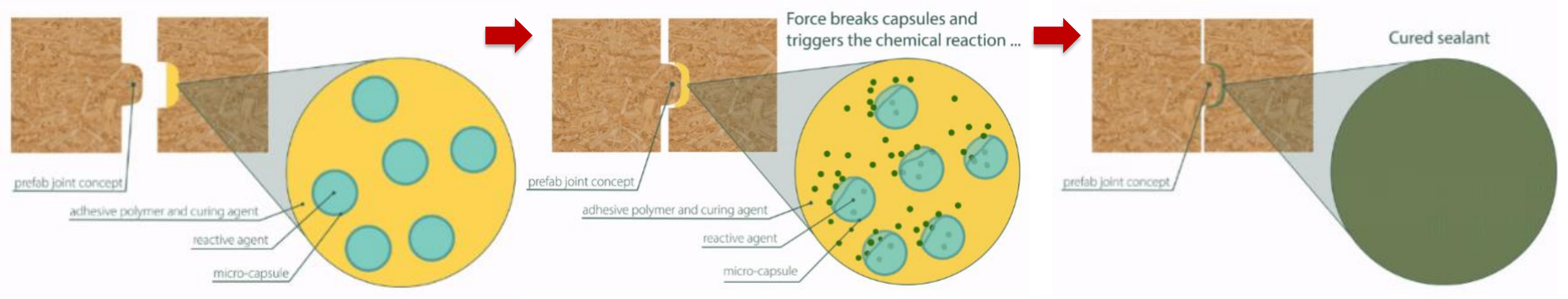
Preinstalled Sealant for Prefab Components



Oak Ridge National Laboratory
Diana Hun, Group Leader, Building Envelope Materials Research
hunde@ornl.gov

Project Summary

Timeline:

Start date: August 1, 2020

Planned end date: July 31, 2023

Key Milestones

July 31, 2021: Synthetized a pressure-triggered sealant that cures in ~4 hours at room temperature.

July 31, 2023: Synthetized a pressure-triggered sealant with adhesion strength ≥20 lb/inch after 5 days curing at 20°F

Budget:

Total Project $ to Date:

- DOE: $1M
- Cost Share: ~$50K

Total Project $:

- DOE: $1M
- Cost Share: $250K

Key Partners:

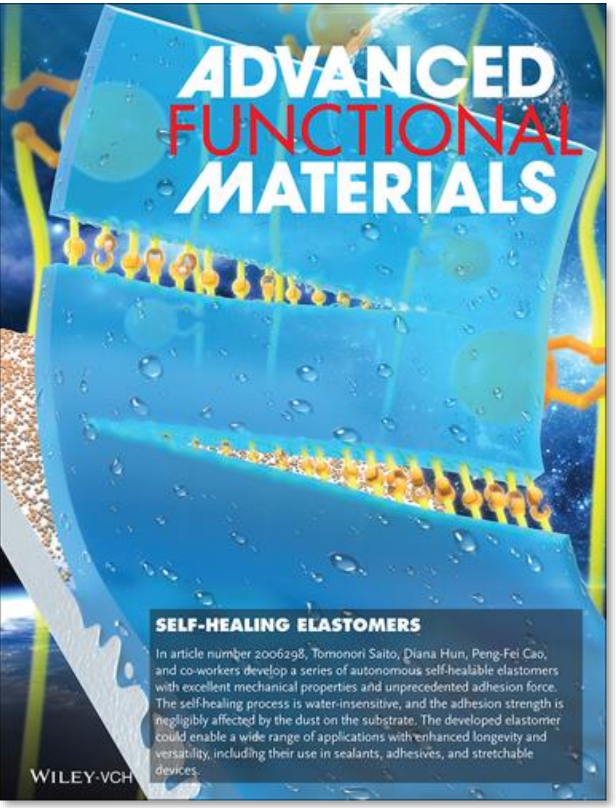
BENSONWOOD

CertainTeed SAINT-GOBAIN

Project Outcome:

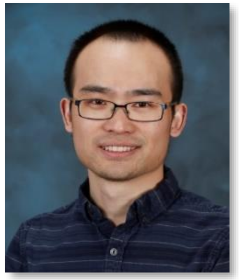
Sealant that is installed at prefab plants and is pressure-activated at the jobsite to improve installation speed and quality of prefab components, reduce energy waste due to air leakage through the building envelope, and decrease assembly cost.

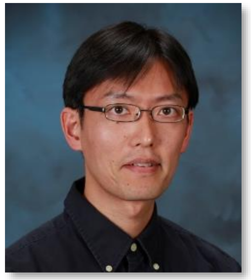
Team

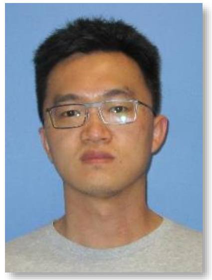


Autonomous Self-Healing Elastomers with Unprecedented Adhesion Force
doi.org/10.1002/adfm.202006298


Diana Hun


Pengfei Cao


Tomonori Saito


Jiancheng Luo


Zoriana Demchuk

OAK RIDGE National Laboratory

Specializes in developing technologies for buildings

Material Synthesis

Scaleup and Deployment

Practical Integration


Dennis Michaud


William Lentlie

CertainTeed SAINT-GOBAIN

110+ years supplying building products


Hans Porschitz


Jay Lepple

BENSONWOOD

40+ years designing and building sustainable homes

Challenge

Current Joint Sealing Techniques

Tapes

Caulks and spray foams

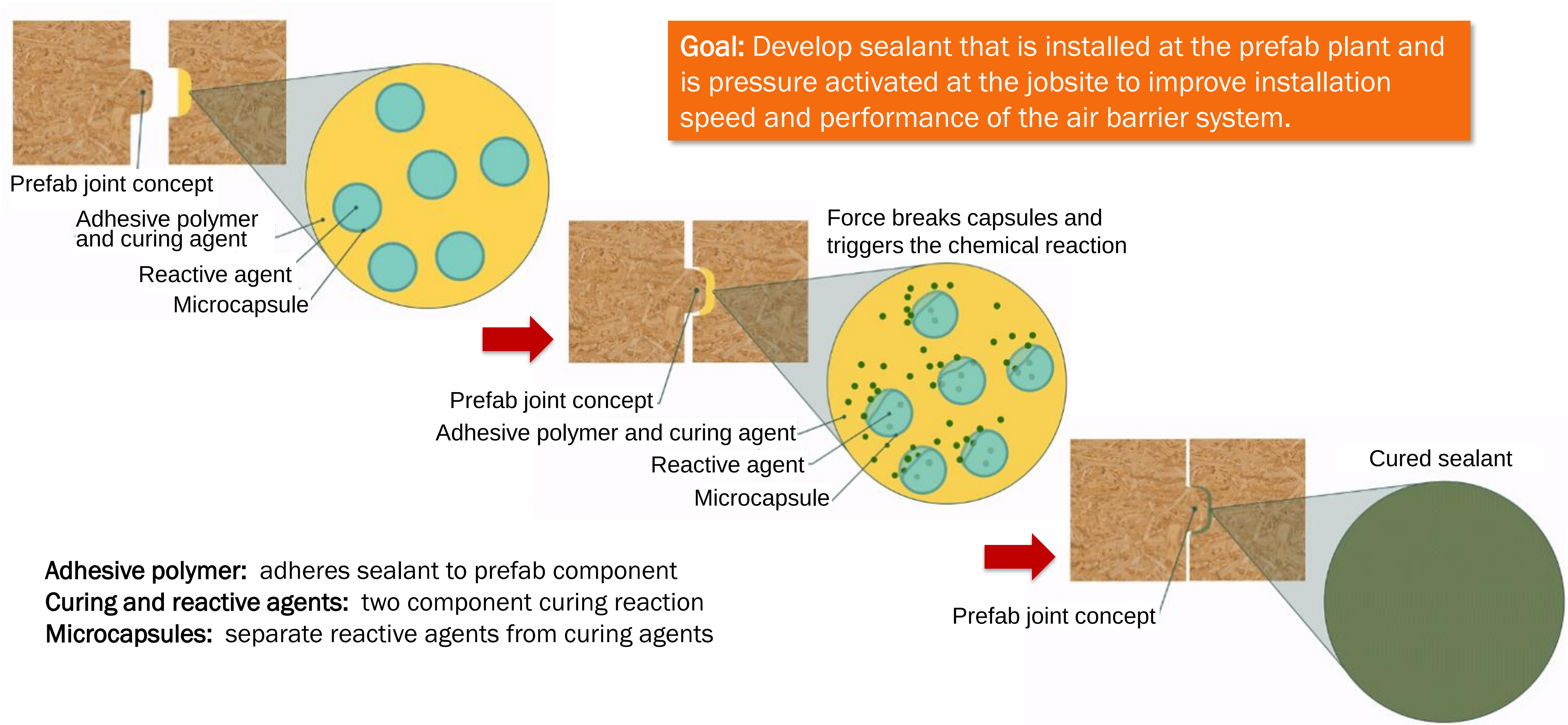
Gaskets

- Very time consuming
- Highly dependent on the installer
- Negate advances in productivity achieved at prefab plants

- Prefab construction has been gaining momentum because assembly is efficiently done in controlled environments with quality control enforcement.
- A main deficiency in prefab construction is joint sealing at the jobsite to maintain continuity of the air and water barriers.
- Time-efficient, high-performance air sealing techniques are needed because air leakage is responsible for ~13% of the energy used in homes and ~6% of the energy used in commercial buildings.
- Improvements in productivity will make prefab construction more affordable.

Approach

Goal: Develop sealant that is installed at the prefab plant and is pressure activated at the jobsite to improve installation speed and performance of the air barrier system.



Adhesive polymer: adheres sealant to prefab component
Curing and reactive agents: two component curing reaction
Microcapsules: separate reactive agents from curing agents

Impact

- BTO's Advanced Building Construction (ABC) Initiative aims to increase affordability of energy efficiency and decarbonization through higher productivity.
- Prefab construction has been successful in increasing productivity at manufacturing plants.
- Onsite assembly of prefab components lacks innovation
  - Hinders performance and affordability
  - Assembling the air barrier system with prefab components is one of the most time-consuming tasks at the jobsite
- Air infiltration is responsible for ~4% of total energy used in the US.
- Preinstalled sealant for prefab construction
  - Enables annual energy savings of ~665 TBU from reductions in infiltration
  - Increases affordability of prefab construction

Productivity and Technological Innovation

	Circa 1940s	Circa 2016	Productivity Growth
Agriculture			1,512
Manufacturing			760
Retail			699
Construction			6

Cumulative real growth in the US, %, 1947-2010

Progress: Research Steps

1. Set initial sealant requirements based on feedback from industry partners
2. Synthetize adhesive polymers and test properties, e.g., adhesive force, mechanical properties
3. Identify curing system with high adhesion and tunable curing time
4. Synthesize microcapsules with tunable size and load reactive agent inside microcapsules
5. Demonstrate prototype of pressure-triggered sealant
6. Co-optimize required parameters to meet specs

Progress: Specs Based on Industry Input

	Item	Bensonwood and CertainTeed Criteria	Status
1	Low VOC emissions	California standards	Ongoing
2	Adhesion strength (ASTM D794)	>20 lb/inch	Ongoing
3	Activation pressure	10-100 Psi	Ongoing
4	Curing temperature and time	20 to 110 °F Separate panels in 30-minute window. Shift/slide panels in 1 hour window. 2 to 5 days max curing at constant 20 °F.	Ongoing
5	Service temperature	-20 to 180 °F	Ongoing
6	Low water permeability		Ongoing
7	Life Expectancy	20 years	Ongoing
8	Max cured elongation (ASTM D412)	Aim for 200% but will try 500%	Ongoing
9	Max. joint movement (ASTM C719)	±25%	Ongoing
10	Max joint width	1/2" to 3/4"	Ongoing
11	Installation temperature at plant	60 to 80 °F	Future
12	Resistance to compression/extension	±50%	Future
13	Hardness (ASTM C661)	15	Future
14	Tack-free time (ASTM C679)	2 hours or less	Future
15	Cut, tear, abrasion resistance		Future
16	Ultra-Violet resistance	2 to 4 weeks outdoor exposure max	Future

Progress: Adhesive Polymer with Self-Healing Properties

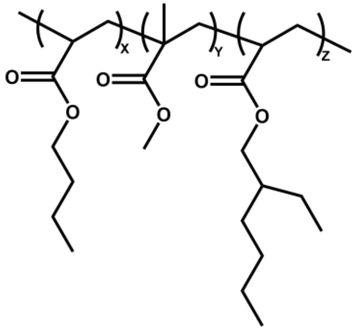
Purpose

- Allow formulation to adhere to the substrate
- Extend life-time of sealant (Spec: life expectancy > 20 years)
- Achieve high elongation (Spec: max cured elongation 50%-500%)

Developed cost-effective approach for adhesive polymer that is highly stretchable and self-healable.

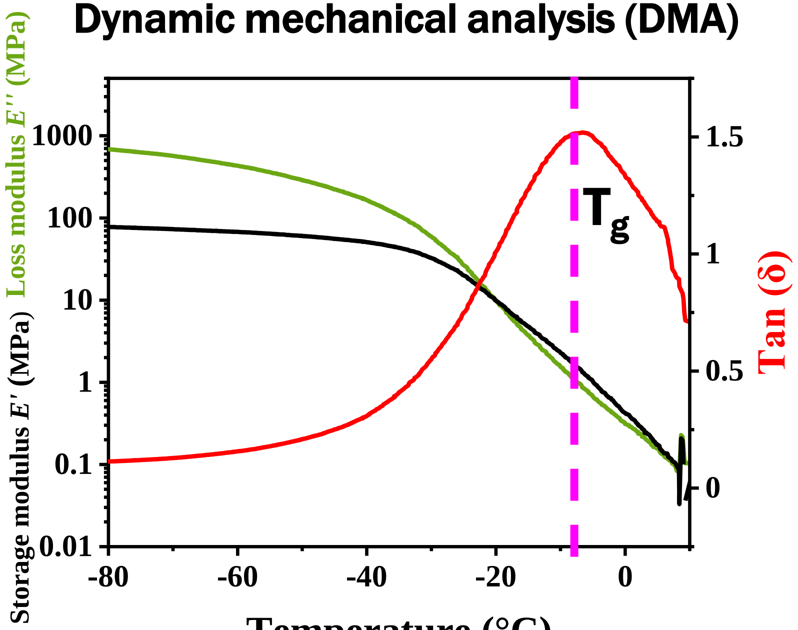
Requirements

- Inexpensive polymerization
- High stretchability (> 1500%)
- Low glass transition temperature
- Self-healable

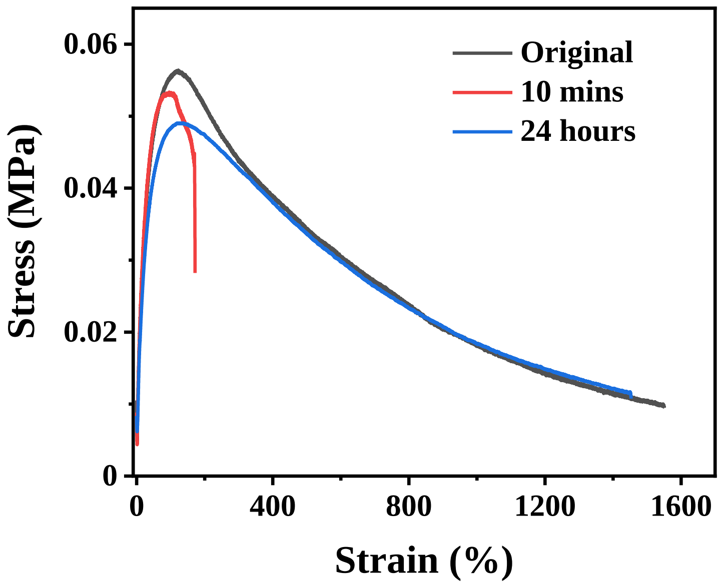


BA MMA EHA

Dynamic mechanical analysis (DMA)



Tensile test of original and healed sample



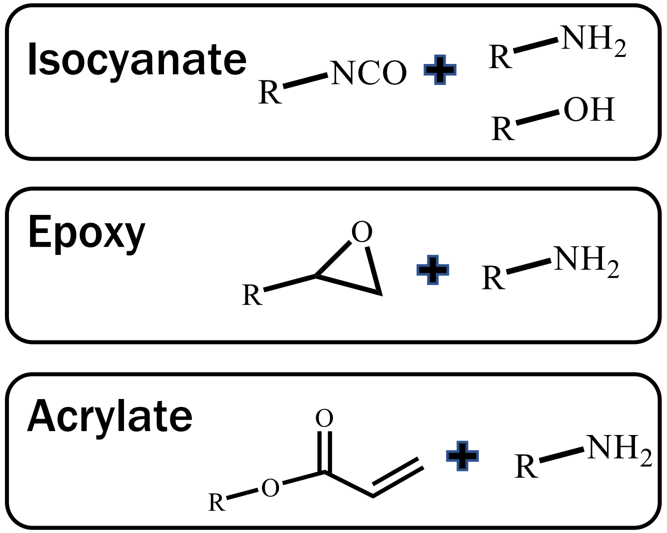
Progress: Curing System

Purpose: two-part system that provides high adhesion force after curing.

Requirements
- Commercially available materials
- Low volatile organic compound (VOCs)
- Tunable curing time

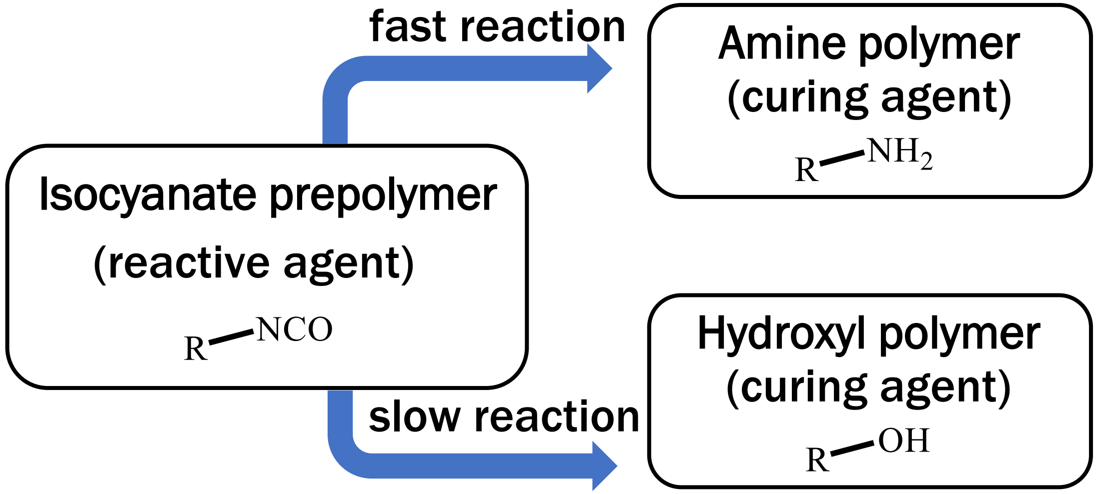
Selected non-toxic isocyanate based prepolymers as curing system with high adhesion force and tunable curing time.

Investigated different two-part curing systems



- Isocyanate system has the best adhesion performance
- Use non-toxic prepolymers instead of toxic monomers

Tuning curing time



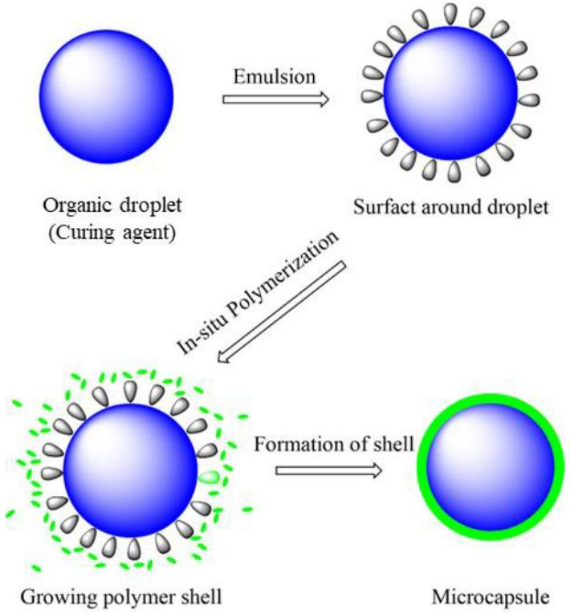
Curing agent (amine polymer wt %)	40	60	80	90
Curing time @ room temperature	>1 d	8 h	2-3 h	1 h

Progress: Microcapsules

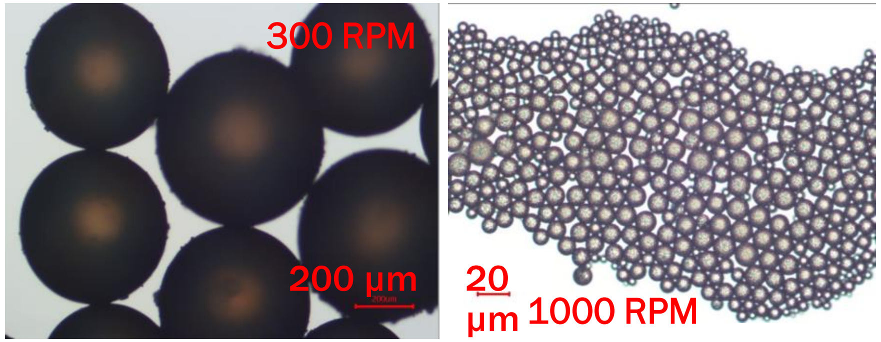
Purpose of microcapsules: separate reactive agents from curing agents to prevent curing until force is applied.

Requirements
- Low cost and feasible
- Easy to scale-up
- Narrow-distributed microcapsule sizes
- Controllable size (tuning activation force)

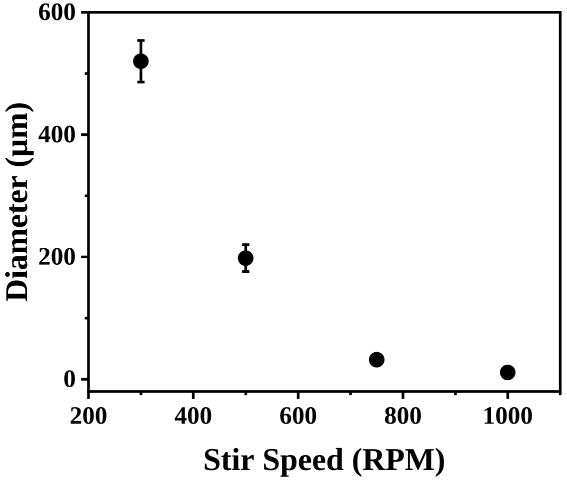
Fabrication method



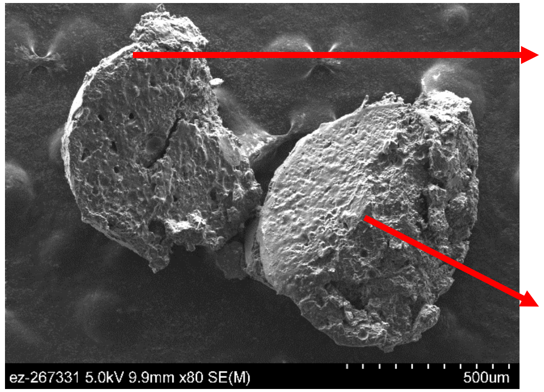
Microscopy image



Diameter vs. stirring speed



SEM image

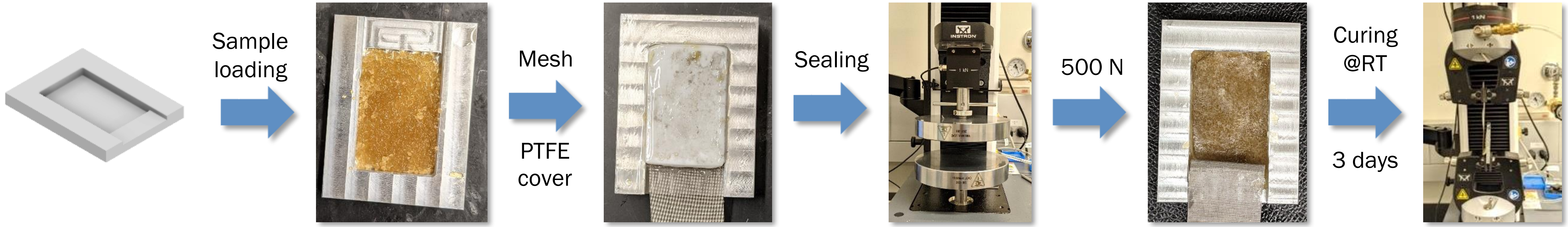


Shell: separates curing agent and reactive agent

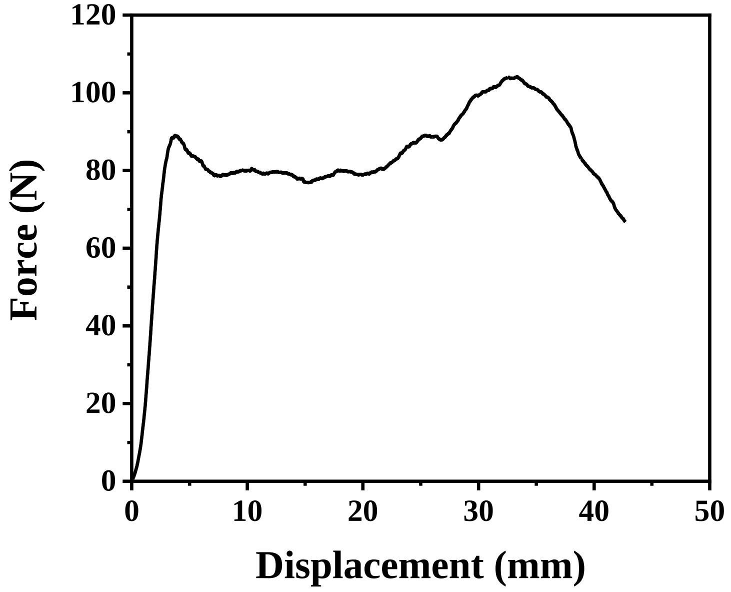
Core: Reactive agent

Developed encapsulation method with tunable diameters for reactive agents.

Progress: Preliminary Prototypes



Peel Test
(ASTM C794)



- Achieved peel strength:
23.4 lb/inch (104.1 N/inch)

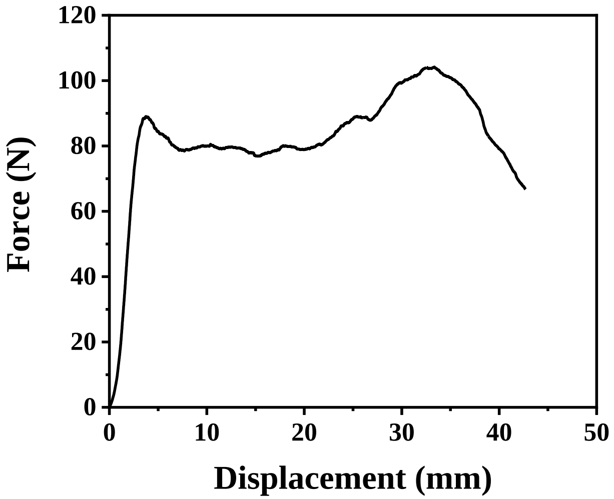
- Targeted strength:
20.0 lb/inch (89.0 N/inch)

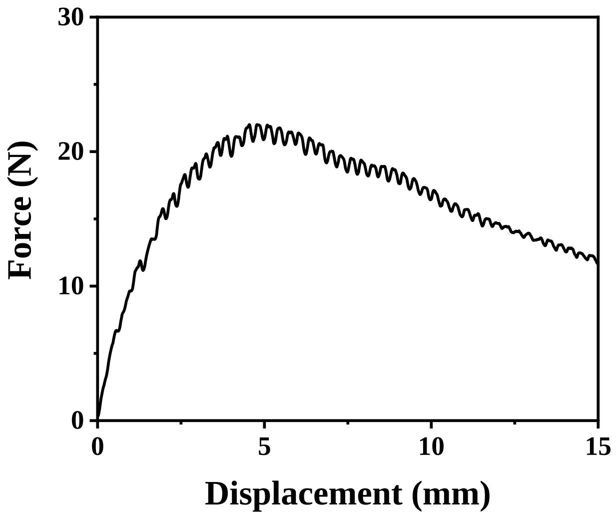
Successful development of preliminary prototypes with satisfactory adhesion.

Remaining Project Work:
Improve Robustness and Shelf-Life After Installation and Before Triggering

Preliminary Results

Decrease in peel strength





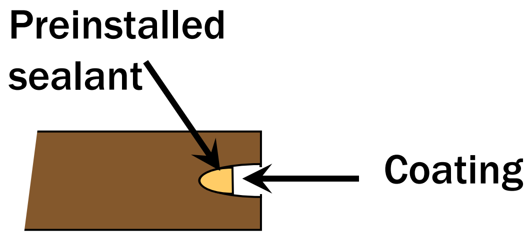
Freshly prepared sealant
Peel strength:
23.4 lb/inch (104.1 N/inch)

After 3 weeks in open air
Peel strength:
4.9 lb/inch (21.8 N/inch)

Reason: isocyanate becomes inactive due to water vapor penetration inside microcapsules

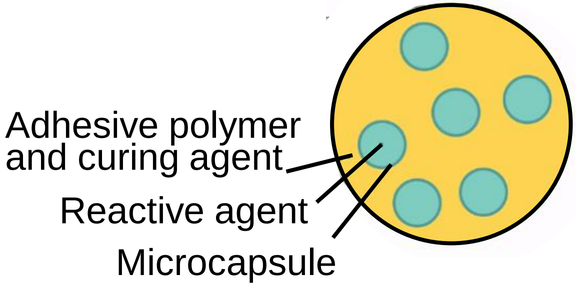
Possible solutions

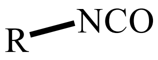
Approach 1: hydrophobic coating on sealant



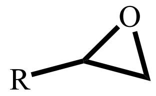
Commercial or custom setup

Approach 2: curing system that is not sensitive to water





water sensitive



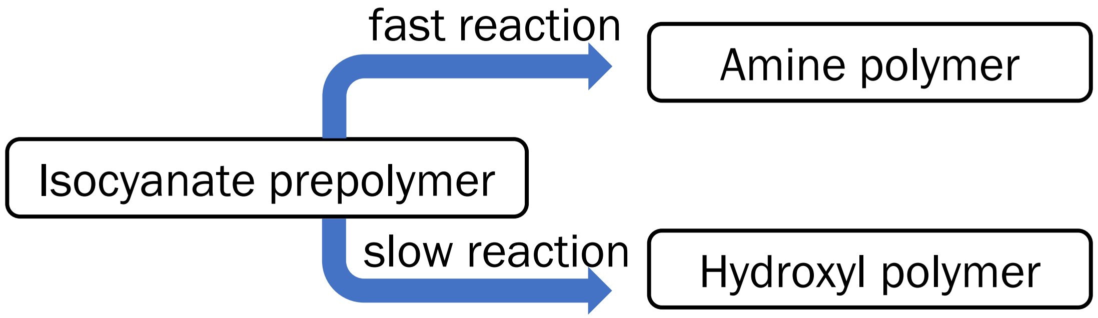
not water sensitive

Tailor Curing Time at Different Temperatures and Triggering Force

Curing time and temperature

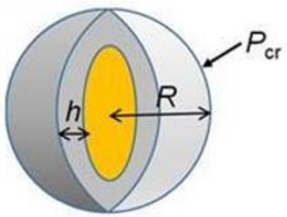
Target: 1-7 days @20 - 110 °F. Will aim for a formulation that can span this temperature range.

Approach: tailor chemical composition in sealant formulation



- Ratio of amine/hydroxyl
- Isocyanate content
- Adhesive polymer content
- Extra fillers

Triggering force



$$P_{cr} = \frac{2Eh^2}{\sqrt{3(1-\mu^2)}}\frac{1}{R^2}$$

Pressure (P_{cr}) is affected by the microcapsule size and shell thickness

Approach:

- Determine required triggering force value
- Correlate and calibrate measured force with calculated value

Current triggered force: 500 N

Tunable force: 100-1000 N

Remaining Project Work:
Co-Optimize Various Required Parameters

- Co-optimize mechanical, adhesive performance and other requirements.
- Continuously consult with industry partners to ensure scalability and practicality.

Item	Criteria
Life Expectancy	20 years
Max cured elongation (ASTM D412)	Aim for 200% but will try 500%
Max. joint movement (ASTM C719)	±25%
Max joint width	1/2" to 3/4"
Installation temperature at plant	60 to 80 °F
Resistance to compression/extension	±50%
Hardness (ASTM C661)	15
Tack-free time (ASTM C679)	2 hours or less
Cut, tear, abrasion resistance	
Ultra-Violet resistance	2 to 4 weeks outdoor exposure max

Stakeholder Engagement

Deployment: industry partners providing guidance on scalability and implementation

CertainTeed SAINT-GOBAIN

- Helped shape the building products industry for more than 110 years.
- Subsidiary of Saint-Gobain, one of the world's largest and oldest building products companies with strong commitment to decarbonization.
- North America's leading brand of exterior and interior building products, and leader in the development of technologies that enable prefab construction.
- 60+ manufacturing facilities throughout the United States and Canada.

BENSONWOOD

- 40+ years designing and building homes sustainably.
- Ultra-precise prefabrication to streamline the process, minimize waste and guarantee performance.

Dissemination

ABC ADVANCED BUILDING CONSTRUCTION Collaborative

Invited presentation

ABC Summit

April 28-29, 2021

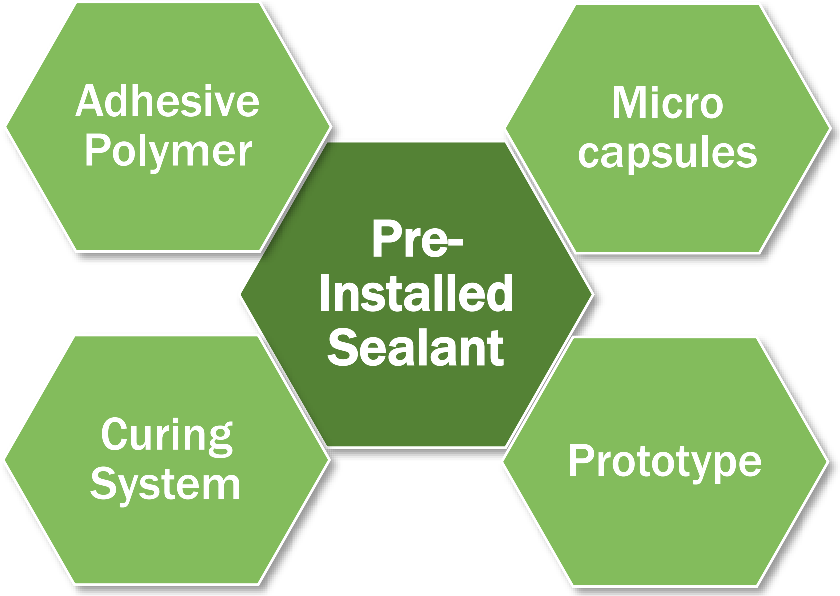
Summary

Demonstrated
- Use of low-cost components
- Self-healability
- High stretchability
- High adhesion

Remaining work
- Co-optimize adhesion force with other requirements

Demonstrated
- Use of low-cost components
- High adhesion

Remaining work
- Tune curing temperature and time
- Improve robustness and shelf-life



Demonstrated
- Encapsulation of reactive agent
- Tunability of capsule size
- Lab-scale scalability

Remaining work
- Low water vapor permeability
- Tune triggering force

Demonstrated
- Lab-scale scalability
- Preliminary peel test results

Remaining work
- Improve test setup based on realistic jobsite conditions

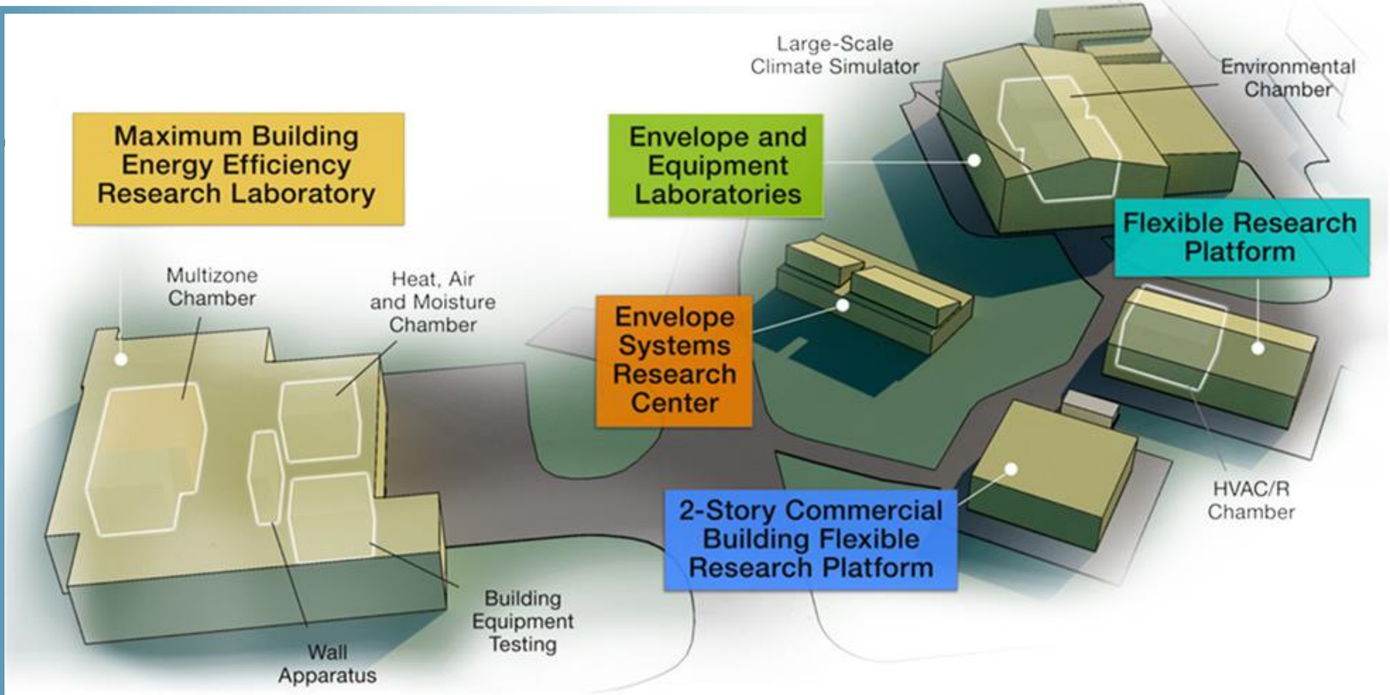
Provisional patent application #63/145,517

Thank you

Oak Ridge National Laboratory

Diana Hun,
Group Leader, Building Envelope Materials Research

(865)-574-5139 | hunde@ornl.gov



ORNL's Building Technologies Research and Integration Center (BTRIC) has supported DOE BTO since 1993. BTRIC is comprised of 50,000+ ft^2 of lab facilities conducting RD&D to support the DOE mission to equitably transition America to a carbon pollution-free electricity sector by 2035 and carbon free economy by 2050.

Scientific and Economic Results

238 publications in FY20
125 industry partners
27 university partners
10 R&D 100 awards
42 active CRADAs

BTRIC is a DOE-Designated National User Facility

REFERENCE SLIDES

Project Budget

Project Budget:
Variances: NA
Cost to Date: $220K
Additional Funding: NA

Budget History					
August 1, 2020 – FY 2020 (past)		FY 2021 (current)		FY 2022 – July 31, 2023 (planned)	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
$300K	$50K	$350K	$100K	$350K	$100K

Project Plan and Schedule

No.	Deliverables/Milestones	10/31/20	1/31/21	4/30/21	7/31/21	10/31/21	1/31/22	4/30/22	7/31/22	10/31/22	1/31/23	4/30/23	7/31/23
Task 1. Develop product requirements Document (PRD): Refine sealant requirements													
M1.1	Set initial sealant requirements with regard to installation in prefab components, curing temperature and time, adhesion strength, service temperature, life expectancy, elongation, VOC emissions, production scaleup, and material cost based on feedback from our industry partners.	Completed											
Task 2. Synthetize, develop and optimize the pressure-triggered sealant													
M2.1	Identified at least three candidates for the epoxy-based and the urethane-based sealant systems that can cure in less than ~8 hours at ~73°F based on the literature and the team's previous research on sealants.	Completed	Completed										
M2.2	Synthetized microcapsules that can be used with the epoxy-based and the urethane-based sealant systems, and identified the variables that can be adjusted to tune the diameter and shell thickness of the microcapsules.		Completed	Completed									
M2.3	Synthetized a prototype for a two-component sealant in which the curing agent is in microcapsules that are dispersed in in a hardener, and demonstrated that the prototype sealant is triggered by pressure and cures in ~4 hours at ~73°F. The prototype will consist of at least 10 grams so that preliminary peel strength tests can be conducted according to ASTM D4541.			Completed	Go/No Go								
Task 3. Tailor curing time at different temperatures													
M3.1	Developed prototype sealants that expand the installation temperature to below freezing conditions; that is, it cures within 2 days at 0°F.				Ongoing	Regular	Regular						
Task 4. Tailor triggering force													
M4.1	Developed a bench-scale test setup that simulates how pressure will be applied by prefab components to active the chemical reaction between the sealant components. The setup will also regulate the applied force so that the relationship between triggering force and peel strength can be studied and the minimum required force can be estimated.				Regular	Regular							
M4.2	Developed a pressure-triggered sealant that is activated by the pressure specified in the PRD. Measurements will be collected using the bench-scale test setup that was assembled for M4.1.					Regular	Regular	Regular					
M4.3	Developed a pressured-triggered sealant that meets the activation pressure and curing time specified in the PRD under the guidance from our industry partners.					Regular	Regular	Regular	Go/No Go				
Task 5. Increase the robustness of the pressure-triggered sealant													
M5.1	Identified the parameters that need to be tailored to lower the probability that the sealant is damaged during handling. Scenarios that could damage the pre-installed sealant will be identified with input from our industry partners. For example, the sealant could be made more robust by lowering its tackiness so it does not stick to unintended surfaces while the prefab part is moved.				Regular	Regular							
M5.2	Developed a more robust pressure-triggered sealant that withstands the damaging scenarios presented by our industry partners, that has the required triggering pressure and curing time according to the PRD, and adhesion strength >10 lb/inch.					Regular	Regular	Regular					
Task 6. Tailor stretchability of cured sealant													
M6.1	Elongation of the pressure-activated sealant that cured for 2 weeks at 73°F is higher than 100%.									Regular	Regular		
Task 7. Increase peel strength to ≥20 lb/inch.													
M7.1	Synthetized a pressure-triggered sealant with adhesion strength ≥15 lb/inch, and curing time and triggering force per the PRD.									Regular	Regular		
M7.2	Synthetized a pressure-triggered sealant with adhesion strength ≥ 20 lb/inch, elongation ≥ 100%, and curing time and triggering force per the PRD.										Regular	Regular	Regular

Regular Go/No Go Completed Ongoing