Design and Simulation of 3D Printed Check Valves Using Fluid-Structure Interaction

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INTRODUCTION

Passive, one-way valves (check valves) are an essential microfluidic feature that facilitates flow rectification. Numerous check valves have been demonstrated in microfluidic systems using PDMS due to its low Young's modulus (0.87 MPa) [1]. Recently, 3D printing has become of interest to microfluidics as it accelerates R&D while reducing time and cost [2-4].This study analyzed the range of valve thicknesses necessary to promote flow and deliver precisely controlled volume droplets for five commonly available 3D printer (FDM) filament materials.

COMPUTATIONAL METHODS

A representative 2D CFD model (**Figure 1**) was created in COMSOL Multiphysics® and fully coupled using the fluid-structure interaction (FSI) module.

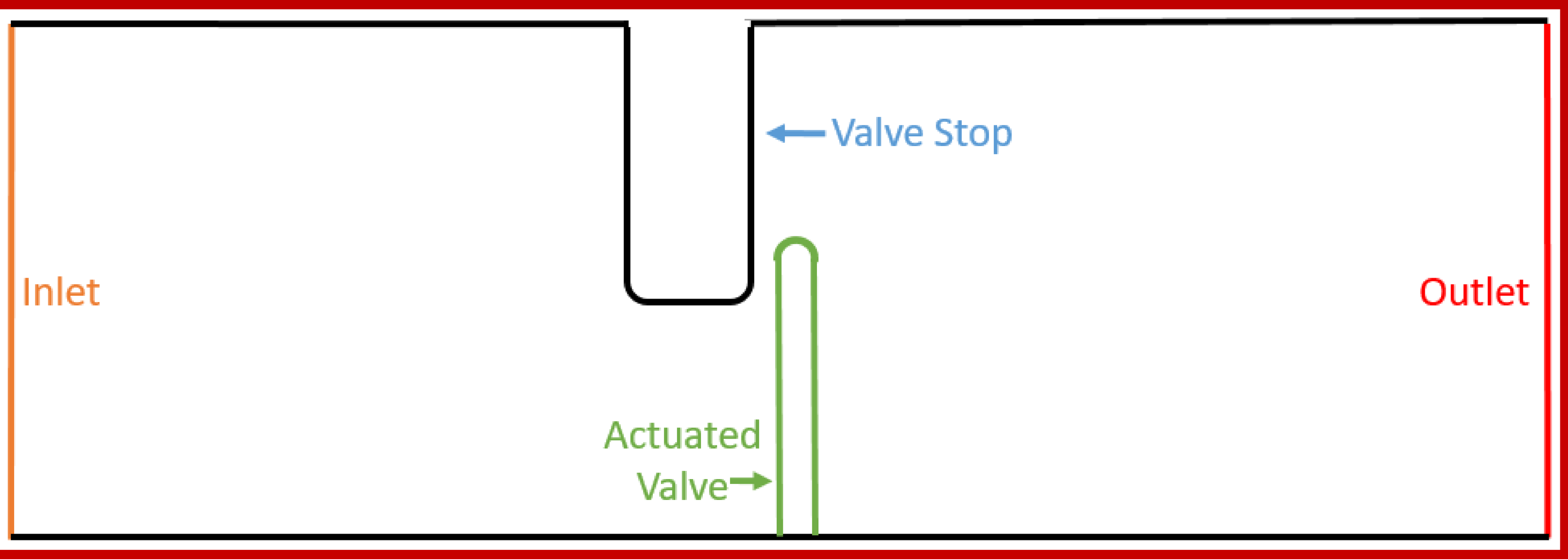
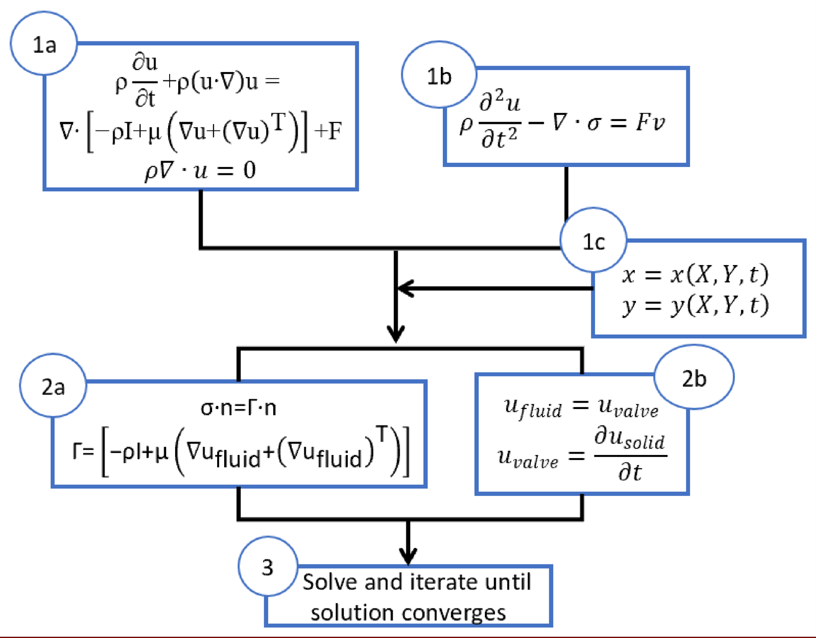


Figure 1. 2D representation of check valve geometry to prevent backflow

Figure 2 graphically outlines the governing equations for FSI. Five 3D printer filament materials were compared in simulations of valve deformation over a 0.75 second transient period using the material properties of PDMS as a baseline. The velocity profile boundary condition was assigned as fully developed laminar flow entering the channel using:

$$v_i = u_{mean} \times 6 \times (H - Y) \times \frac{Y}{H^2};\ u_{mean} = \frac{U \times t^2}{\sqrt{t^4 - 0.07t^2 + 0.0016}}$$



1. Set up equations for:
   a. Fluid flow
   b. Solid deformation
   c. Moving mesh
2. Apply boundary conditions
   a. Fluid forces
   b. Fluid velocities
3. Solve system of equations and iterate

Figure 2. Governing Equations and process used for FSI

Table 1. Properties of materials tested

Material	ρ (kg/m^3)	ν	E (Pa)
PLA	1250	0.33	3.5×10^9
ABS	1100	0.35	2.05×10^9
Nylon	1130	0.39	2.95×10^9
PETG	1260	0.40	2.0×10^9
TPU	1100	0.40	4.5×10^6
PDMS	0.97	0.40	0.87×10^6

RESULTS

Five 3D printer filament materials were compared in simulations of valve deformation over a 0.75 second transient period using the material properties of PDMS as a baseline. The maximum valve deflection for ABS, nylon, PETG, PLA, and TPU was 3.34, 3.08, 3.37, 3.00, and 6.45 µm, respectively. The simulation resulted in a maximum valve deformation of 6.65 µm for PDMS.

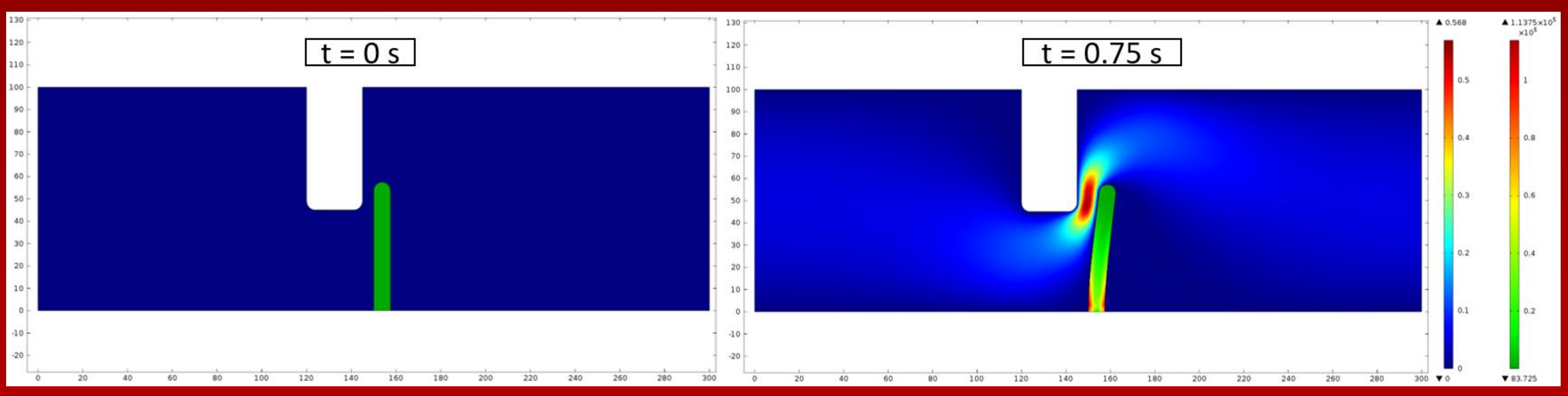


Figure 3. Surface von Mises Stresses and surface velocity magnitude at 0 sec and 0.75 sec for a TPU valve with a width of 7.5 µm.

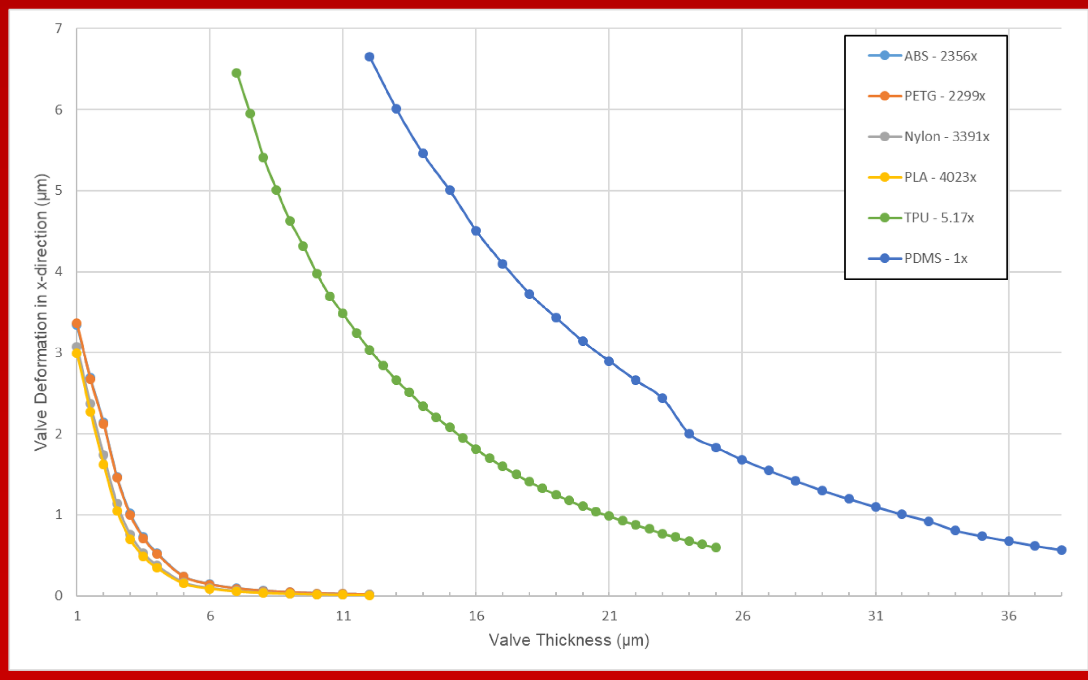


Figure 4. Maximum valve deformation of the 3D printer filaments

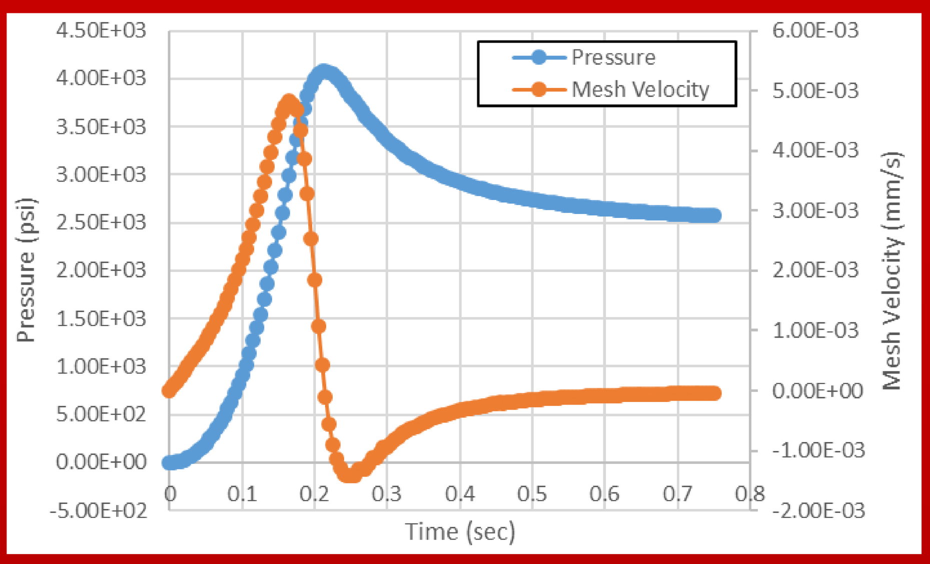


Figure 5. Solid deformation and pressure vs. time (ABS)

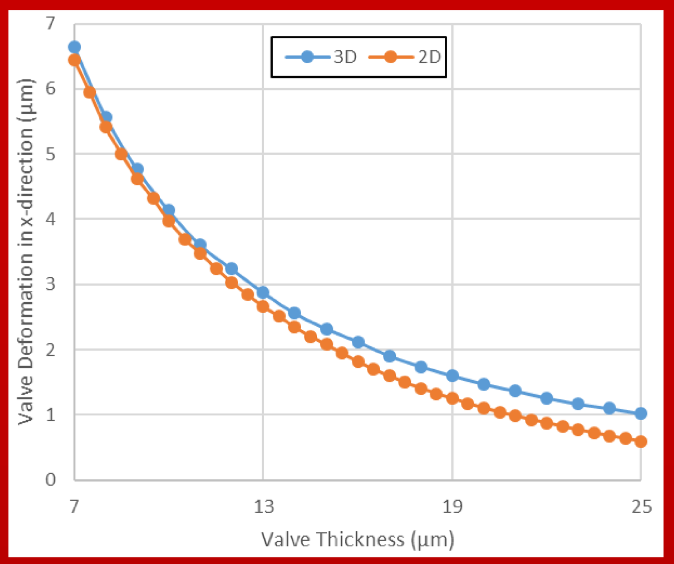


Figure 6. Comparison of TPU valve deformation in 2D and 3D simulations

CONCLUSIONS AND FUTURE WORK

As expected, materials with a Young's modulus close to PDMS allows valve structures to actuate with adequate forward flow. TPU exhibited similar deformations to PDMS but required smaller valve widths. Future studies planned include optimization of check valve geometry related to realizable 3D printed features, determining the minimum flow rates required to open the check valves for a variety of designs including interdigitated arrays of the valves, and custom geometric shapes to prevent backflow.

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