Quarterly Progress and Performance Indicators 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): *Sunil Bhandari, University of Maine*
Reporting Period: *1/1/2022-3/31/2022*
Submission Date: *3/31/2022*

Overview:

*Provide **BRIEF** highlights of activities performed during the reporting period.*

- Plan developed with Unistress for monitoring and data gathering during concrete casting operations.
- Instrumentation reviewed for measuring surface roughness and temperature history during casting.
- Preparation for casting concrete carried out at Unistress plan in Massachusetts.

Meeting the Overarching Goals of the Project:

How did the previous items help you achieve the project goals and objects? Please give one bullet point for each bullet point listed above.

- Evaluate the performance of 3D printed formwork through repeated cycles of concrete casting/demolding.
- Assess longevity and establish the useful fatigue life for 3D printed formwork.
- Investigate the cost/benefit of 3D printed formwork, which will be realized provided the material is durable and dimensionally stable.

Accomplishments:

List any accomplishments achieved under the project goals in bullet point form…

- Preparation for initial testing of 3D printed formworks on a production scale at a plant.

Task Progress and Budget:

Complete the following tables to document the work toward each task and budget.

Table 1: Phase 1 and Phase 2 - Task Progress			
Task Number	**Start Date**	**End Date**	**% 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	100%
Task 1.4: Design and analyze large-scale 3D printed forms for precast concrete operation requirements	04/01/2020	06/30/2021	100%
Task 1.5: Design additive manufacturing, machining and assembly process for large-scale 3D printed forms	07/01/2020	12/31/2021	100%
Task 2.1: Manufacture large-scale 3D printed forms for precast concrete construction	10/01/2020	06/30/2021	100%
Task 2.2: Monitor concrete casting and demolding operations using 3D printed forms	07/01/2021	09/30/2022	15%
Task 2.3: Disseminate large-scale 3D printed form technology for precast concrete construction	01/01/2021	09/30/2022	20%
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%
Phase 1 Overall	01/01/2019	12/31/2021	100% Complete
Phase 2 Overall	10/01/2020	12/31/2022	30% Complete

Table 2: Budget Progress		
Project Budget	**Spend – Project to Date**	**% Project to Date (include the date)**
Enter Phase 1 Full Budget: $149,912	$149,912.00	100%
Enter Phase 2 Full Budget: $158,467	$44,963.00	28.37%
Enter Phase 3 Full Budget: $280,374	$0.00	0%

Is your Research Project Applied or Advanced?

☒ **Applied** (*The systematic study to gain knowledge or understanding necessary for determining the means by which a recognized and specific need may be met.)*

☐ **Advanced** *(An intermediate research effort between basic research and applied research. This study bridges basic (study to understand fundamental aspects of phenomena without specific applications in mind) and applied research and includes transformative change rather than incremental advances. The investigation into the use of basic research results to an area of application without a specific problem to resolve.)*

Professional Development/Training Opportunities:

Describe any opportunities for training/professional development that have been provided. Did you provide a training to a State DOT/AOT or industry organization? What was the training? When was it offered? How many people attended? Did you meet with a State DOT/AOT or industry organization to inform them of your findings and how these findings could help their organization? When? How many attended the meeting?

- *N/A*

Technology Transfer:

Complete all of the tables below and provide additional information where requested. Please provide ALL requested information as this is one of the most important sections for reporting to the USDOT. ***ONLY provide information relevant to this reporting period.***

Use the table below to complete information about conference sessions, workshops, webinars, seminars, or other events you led/attended where you shared findings as a result of the work you conducted on this project:

Table 3: Presentations at Conferences, Workshops, Seminars, and Other Events					
Type	**Title**	**Citation**	**Event**	**Location**	**Date(s)**
N/A	N/A	N/A	N/A	N/A	N/A

Use the table below to report any publications, technical reports, peer-reviewed articles, newspaper articles referencing your work, graduate papers, dissertations, etc. written as a result of the work you conducted on this project. Please list only completed items and exclude work in progress.

Table 4: Publications and Submitted Papers and Reports

Type	Title	Citation	Date	Status
Peer-reviewed journal	Design and Manufacture of Precast Concrete Formwork Using Polymer Extrusion-Based Large Scale Additive Manufacturing and Postprocessing	Bhandari, S., Lopez-Anido, R.A., Saavedra Rojas, F., and LeBihan, A. "Design and Manufacture of Precast Concrete Formwork Using Polymer Extrusion-Based Large Scale Additive Manufacturing and Postprocessing," STP1644 on ASTM International Conference on Additive Manufacturing (ICAM 2021).	Mar. 30, 2022	Reviewed and re-submitted with minor revisions

Answer the following questions (N/A if there is nothing to report):

1. Did you deploy any technology during the reporting period through pilot or demonstration studies as a result of this work? If so, what was the technology? When was it deployed?
   N/A
2. Was any technology adopted by industry or transportation agencies as a result of this work? If so, what was the technology? When was is adopted? Who adopted the technology? *N/A*
   N/A
3. Did findings from this research project result in changing industry or transportation agency practices, decision making, or policies? If so, what was the change? When was the change implemented? Who adopted the change?
   N/A
4. Were any licenses granted to industry as a result of findings from this work? If so, when? To whom was the license granted?
   N/A
5. Were any patent applications submitted as a result of findings from this research? If so, please provide a copy of the patent application with your report.
   N/A
6. Were any industrial contracts awarded base on furthering planned research and development activities as a result of findings from this work? If so, when? How much was awarded? Who awarded the contract?
   N/A

Please add figures/images that can be included on the website and/or in marketing/social media materials to further clarify your research to the general public.

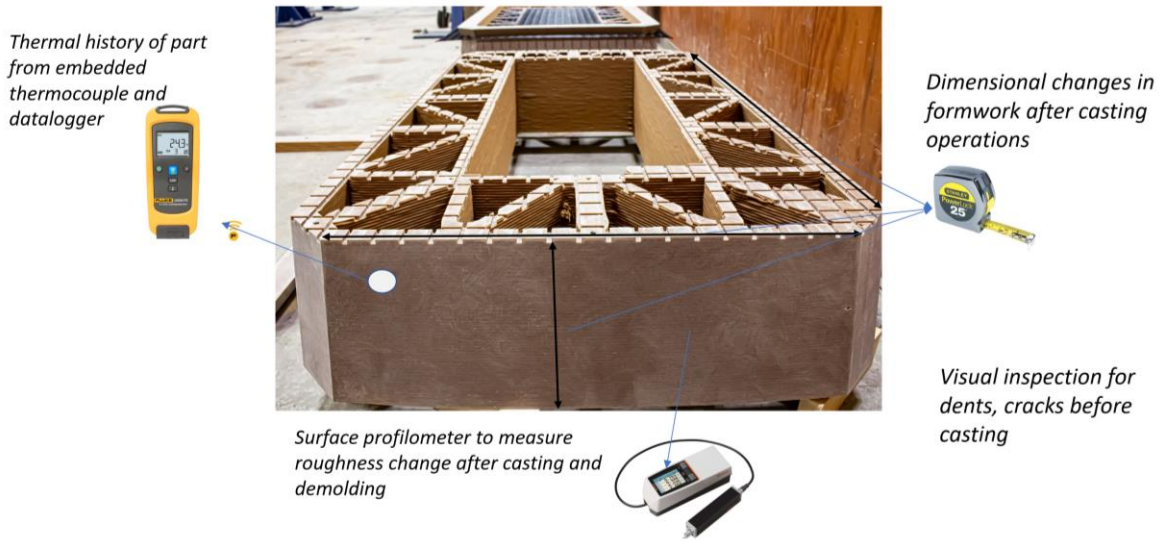

Figure 1 – Methods to monitor the formwork quality during casting and after each casting cycles.

Describe any additional activities involving the dissemination of research results not listed above under the following headings:

Outputs:
Definition: Any new or improved process, practice, technology, software, training aid, or other tangible product resulting from research and development activities. They are used to improve the efficiency, effectiveness, and safety of transportation systems. List any outputs accomplished during this reporting period: N/A

Outcomes:
Definition: The application of outputs; any changes made to the transportation system, or its regulatory, legislative, or policy framework resulting from research and development activities. List any outcomes accomplished during this reporting period: N/A

Impacts:

Definition: The effects of the outcomes on the transportation system such as reduced fatalities, decreased capital or operating costs, community impacts, or environmental benefits. The reported impacts from UTCs are used for the assessment of each UTC and to make a case for Federal funding of research and education by demonstrating the impacts that UTC funding has had on technology and education. NOTE: The U.S. DOT uses this information to assess how the research and education programs (a) improve the operation and safety of the transportation system; (b) increase the body of knowledge and technologies; (c) enlarge the pool of people trained to develop knowledge and utilize technologies; and (d) improves the physical, institutional, and information resources that enable people to have access to training and new technologies. List any outcomes accomplished during this reporting period:
N/A

Participants and Collaborators:

*Use the table below to list **all** individuals (compensated or not) who have worked on the project.*

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	PI
Sunil Bhandari	sunil.bhandari@maine.du	Advanced Structures and Composites Center	Co-PI
James Bryce	James.bryce@maine.edu	Advanced Structures and Composites Center	Project Manager

*Use the table below to list **all** students who have participated in the project during the reporting period. (This includes all paid, unpaid, intern, independent study, or any other student that participated in this project.)*

Table 6: Student Participants during the reporting period								
Student Name	**Start Date**	**End Date**	**Advisor**	**Email Address**	**Level**	**Major**	**Funding Source**	**Role in research**
Felipe Saavedra	2021-01-01	present	R. Lopez-Anido		M.S. student	Civil Engineering	TIDC	Mechanical property characterization of WF-PLA and CF-ABS

Use the table below to list any students who worked on this project and graduated or received a certificate during this reporting period. Include information about the student's accepted employment (i.e. the student is now working at MaineDOT) or if they are continuing their students through an advanced degree (list the degree and where they are attending).

Table 7: Students who Graduated During the Reporting Period			
Student Name	**Degree/Certificate Earned**	**Graduation/Certification Date**	**Did the student enter the transportation field or continue another degree at your university?**
N/A	N/A	N/A	N/A

Use the table below to list any students that participated in Industrial Internships:

Table 8: Industrial Internships			
Student Name	**Degree/Certificate Earned**	**Graduation/Certification Date**	**Did the student enter the transportation field or continue another degree at your university?**
N/A	N/A	N/A	N/A

*Use the table below to list **organizations** that have been involved as partners on this project and their contribution to the project.*

Table 9: Research Project Collaborators during the reporting period						
Organization	**Location**	**Contribution to the Project**				
		Financial Support	**In-Kind Support**	**Facilities**	**Collaborative Research**	**Personnel Exchanges**
		List the amount	List the amount	Mark with an "x" where appropriate		
MaineDOT	Augusta, ME				x	
Precast/Prestressed Concrete Institute Northeast (PCI-NE)	Belmont, MA				X	
Unistress Corporation	Pittsfield, MA		40,000		X	
American Concrete Industries	Veazie, ME			X	X	

*Use the table below to list **individuals** that have been involved as partners on this project and their contribution to the project.*
*(**List your technical champion(s) in this table.** This also includes collaborations within the lead or partner universities who are not already listed as PIs; especially interdepartmental or interdisciplinary collaborations.)*

Table 10: Other Collaborators

Collaborator Name and Title	Contact Information	Organization and Department	Date(s) Involved	Contribution to Research
	For internal use only			(i.e. technical champion, technical advisory board, test samples, on-site equipment, data, etc.)
Rita L. Seraderian, P.E., FPCI, Executive Director		PCI-NE	2019-02-01 present	Technical champion
Joseph Stilwell P.E., Fabrication Engineer		MaineDOT-Bridge Program	2021-03-03 present	3D printed formwork for railroad bridge ballast retainer

Use the following table to list any transportation related course that were taught or led by researchers associated with this research project:

Table 11: Course List

Course Code	Course Title	Level	University	Professor	Semester	# of Students
i.e. CE 123		Grad or undergrad?	Where was the course taught?	Who taught the course?	Enter Spring, Fall, Summer, Winter and the year	How many students were enrolled in the class?
CIE 545	Structural Dynamics	Grad	Orono, ME	Dr. Bhandari	Spring 2022	5

Changes:

List any actual or anticipated problems or delays and actions or plans to resolve them (list no-cost extension requests here)…

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.

List any changes in approach and the reasons for the change…

Planned Activities:

List the activities planned during the next quarter.

- Cast the concrete part using Wood fiber/PLA and Carbon fiber/ABS forms at Unistress Corp. plant in Pittsfield, Massachusetts
- Cast railroad bridge ballast retainer formwork at American Concrete Industries plant in Veazie, Maine.
- Monitor the temperatures and deformation in the forms during concrete casting operations.
- Assess and monitor the damage to the forms during repeated castings.
- Assess the durability of the WF/PLA and CF/ABS forms compared to traditional steel forms in terms of number of castings before failure.
- Further investigate the repair methods and their effects on durability of the 3D printed forms.