclusion

- In printing of 316L fine porous cup shaped metal membrane, 316L powder with particle size of D50=4µm and 12 wt% of PMMA with particle size of D50=5µm powder was used.
- laying cup in horizontal direction during printing will shorten the printing time, and also leads to less density variation across the printed parts.
- Tilting cup in small angle from 1 to 5 degree can avoid the formation of inner crack line during printing.
- The upward laying method during sintering is the best to be employed as it has the less deformation and also easily be scaled up for mass production.
- For cups laying in vertical direction, their open porosity after sintering is ranged from 59% to 65%. However, the difference of porosity across the same cup is 3.83% with the bottom is the most dense area.
- For cups laying in horizontal direction, the open porosity after sintering is ranged from 57% to 62%. The variation of porosity is within 1% across the same cup, indicating the structure is more uniform.
- The microstructure reveals porous structure with uniformly distributed fine pores.

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Acknowledgement

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In printing of 316L fine porous cup shaped metal membrane, the mixed feedstock consisting of 316L powder with particle size of D50=4μm and 12 wt% of PMMA with particle size of D50=5μm powder was used. With high aspect ratio of length vs. diameter for cup's geometry, it is found that laying cup in horizontal direction and setting layer thickness along its circular diameter during printing will shorten the printing time, and also leads to less density variation across the printed parts. Meanwhile, tilting cup in small angle from 1 to 5 degree can avoid the formation of inner crack line during printing.

In sintering of printed cups, several methods in terms of laid parts in different orientation were accessed. The results showed the upward laying method is the best to be employed as it has the less deformation and also easily be scaled up for mass production.

For cups laying in vertical direction by setting its length as layer thickness during printing, their open porosity after sintering is ranged from 59% to 65%. However, the difference of porosity across the same cup in three different positions, i.e., top, middle and bottom is 3.83% with the bottom is the most dense area.

For cups laying in horizontal direction by setting its circular diameter as layer thickness during printing, the open porosity after sintering is ranged from 57% to 62%. The variation of porosity is within 1% across the same cup from top area to bottom area, indicating the structure is more uniform. The microstructure reveals porous structure with uniformly distributed fine pores.

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