CAAP Quarterly Report

Date of Report: *Jan. 7th, 2020*

Contract Number: *693JK31850009CAAP*

Prepared for: *U.S. DOT Pipeline and Hazardous Materials Safety Administration*

Project Title: New Bio-Inspired 3D Printing Functionalized Lattice Composites for Actively Preventing and Mitigating Internal Corrosion

Prepared by: *North Dakota State University*

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For quarterly period ending: *Jan. 7th, 2020*

Business and Activity Section

(a) Contract Activity

Chemicals were mainly purchased for synthesizing surface treatment of the lattice structures

Conference presentation in post sections: Dr. Lin attended and presented their work on high-performance coatings for corrosion control *"Corrosion-induced damage identification in metallic structures using machine learning approaches"*, and new 3-D printing composites for corrosion control ("*Wettability properties of 3D printable polymers and 3D printed structures for engineering applications*") in national conference 2019 Defense TechConnect Innovation Summit, Oct. 8-10, National Harbor, Washington D.C., USA.

Invited talk: Dr. Lin was invited to give a talk at Civil Engineering department in University of North Dakota, "*Data-Driven Structural Diagnosis and Conditional Assessment*" in Nov. 6th, 2019, Grand Forks, ND.

Conference paper accepted: two conference papers, entitled "*Nanoparticles for improved functional composite coatings for corrosion control of underground and marine civil infrastructure systems*", was accepted as conference papers and presentation in the international conference, 10TH International Conference on Bridge Maintenance, Safety and Management 2020, June 28-July 2, Sapporo, Hokkaido, Japan.

(b) Status Update of Past Quarter Activities

The research activities in the 5th quarter included: (i) Continuing efforts by design and optimization of the 3D printing lattice structures; (ii) Continuing efforts by characterization of functional materials; and (iii) Characterization of the new lattice composites as a system in a pipe environment, as summarized in Section (d).

(c) Cost share activity

Cost share was from the graduate students' tuition waiver.

(d) Summary of detailed work for Tasks 2, 3 and 5

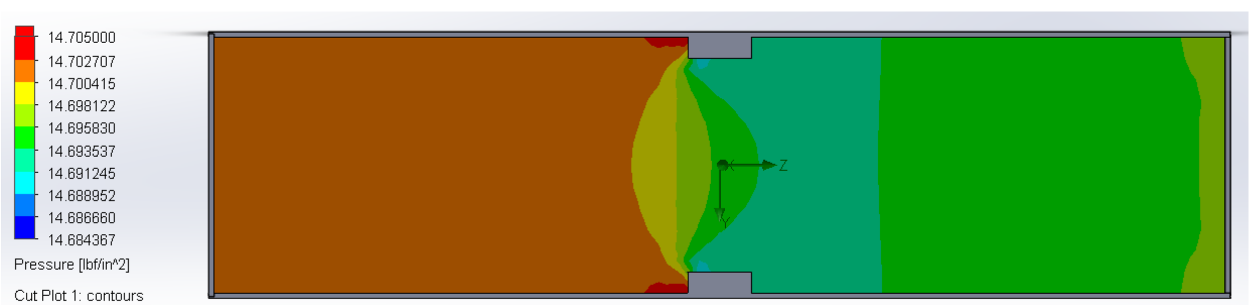
We developed a customized multi-material delivery system to print the porously structure with lattice architecture for better solution in corrosion control. To further calibrate and validate the concept as designed in Task 5-8, two tentative implementation plans of the lattice composites in a pipe environment were proposed.

1. Experimental Program and Numerical Investigation in the 5th Quarter

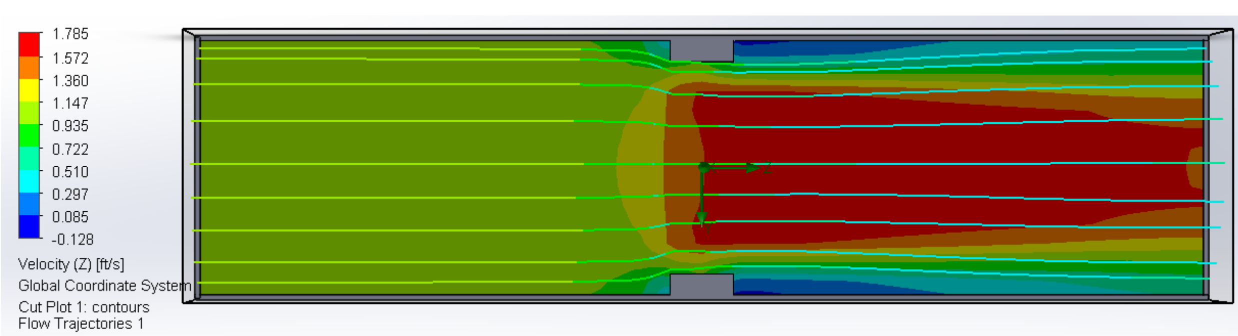
In this section, as a part of Task 5, we conducted a numerical simulation in detail for gaining understanding of design parameters for the composite layers in a pipe environment. For simplicity, we attempted to mode a pipe with idealized conditions. Also, the segment of the pipe used for simulation was a straight and smooth part, without consideration of any intersection, uneven surface, or other complex situations.

Finite element method (FEM), as a numerical tool, was used to simulate a similar situation with the real state. The three-dimensional (3-D) pipes under different cases were modeled, where mixed water and hexadecane were considered.

As typically illustrated in **Figs. 1a and 1b**, the results of the Finite Element Method were presented and discussed in Section 3.



(a) Pressure contour



(b) Velocity contour

Fig. 1 FE results of the pipe under different cases.

1.1 Continuous efforts on design of 3D printing lattice structures

We developed a customized multi-material delivery system to print the porously structure with lattice architecture within five-micron spatial accuracy. As well known, periodic cellular structure is the most known man-made cellular structure which are used in the design of light weight sandwich panel structures.

1.2 Continuous efforts on composites

We selected the PLA and ABS as our base for printing materials in that there were no preferable 3D printable materials so far.

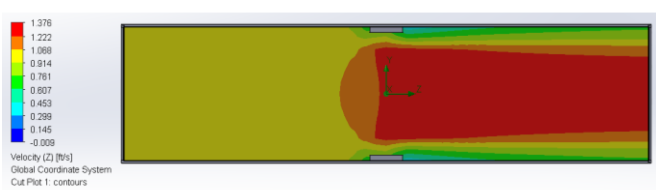
Surface morphologies of pristine samples and modified ones were observed by Scanning Electron Microscopy (SEM, JEOL, Japan) and the elemental distribution of the as-prepared samples were investigated by Energy-dispersive X-ray Spectroscopy (EDS) attached to SEM.

2. Results and discussion

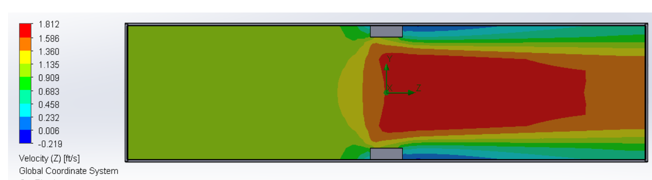
2.1 Effects of the composite thickness on the flow conditions

This group of the simulation was to understand the impacts of composite thickness on the flow conditions, and the findings could help to design the composite layers.

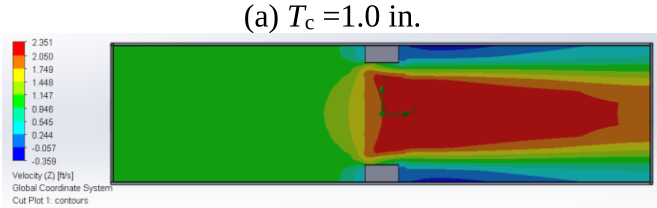
Figs. 2 and 3 were plotted in the cross-sectional view in contour, where flow velocity was 1.0 ft/s and initial pressure was about 15 psi, and pipe dimension was 24-in in diameter. Clearly, the flow conditions (velocity or rate in **Fig. 2** and pressure in **Fig. 3**) were disturbed near the location of the composite layers. With the increase of the thickness, the initial flow rate raised up to over 3 times higher at the narrow pathway than those at other locations, particularly when at the composite layer of T_c =4.0 in as expected. Differently, the flow pressure was less disturbed by the composite layers by less 0.2% over all cases, with slightly more uniformly distribution over the whole flow. Note that the fluid viscosity (friction) such as oil type fluid was not considered in this stage, and we will discuss that in the further study.



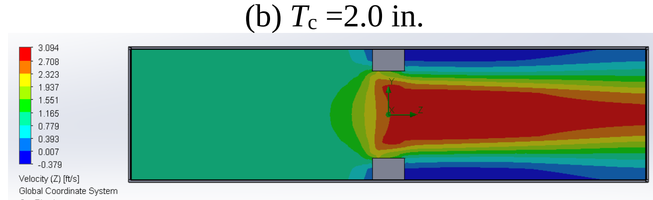
(a) T_c =1.0 in.



(b) T_c =2.0 in.

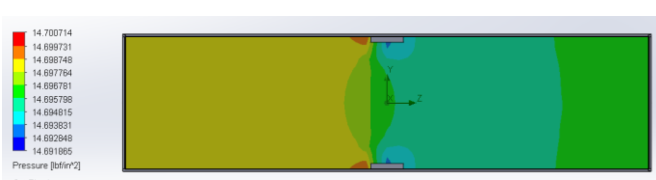


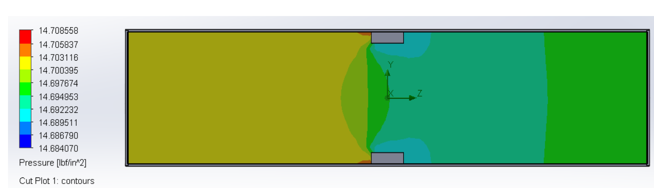
(c) T_c =3.0 in.



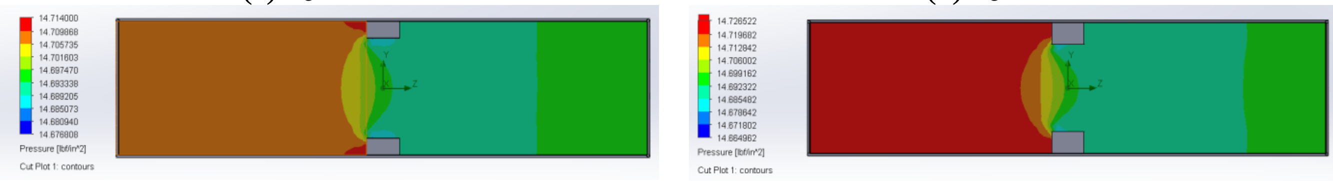
(d) T_c =4.0 in.

Fig. 2 Impacts of different composite thickness on the flow conditions (velocity) by D_p=24-in dia.





(a) T_c =1.0 in. (b) T_c =2.0 in.

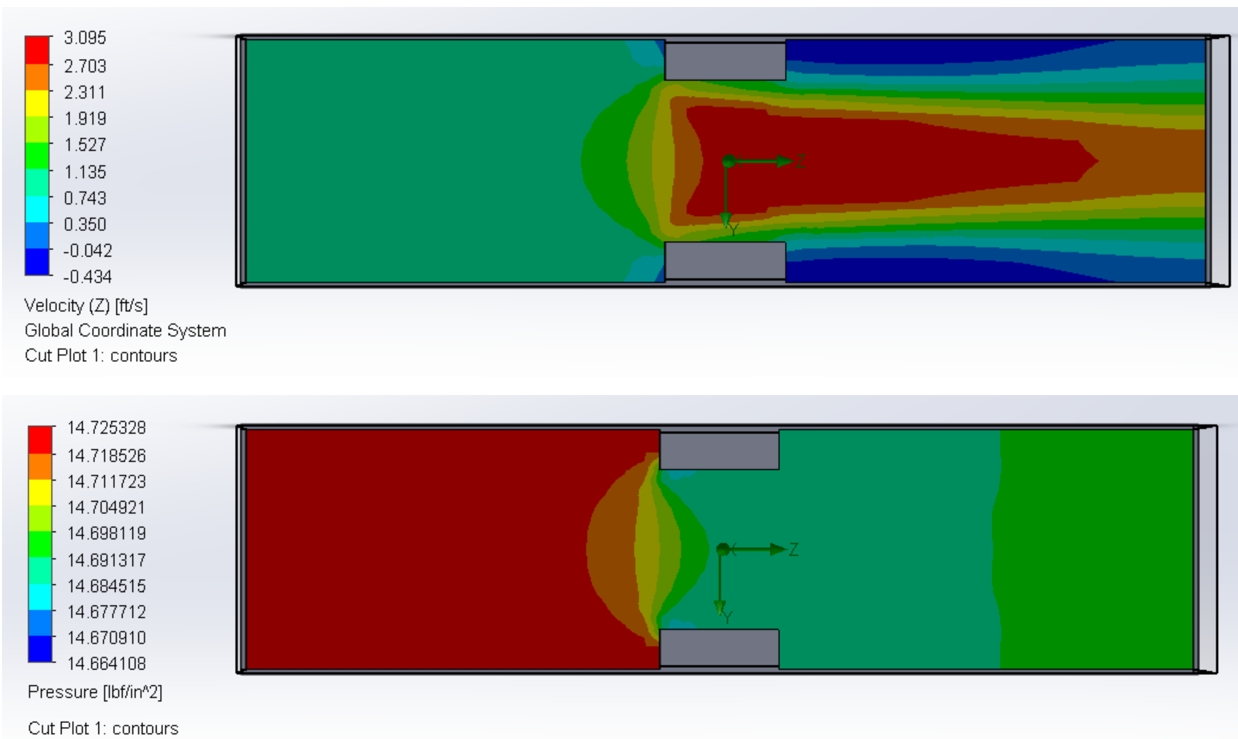


(c) T_c =3.0 in. (d) T_c =4.0 in.

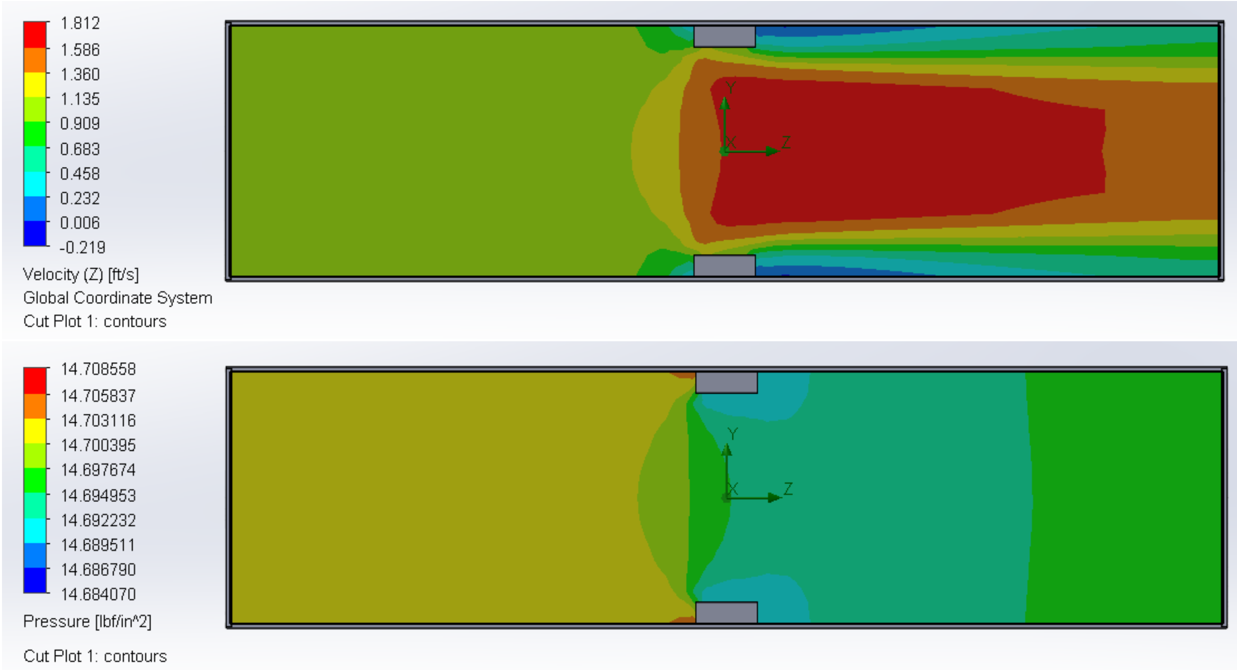
Fig. 3 Impacts of different composite thickness on the flow conditions (pressure) by D_p=24-in dia.

2.2 Effects of the diameter size on the composite layers

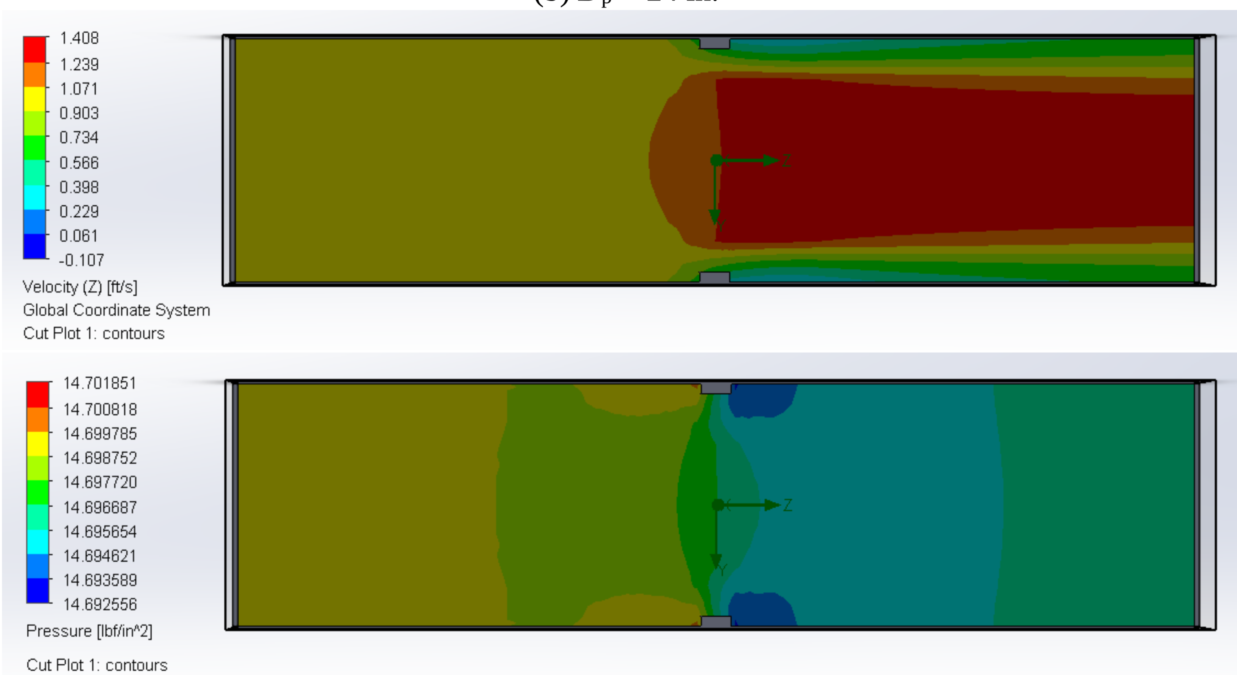
To better qualitatively determine the effectiveness of the composite layers under varying pipe sizes, three typical sizes, 12-, 24-, and 48-in diameters, were selected from small to large scale pipes. The results were shown in **Figs. 4 and 5**, where different diameters and different composite thickness were presented. Clearly, with the increase of the pipe size, the composite layers have less sensitivity to flow conditions (velocity and pressure).



(a) D_p = 12 in.

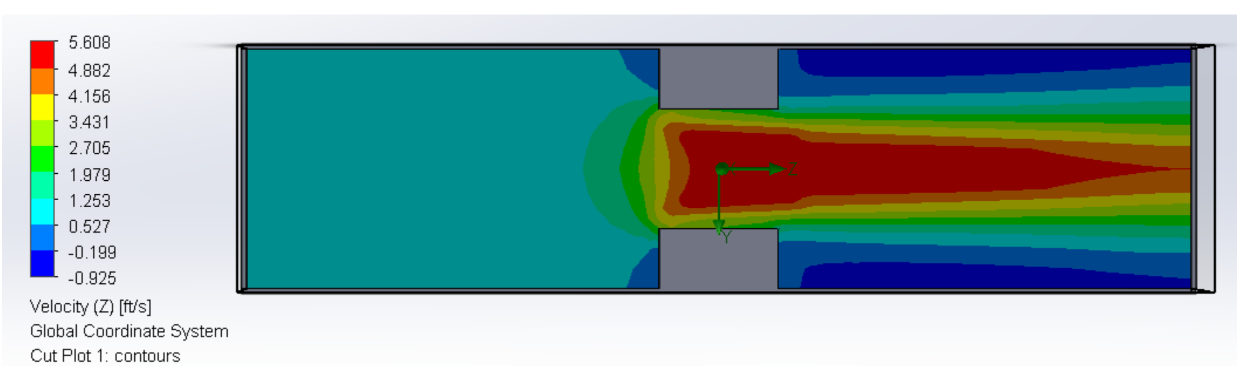


(b) D_p = 24 in.

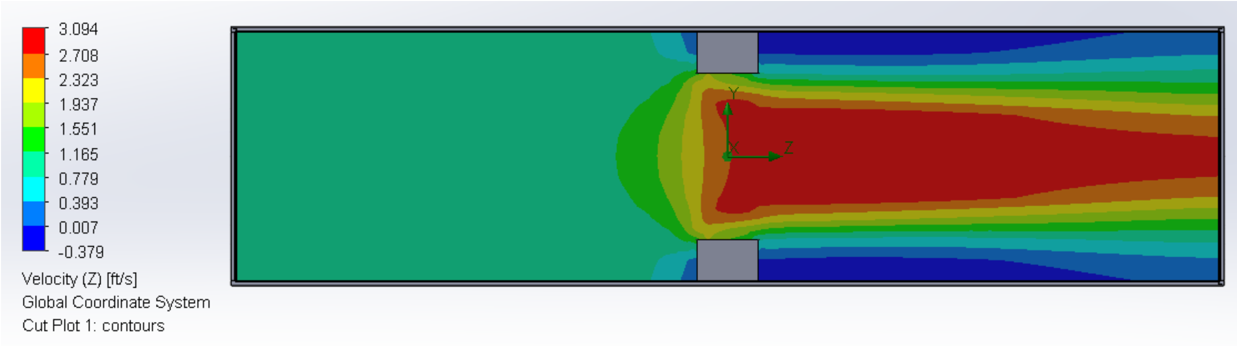


(c) D_p = 48 in.

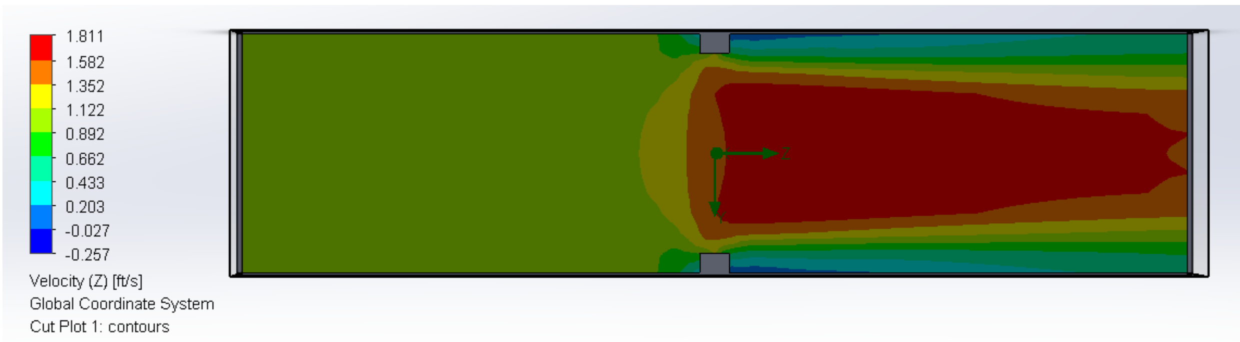
Fig. 4 Impacts of pipe sizes on the composites by T_c =2.0 in.



(a) D_p = 12 in.



(b) D_p = 24 in.

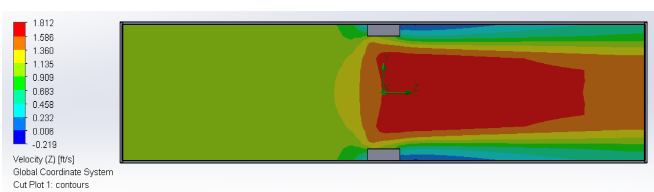


(c) D_p = 48 in.

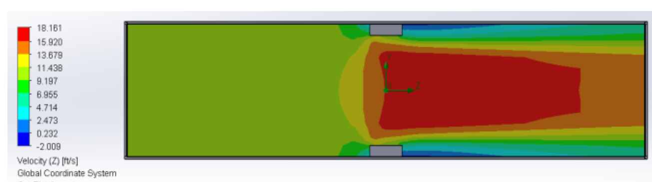
Fig. 5 Impacts of pipe sizes on the composites by T_c =4.0 in.

2.3 Effects of the initial flow velocity on the performance of the composite layers

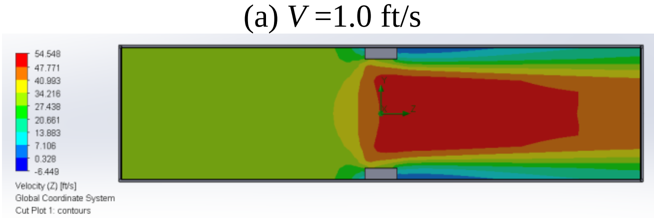
Consider that actual gas pipe could use the initial velocity reach up to 30~60 ft/s, the initial flow velocity could affect the performance of the composite layers on the internal surface of a pipe. The results were shown in **Fig. 6**. The major trend in the flow conditions (velocity and pressure) was identical. The resulting flow velocity was approximately proportional to the amplitude of the initial flow rate, while the resulting flow pressure, illustrated in **Fig. 7**, raised with the increase of the flow velocity as expected.



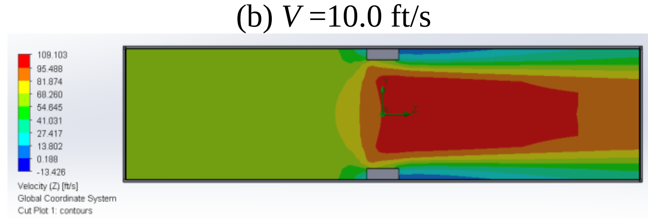
(a) V =1.0 ft/s



(b) V =10.0 ft/s

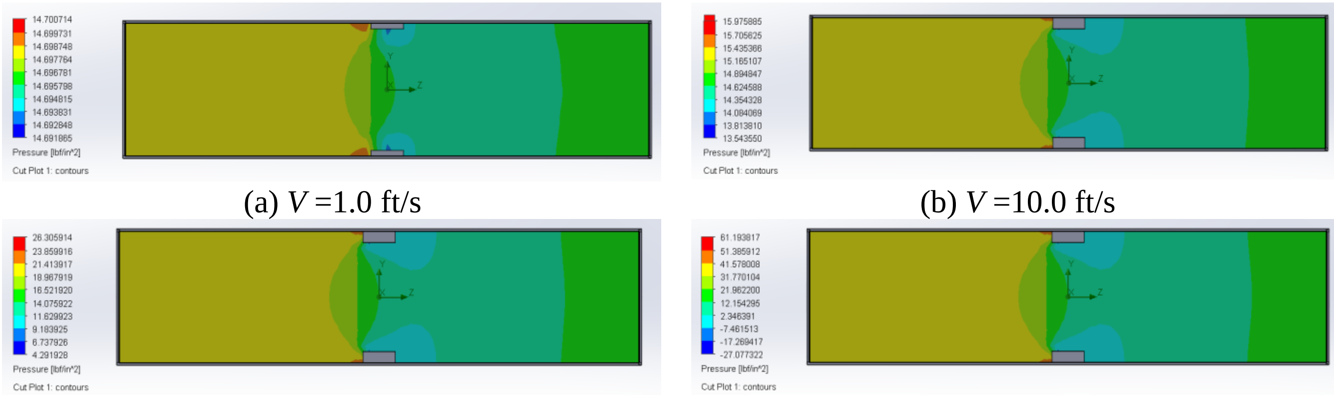


(c) V =30.0 ft/s



(d) V =60.0 ft/s

Fig. 6 Impacts of flow velocity on the composite layers by D_p=24-in dia.



(a) V =1.0 ft/s (b) V =10.0 ft/s

(c) V =30.0 ft/s (d) V =60.0 ft/s

Fig. 7 Impacts of flow velocity on the composite layers by D_p=24-in dia.

2.4 Summary of the work

This research activities in the 5 quarter included: (i) Continuing efforts by design and optimization of the 3D printing lattice structures; (ii) Continuing efforts by characterization of materials; and (iii) conducting numerical simulation in detail for gaining understanding of design parameters for the composite layers in a pipe environment.

3. Description of any Problems/Challenges

No problems are experienced during this report period

4. Planned Activities for the Next Quarter

The planned activities for next quarter are listed below:

- To continue efforts on the design the hierarchy structures of 3D lattices and their performance in a pipe environment;
- To continue efforts on the stabilization of materials in a pipe environment;
- To experimentally investigate and characterize the prototypes for both implementation plans.

ning and oil–water separation[J]. Journal of Materials Chemistry A, 2015, 3(6): 2825-2832.