Pressure drop and velocity simulations in non-stochastic lattice structure for filter applications fabricated using additive manufacturing

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ABSTRACT
This research utilises additive manufacturing technology to fabricate filter mesh designed with non-stochastic lattice structures. Disc filters with 1-layer, 2-layer and 3-layer thicknesses of repeated 1.8 mm lattice unit cell as the filter mesh are modelled in SolidWorks. Computational Fluid Dynamic (CFD) simulation using ANSYS CFX is performed at eight different flow rates (250 lit/min, 270 lit/min, 290 lit/min, 310 lit/min, 330 lit/min, 350 lit/min, 370 lit/min and 390 lit/min) and the results (pressure drop and velocity) are analysed. Simulations are also done for perforated plates with circular-shaped and square-shaped holes with the same aperture size and filter cut point for benchmarking purposes. The outcomes indicate that the pressure drop of the lattice filters is noticeably lower than the perforated plates'. These findings show that several layers of lattice structure could be stacked together as filter mesh to increase filtration efficiency with minimal pressure drop and to create a more tortuous path for the fluid.

KEYWORDS: Additive Manufacturing; Non-stochastic Lattice Structures; Disc Filters; Pressure Drop; Velocity

1. INTRODUCTION

Conventionally, metal filters have been fabricated using perforated plates, mesh and wedge wire, while others are fabricated from subtractive processes such as cutting, rolling, welding and punching [1, 2]. However, recently, researchers including Burns [2] and Vijayakumar et al. [3] suggest that AM technology such as Selective Laser Melting (SLM) could be used not only as an alternative manufacturing process, but also for improving the filters efficiency and reducing manufacturing cost.

Additive Manufacturing (AM) technologies have been used to fabricate non-stochastic cellular structures for a number of years in a variety of applications. These structures can exhibit unique characteristics that make them superior to solid metals. They are lightweight structures with low densities and have good strength to weight ratios. The structures also exhibit high surface-to-volume fractions. A combination of the properties above enables applications such as the fabrication of silencers, heat exchangers, impact energy absorbers and biomedical implants feasible [1, 4-7].

Klumpp *et al*. [8] has studied the effect of using periodic cellular structures with different cell orientations and porosities towards pressure drop and their results confirm that both customisation types affect the pressure drop of such structures. Such customisation could be applied on filter media. By designing filters with bespoke, functionally graded, non-stochastic lattice structures, not only will the flow characteristics be altered in a positive way, but the filter's strength as well. Meanwhile, a preliminary study by Hasib *et al*. [9] indicates that using a filter mesh based on a lattice structure has the potential to reduce pressure drop without compromising mechanical strength.

Functionally graded non-stochastic lattice structures have also been used in other applications, for example, biomedical prostheses. These structures were bespoke in numerous ways to attain the preferred mechanical properties. Research conducted by Emmelmann *et al*. [10] effectively integrated a functionally graded lattice structure onto a hip endoprosthesis by applying mathematical equations to generate the structure in the form of a curved surface.

One of the fundamental approaches for improving the efficiency of filtration is the reduction of the pressure drop across the filter. Hence, the objective of this study is to design disc filters with different lattice mesh thicknesses (1-layer, 2-layer and 3-layer) and observe the pressure drop at different inlet velocities. The pressure drop results are later compared to that of circular-shaped and square-shaped perforated plates.

2. DESIGN AND ANALYSIS OF FILTERS

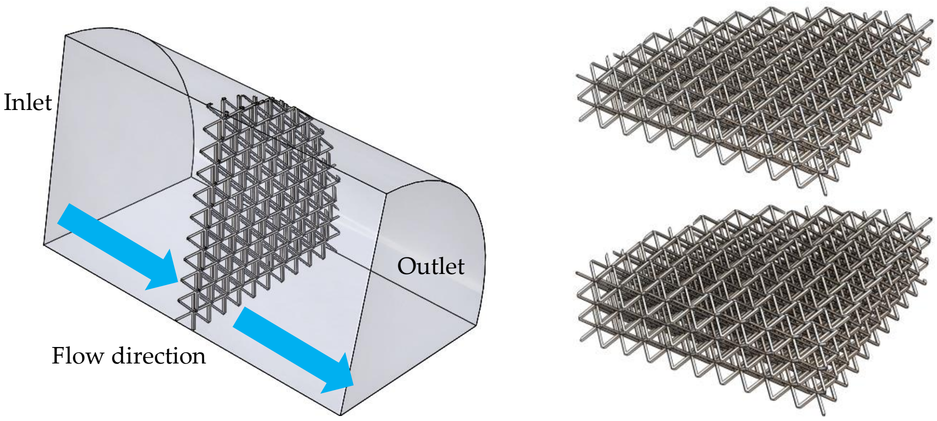
2.1 Filter Design

Flow characteristics and strength of filter media could be customised to the required specifications using bespoke non-stochastic lattice structures as filter mesh. In this study, a unit cell of cellular structure with 1.80 mm pore size (2 mm edge-to-edge length) was designed in SolidWorks and this cell was patterned linearly to create a layer of cellular mesh for a 44 mm diameter disc filter (40 mm mesh diameter), as shown in **Figure 1** below.

Figure 1: Lattice unit cell and the 1-layer disc filter.

2.2 CFD Simulations

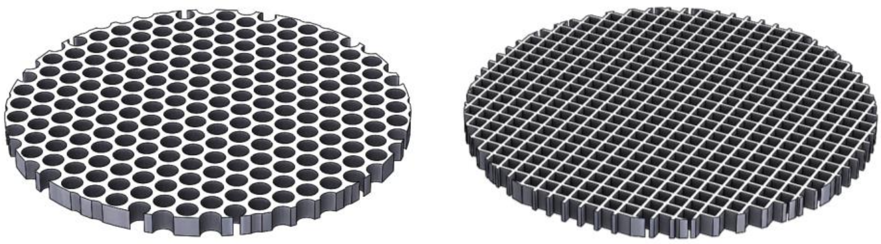
The complexity of the filter designs has led to some computational difficulties for the Computational Fluid Dynamics (CFD) simulations. Symmetrical boundary conditions were used to ease the computational load, therefore only a quarter of the 1-layer disc filter was used for simulation. The CFD simulation domain was designed as in **Figure 2 (a)**, and simulations were run in ANSYS CFX software tool with eight different flow rates (250 lit/min, 270 lit/min, 290 lit/min, 310 lit/min, 330 lit/min, 350 lit/min, 370 lit/min and 390 lit/min). These flow velocities were chosen as they were within the operational capability of the test rig situated at Croft Filters Ltd. This particular test rig will be used to verify the results experimentally.



(a) (b)

Figure 2: (a) Computational domain (b) 2-layer and 3-layer lattice meshes.

The same domain was used again to simulate the 2-layer and 3-layer lattice filters (**Figure 2 (b)**), along with the circular-shaped and the square-shaped perforated plates shown in **Figure 3** below.



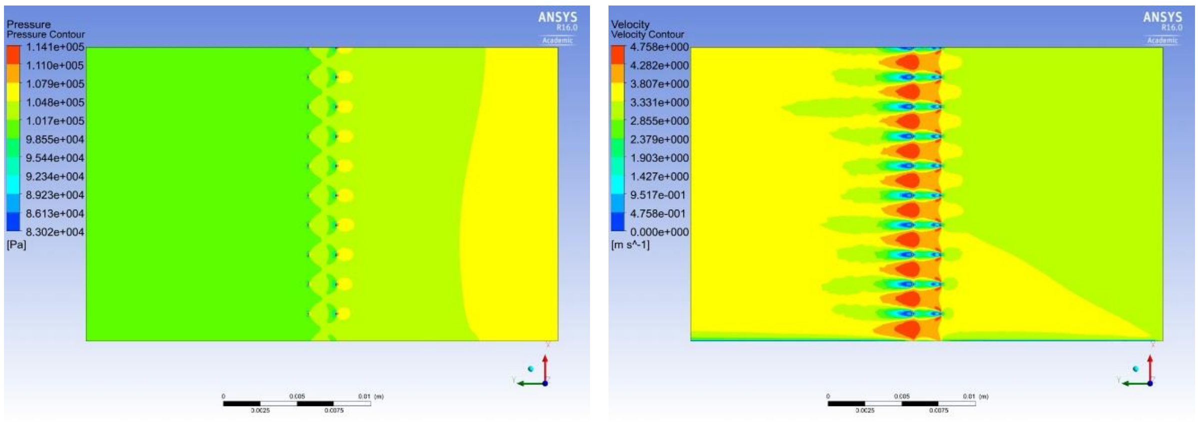
(a) (b)

Figure 3: (a) Circular-shaped perforated plate (d) Square-shaped perforated plate.

3. RESULTS

3.1 Pressure and velocity contour

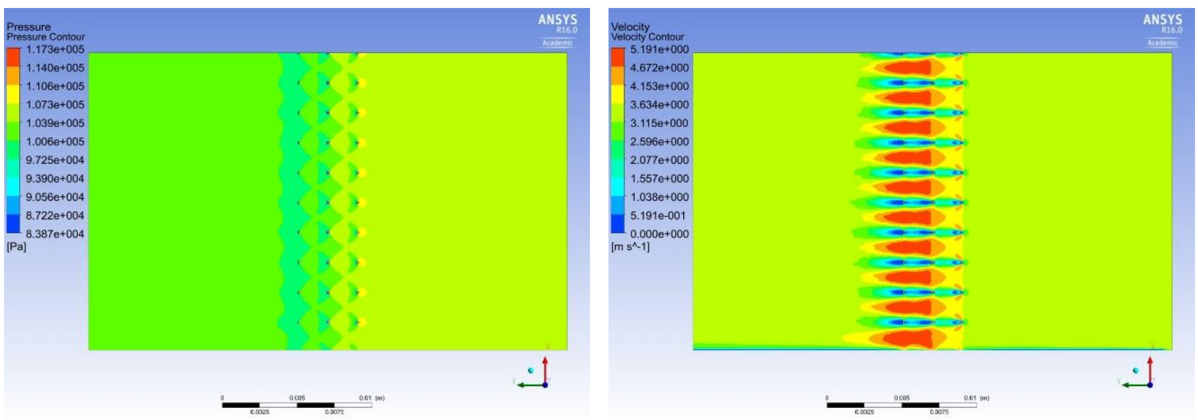
The pressure and velocity contour for a 1-layer filter model at 250 lit/min flow rate is presented in **Figure 4**. The pressure drop through the 1-layer lattice filter ranges from 3100 Pa at 250 lit/min flow rate to approximately 7100 Pa at 390 lit/mins inlet flow rate. The velocity of the fluid changes rapidly as the fluid hits the lattice struts (**Figure 4 (b)**).



(a) (b)

Figure 4: 1-layer lattice filter model with 250 lit/min flow rate (a) Pressure contour (b) Velocity contour.

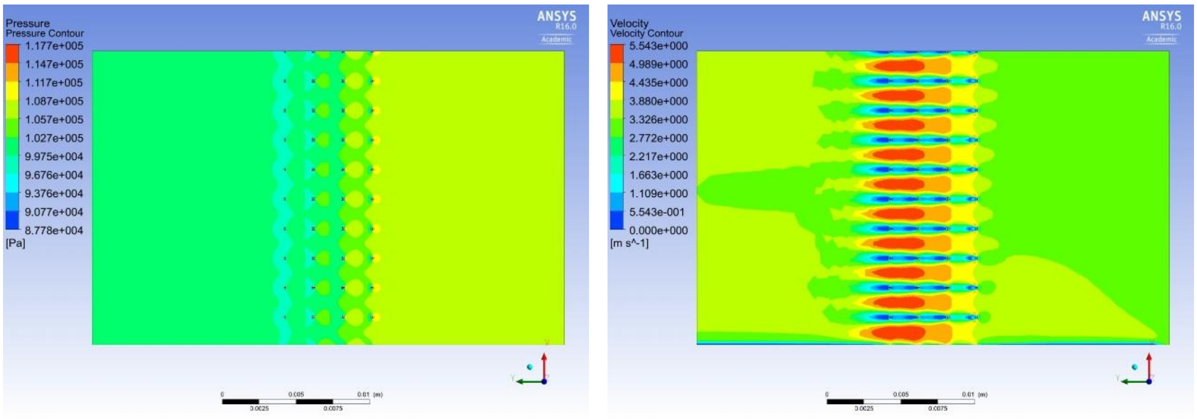
Similarly to the 1-layer filter model, when the fluid comes in contact with the struts in the 2-layer filter model, the fluid velocity increases and the fluid is diverted around the struts creating a convective flow through the porous region as shown in **Figure 5**. The pressure drop for the 2-layer lattice model is comparably higher, ranging from 3400 Pa at 250 lit/min flow rate to about 7800 Pa at 390 lit/mins flow rate.



(a) (b)

Figure 5: 2-layer lattice filter model with 250 lit/min flow rate (a) Pressure contour (b) Velocity contour.

As expected, the pressure drop for the 3-layer lattice model is the highest, where the values recorded range from 6000 Pa to 14000 Pa. The thicker lattice structure also results in a longer travelling distance for the fluid, creating a tortuous fluid flow through the structure as depicted in **Figure 6**.



(a) (b)

Figure 6: 3-layer lattice filter model with 250 lit/min flow rate (a) Pressure contour (b) Velocity contour.

3.2 Pressure drop comparison

Pressure drop on the perforated plates was simulated and an overall comparison of the pressure drop between the lattice filter models and the perforated plate models was undertaken as shown in **Figure 7** below.

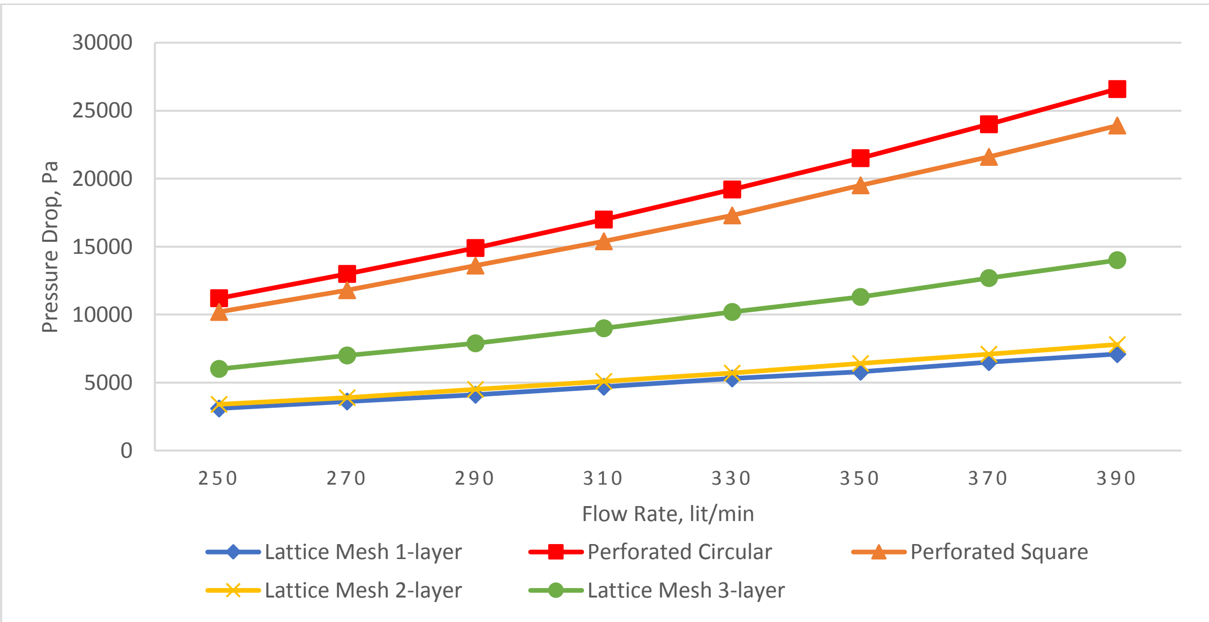


Figure 7: Pressure drop comparison.

It can be clearly seen that the pressure drop values for the lattice filters are much lower than the perforated plates' at all flow rates. It is also observed that the pressure drop increases as the number of lattice layers increase. The values for 1-layer and 2-layer lattice filters are quite close, whereas the pressure drop of the 3-layer lattice filter is noticeably higher.

3.3 Filter fabrication

SLM technology by Realizer Gmbh was used to manufacture the disc filters in this study. This process involves metal powder fusion using a laser beam to form structures in accordance with the 3D CAD model. The part is then sliced into a series of sequential layers. Each layer is then consecutively reconstructed by depositing powder layers, one on top of the other. The surface of each layer is melted according to the layer's cross-sectional profile by scanning a laser beam. A schematic of this process is shown in **Figure 8**. Completed filters are depicted in **Figure 9**, whilst **Figure 10** displays the close-up look on the lattice mesh.

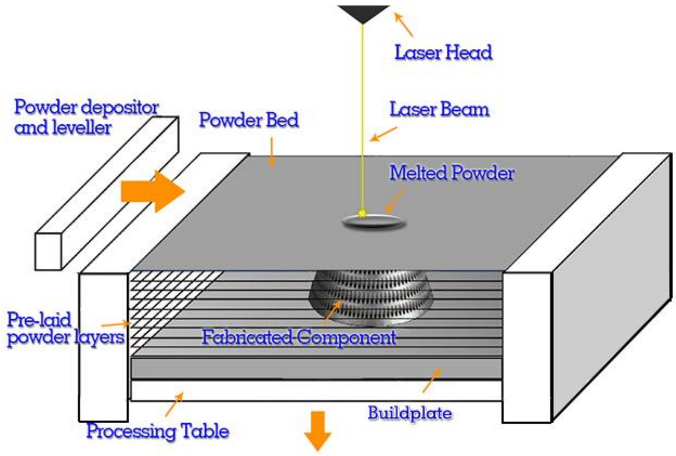


Figure 8: Schematic of the additive manufacturing build process with Selective Laser Melting technology.

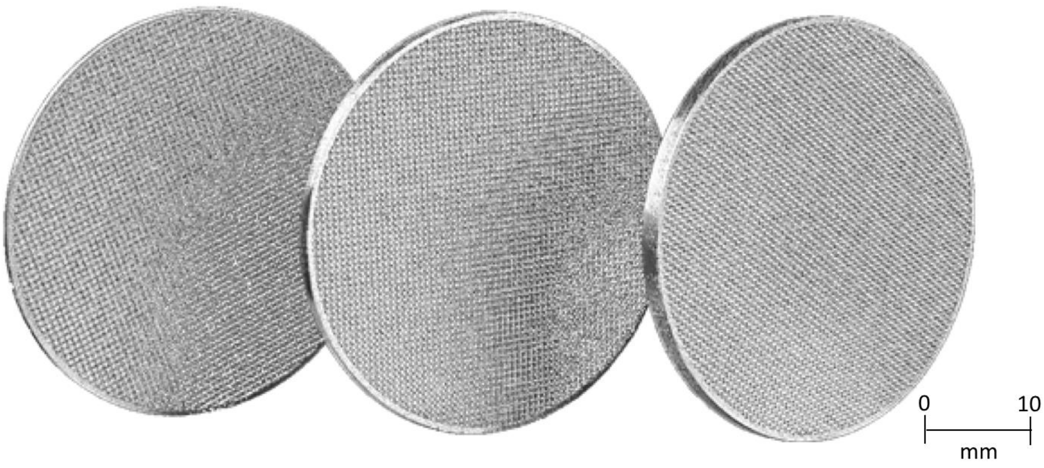


Figure 9: 1-layer, 2-layer and 3-layer lattice filter fabricated via SLM.

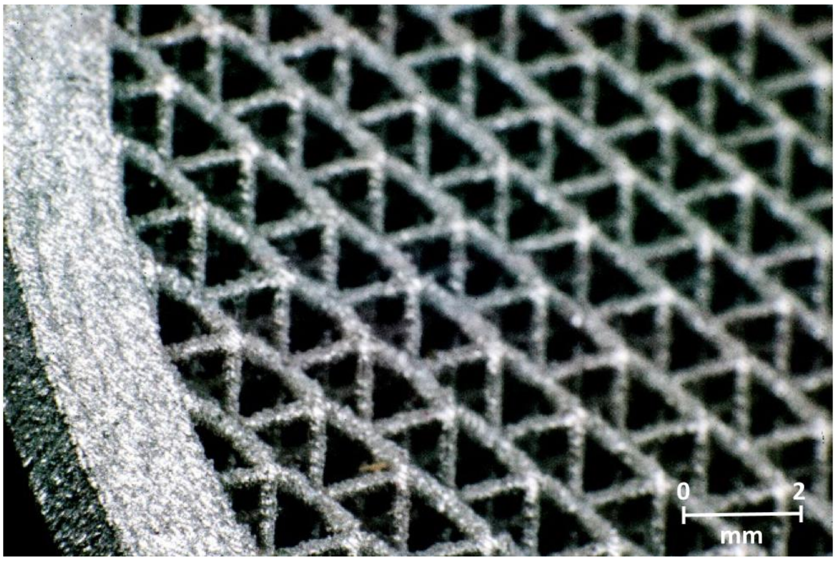


Figure 10: Detailed view of the lattice filter.

4. CONCLUSIONS AND FUTURE RECOMMENDATIONS

The conclusions resulting from the study can be summarised into two main points. Firstly, the progress in AM technologies has rapidly aided the development of non-stochastic lattice structures, and using these structures as filter mesh would minimise the pressure loss from the inlet to the outlet. Secondly, the fluid travel path can be made longer by using more layers of lattice mesh. As the pressure drop is relatively lower compared to the one of perforated plates, the mesh could filter out more particles from the fluid.

The next step is to integrate the lattice structure with different porosities into a filter mesh and apply it not only to disc filter, but also within conical filter configurations. The bespoke nature of these structures will allow for a wide range of customisation for filtration applications. Nevertheless, the simulation results need to be validated first. Two options have been recognised: calculations using appropriate mathematical models, such as *Dupuit-Forchheimer* and *Fourie & Du Plessis* models [11], and physical experimentation with a customised test rig [3].

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