Quarterly Progress Report:

Project Number and Title: Project 2.4 - Thermoplastic Composites by 3D Printing and Automated Manufacturing to Extend the Life of Transportation Facilities
Research Area: 2 - New Materials for Longevity and Constructability
PI: *Roberto Lopez-Anido, University of Maine*
Co-PI(s): *James Anderson, Douglas Gardner and Yousoo Han, University of Maine*
Reporting Period: *10/01/2020 to 12/31/2020*
Submission Date: *12/28/2020*

Overview of work performed during the reporting period:

Accomplishments achieved under the project goals

- Published journal paper on research findings
  The material properties of thermoplastic polymer parts manufactured by the extrusion-based additive manufacturing process are highly dependent on the thermal history. This paper describes the numerical implementation of a simplified discrete-event simulation model that offers accuracy comparable to a finite element model but is faster by two orders of magnitude. Two polymer systems with distinct thermal properties were selected to highlight differences in the simulation of the orthotropic response and the temperature-dependent material properties. The time–temperature histories from the numerical model were compared to the time–temperature histories from a conventional finite element model and were found to match closely (Figure 1). The model would enable designers to compare the effects of several printing parameters for specific 3D-printed parts and select the most suitable parameters for the part.

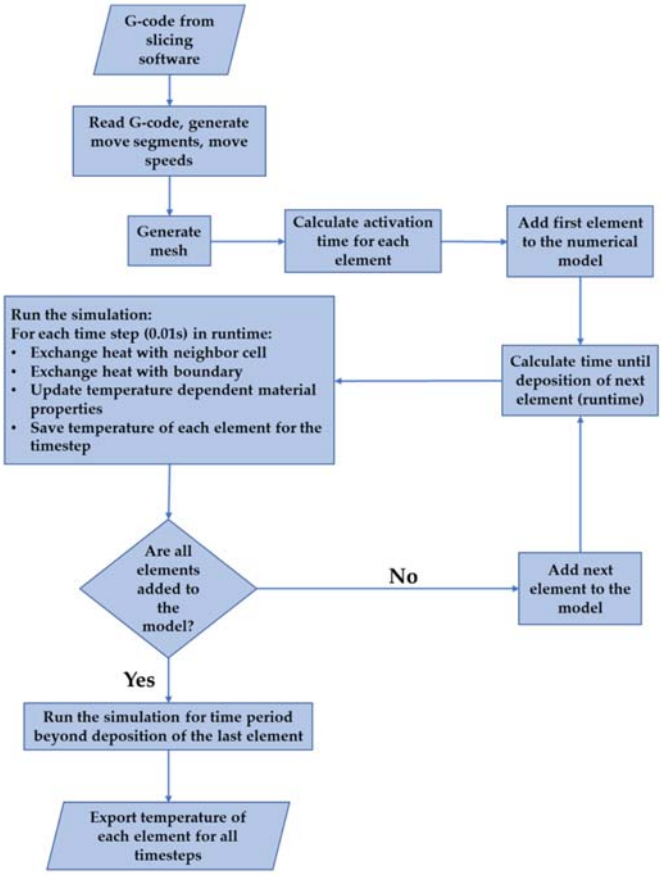

Figure 1. Flow chart of model developed to enable design of 3D printed parts

Ref.: Bhandari S., and Lopez-Anido, R.A. "Discrete event simulation thermal model for extrusion-based additive manufacturing of PLA and ABS," Materials, 13(21), 4985 (2020) https://doi.org/10.3390/ma13214985 (Open Access).

Opportunity for training of Ph.D. student

- Attended Transportation Research Board (TRB) webinar:

  Sunil Bhandari, Ph.D. candidate, attended "Tools of the Future - Printing Cement-Based Materials in 3D," Nov. 1, 2020.

Opportunity for dissemination of research results

- Presented research findings at international conference

  Professor Roberto Lopez-Anido, P.I., presented the feasibility of using large scale extrusion-based additive manufacturing with bio-based thermoplastic composite materials for making 3D printed forms for casting precast concrete structures (Figure 2).

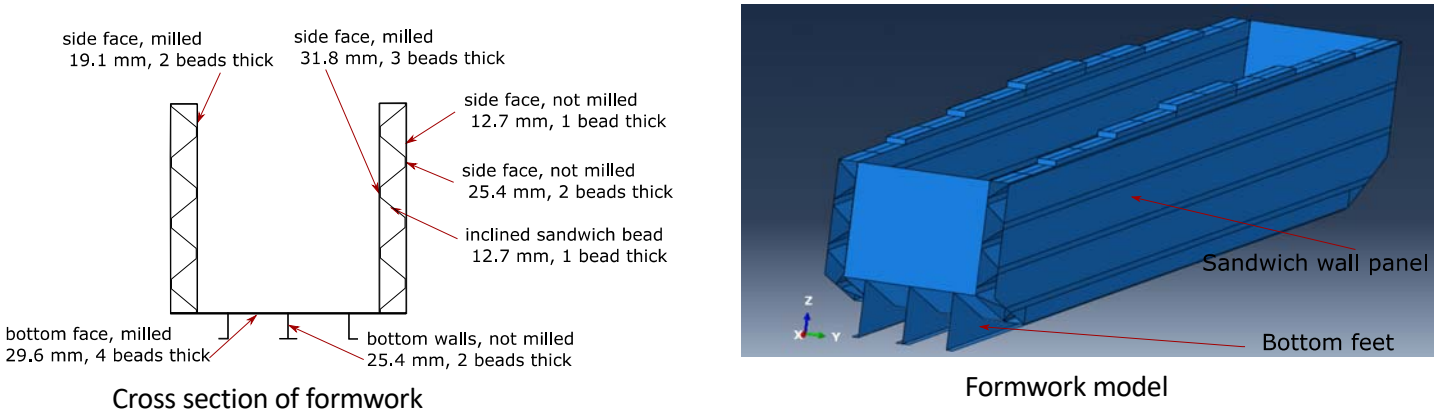

Figure 2. 3D Printed form design

Ref.: Bhandari, S., Lopez-Anido, R., and Anderson, J. "Large scale 3D printed thermoplastic composite forms for precast concrete structures," 5th International Conference & Exhibition on Thermoplastic Composites, ITHEC 2020 Virtual Edition, in proceedings p.182, Oct. 13-15, Bremen, Germany (2020).

Technology deployed in transportation applications through demonstration studies as a result of this research project

- Organized meetings with Technical Champion, Rita Seraderian, Precast/Prestressed Concrete Institute Northeast (PCI)-NE and precasters/producers to identify demonstration studies for large-scale 3D printed forms for precast concrete construction. Dates: Oct. 29, Nov. 20, Nov. 23 and Dec. 7, 2020.
- The feasibility of three demonstrations studies for the large scale 3D printing technology is currently being investigated:
  1) Unistress Corporation, Pittsfield, MA: 3D printed form for window screen system in Litewall panel for parking structures.
  2) Coreslab, Thomaston, CT: 3D printed form for mock-up panel mold for the PCI certification (Category AA Type 3). Compare with existing wood form
  3) American Concrete Industries, Veazie, ME, and Sargent Corporation, Stillwater, ME: 3D printed transition pipe invert for conduit for combined sewer overflow into Back Cove in Portland, ME.

Technology adoption by industry or transportation agencies as a result of findings from this research project

- Provided technical feedback to Dale Peabody, Maine DOT, on durability testing of 3D printed thermoplastic composites materials for an acceptance criteria to be included in the Qualified Products List. Date: Dec. 18, 2020.

Table 1.1: Phase 1 - Task Progress			
Task Number	**Start Date**	**End Date**	**Percent Complete**
Task 1.1: Review of the state-of the-art	01/01/2019	06/30/2019	100%
Task 1.2: Study the feasibility of using large-scale 3D printed forms for casting precast concrete structures	07/01/2019	12/31/2019	100%
Task 1.3: Select thermoplastic composite materials and surface finishing for 3D printed forms	01/01/2020	03/31/2021	90%
Task 1.4: Design and analyze large-scale 3D printed forms for precast concrete operation requirements	04/01/2020	06/30/2021	80%
Task 1.5: Design additive manufacturing, machining and assembly process for large-scale 3D printed forms	07/01/2020	12/31/2021	70%

Table 1.2: Phase 2 - Task Progress			
Task Number	**Start Date**	**End Date**	**Percent Complete**
Task 2.1: Manufacture large-scale 3D printed forms for precast concrete construction	10/01/2020	06/30/2021	10%
Task 2.2: Monitor concrete casting and demolding operations using 3D printed forms	07/01/2021	09/30/2022	0%
Task 2.3: Disseminate large-scale 3D printed form technology for precast concrete construction	01/01/2021	09/30/2022	0%
Task 2.4: Evaluate durability of 3D printed forms after reuse cycles of casting and demolding concrete operations	10/01/2021	09/30/2022	0%
Task 2.5: Facilitate large-scale 3D printed technology deployment and adoption by specifying material, manufacturing and operational requirements.	07/01/2022	12/31/2022	0%

Table 2.1: Phase 1 - Budget Progress		
Project Budget	**Spend – Project to Date**	**% Project to Date***
To be completed by Grant/Fiscal Manager, Advanced Structures and Composites Center, UMaine		

Phase 1: Total budget $149,912 ($52,881 from Federal Share and $97,031 from cost share).

Table 2.2: Phase 2 - Budget Progress		
Project Budget	**Spend – Project to Date**	**% Project to Date***
To be completed by Grant/Fiscal Manager, Advanced Structures and Composites Center, UMaine		

Phase 2: Total budget $158,467 ($51,522 from Federal Share and $106,945 from cost share).

Table 3: Presentations at Conferences, Workshops, Seminars, and Other Events				
Title	**Event**	**Type**	**Location**	**Date(s)**
Large Scale 3D Printed Thermoplastic Composite Forms for Precast Concrete Structures	5th International Conference & Exhibition on Thermoplastic Composites, ITHEC 2020	International Conference	Virtual	Oct. 13-15, 2020

Table 4: Publications and Submitted Papers and Reports				
Type	**Title**	**Citation**	**Date**	**Status**
Conference paper	Large scale 3D printed thermoplastic composite forms for precast concrete structures	Bhandari, S., Lopez-Anido, R., and Anderson, J., 5th International Conference & Exhibition on Thermoplastic Composites, ITHEC 2020 Virtual Edition, in proceedings p.182, Bremen, Germany (2020).	Oct. 13-15, 2020	Published
Journal paper	Discrete event simulation thermal model for extrusion-based additive manufacturing of PLA and ABS	Bhandari S., and Lopez-Anido, R.A., Materials, 13(21), 4985 (2020) (Open Access). https://doi.org/10.3390/ma13214985	Nov. 5, 2020	Published

Participants and Collaborators:

Table 5: Active Principal Investigators, faculty, administrators, and Management Team Members			
Individual Name	**Email Address**	**Department**	**Role in Research**
Roberto Lopez-Anido	rla@maine.edu	Civil and Environmental Engineering	P.I.
Douglas Gardner	douglasg@maine.edu	School of Forest Resources	Co P.I.
James Anderson	James.m.anderson@maine.edu	Advanced Structures and Composites Center	Co PI
James Bryce	James.bryce@maine.edu	Advanced Structures and Composites Center	Project Manager

Table 6: Student Participants during the reporting period				
Student Name	**Email Address**	**Class**	**Major**	**Role in research**
Sunil Bhandari		Ph.D. Candidate	Civil Engineering	Design the 3D printed formwork, conduct Finite Element Analysis of stresses and deformations, optimize the formwork.

Table 7: Student Graduates			
Student Name	**Role in Research**	**Degree**	**Graduation Date**
N.A.			

Table 8: Research Project Collaborators during the reporting period						
Organization	**Location**	**Contribution to the Project**				
		Financial Support	**In-Kind Support**	**Facilities**	**Collaborative Research**	**Personnel Exchanges**
Precast/Prestressed Concrete Institute Northeast (PCI-NE)	Belmont, MA				X	
Unistress Corporation	Pittsfield, MA				X	
Coreslab	Thomaston, CT				X	
American Concrete Industries	Veazie, ME				X	

Table 8: Research Project Collaborators during the reporting period						
Organization	**Location**	**Contribution to the Project**				
		Financial Support	**In-Kind Support**	**Facilities**	**Collaborative Research**	**Personnel Exchanges**
MaineDOT	Augusta, ME				x	
Precast/Prestressed Concrete Institute Northeast (PCI-NE)	Belmont, MA				x	

Technical Champion:
Name: Rita L. Seraderian
Title: Executive Director
Organization: PCI-NE
Location (City & State): Belmont, MA
Email: rseraderian@pcine.org

Changes:
The schedule has been affected by disruption of day-to-day laboratory and office work due to the University shutdown in response to COVID-19 health safety precautions.

Planned Activities:
During the first quarter of 2021 we plan to work on the following tasks:

- Task 1.3: Select thermoplastic composite materials and surface finishing for 3D printed forms
- Task 1.4: Design and analyze large-scale 3D printed forms for precast concrete operation requirements
- Task 1.5: Design additive manufacturing, machining and assembly process for large-scale 3D printed forms
- Task 2.1: Manufacture large-scale 3D printed forms for precast concrete construction