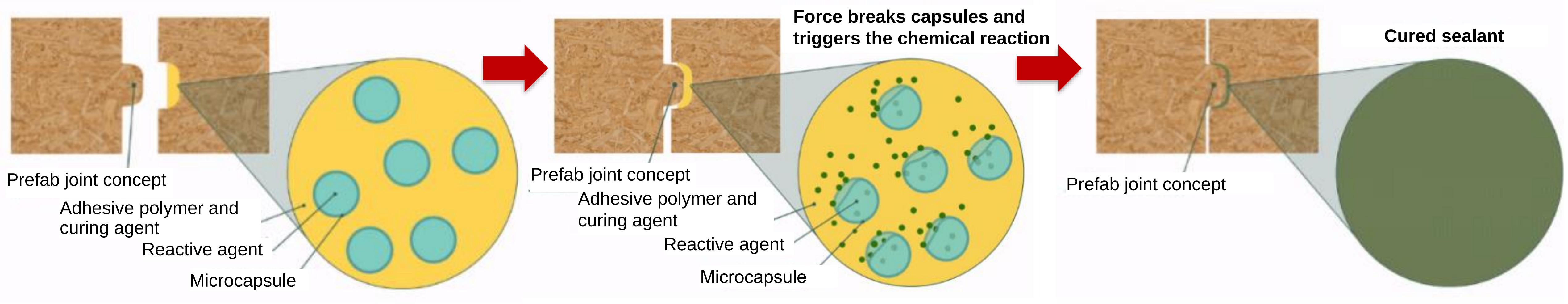
Preinstalled Sealant for Prefab Components



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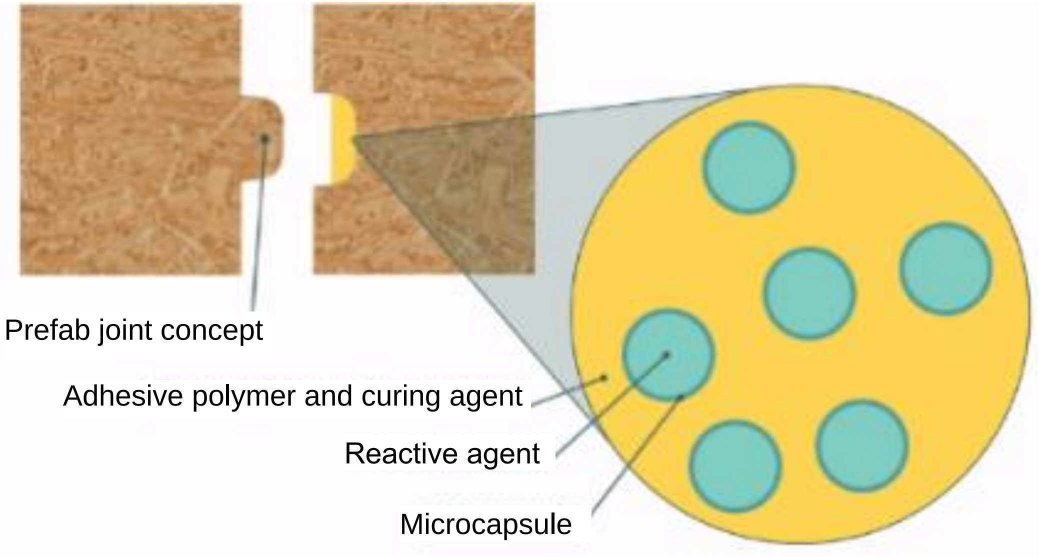
BTO-03.04.06.97, DE-FOA-0002099

Project Summary

Objectives

- Reduce time to seal joints between prefabricated components at the jobsite
- Develop sealant that is installed at the prefab plant and is pressure activated at the jobsite

Outcome: Low-carbon preinstalled sealant that reduces time and cost to assemble prefabricated components and meet airtightness requirements.



Team and Partners

Oak Ridge National Laboratory
CertainTeed Saint-Gobain
Bensonwood
Saint-Gobain

Stats

Performance Period: 10/1/20 to 9/30/23

DOE budget: $1M, Cost Share: $250K

Milestone 1: Sealant with peel strength> 20 ppi

Milestone 2: Sealant that meets specified activation pressure and curing time.

Milestone 3: Sealant meets specified activation pressure and curing time, peel strength >20 ppi, and elongation >100%

Problem

- Prefab construction is increasing because of labor shortage
- Improvements are primarily related to the prefab plant
  – Partial automation in controlled environments
  – Components are efficiently assembled
  – Better assembly and higher quality
- Jobsite
  – Minimal improvements to assembly of prefab components
  – Assembling air barrier system with prefab components is one of the most time-consuming tasks
  – Current methods to seal joints between prefab components
    – Very time consuming
    – Performance is highly dependent on the installer

Sealing mechanism that is installed at prefab plant and triggered at the jobsite will reduce labor and cost and improve airtightness

State of the Art Joint Sealing Techniques

Tapes

Caulks and spray foams

Gaskets

Alignment and Impact

- Prefab components used in both new and existing construction
- Airtightness is highly dependent on sealing of prefab joints
- Air leakage responsible for ~4% of US primary energy use

Successful preinstalled sealant

- Installers of prefab panels attain required airtightness w/o applying tape/caulk/gaskets to joints at the jobsite
- ≥2 × faster installation at the jobsite than tape/caulk/gaskets
- 50% lower embodied carbon than typical petroleum-based sealants

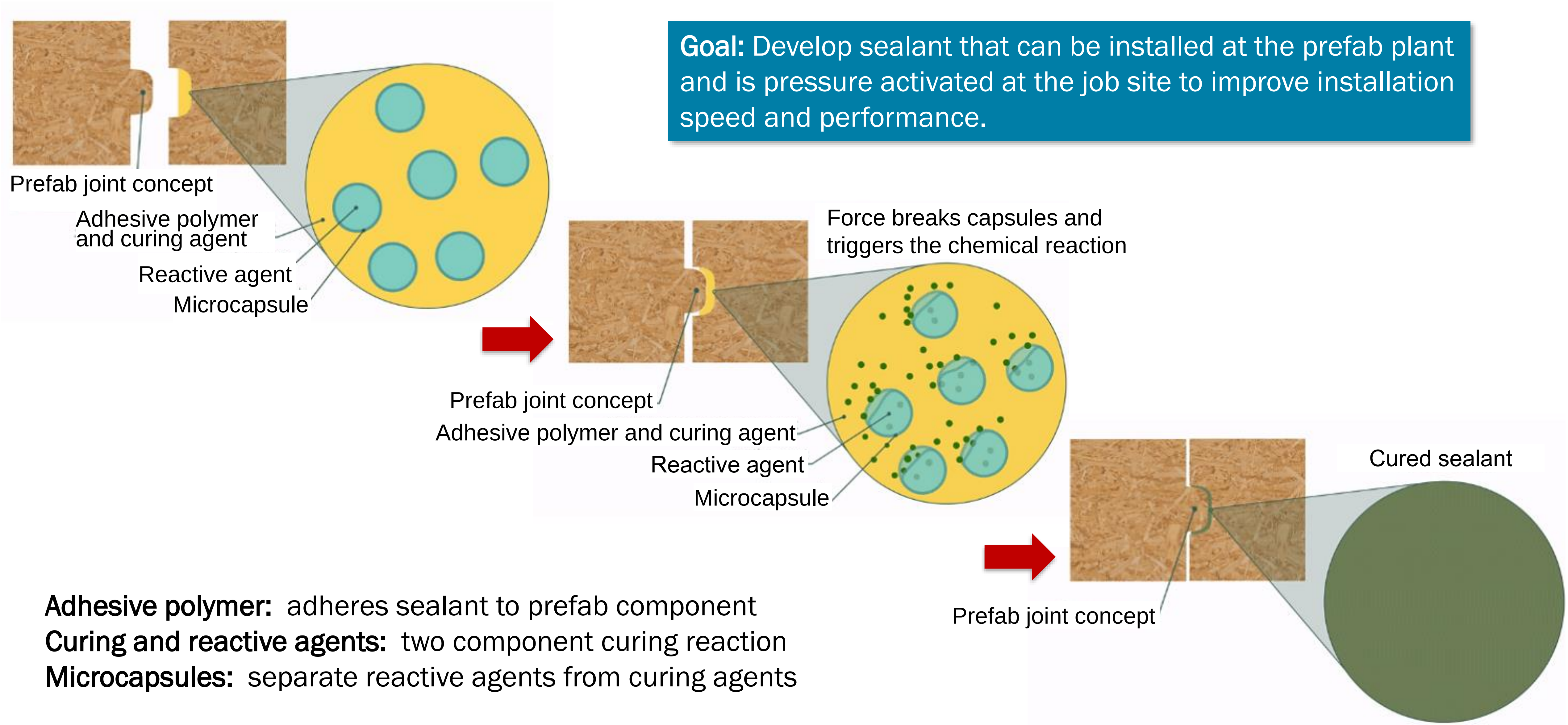
EERE/BTO's vision for a net-zero U.S. building sector by 2050

Increase building energy efficiency
Reduce onsite energy use intensity in buildings 30% by 2035 and 45% by 2050, compared to 2005 ✓

Accelerate building electrification
Reduce onsite fossil -based CO_2 emissions in buildings 25% by 2035 and 75% by 2050, compared to 2005 ✓

Transform the grid edge at buildings
Increase building demand flexibility potential 3X by 2050, compared to 2020, to enable a net-zero grid, reduce grid edge infrastructure costs, and improve resilience. ✓

Concept



Goal: Develop sealant that can be installed at the prefab plant and is pressure activated at the job site to improve installation speed and performance.

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

Preinstalled Sealant Design

1. Set specs with industry partners
2. Identify curing system
3. Encapsulate reactive agent
4. Demonstrate prototype of pressure-triggered sealant
5. Co-optimize required parameters to meet specs

Specifications

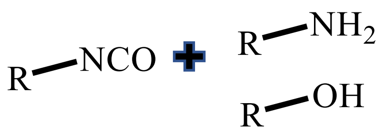
Property	Requirement	Status
Volatile organic compound (VOC) emissions	Low (<150 g/L)	Met
Viscosity	~70,000 cPs	Ongoing
Installation temperature at plant	30 – 100 ºF	Met
Shelf-life after application and before pressure is applied	6 – 12 months	Ongoing
Tack-free time (ASTM C679)	2 – 3 h	Ongoing
Activation pressure	25 – 75 psi	Ongoing
Curing temperature	20 – 80 ºF	Met
Adhesion strength (ASTM D794)	20-30 ppi (60 – 80 ºF) in 3 – 7 days 18 ppi (20 ºF)	Met
Service temperature range	-4 – 130 ºF	Ongoing
Max cured elongation (ASTM D412)	> 100%	Met
Life expectancy	20 years	Ongoing

Curing System

- Goal: two-part system with high adhesion force after curing
- Requirements
  - Commercially available materials
  - Low VOC emissions
  - Tunable curing time
  - Long shelf-life
- Start with prepolymer isocyanate-based formulation
  - Higher adhesion
  - Faster curing rate

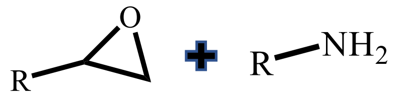
Two-part curing system options

Isocyanate



- High adhesion performance
- Use nontoxic prepolymers instead of toxic monomers

Epoxy



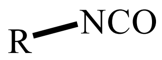
Nontoxic and not water sensitive

Tuning curing time

Amine polymer
(curing agent)

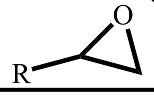
fast reaction →

Isocyanate prepolymer
(reactive agent)



slow reaction →

Epoxy polymer
(reactive agent)



Challenges, Risks, Validation, Commercialization

Technical challenges

- Attaining right balance between peel strength, curing rate, and shelf-life

Risks and mitigation strategies

Curing of sealant may be slow in cold conditions

- Use polymer matrix with lower glass transition temperature (T_g)
- Use curing agents with lower molecular weight and higher functionality
- Add catalyst

Validation

Feedback from industry partners

- CertainTeed: peel strength, tack free time, rheology, weathering, abrasion resistance, vapor transmission
- Bensonwood: installation on building materials, shelf-life, triggering pressure

Commercialization

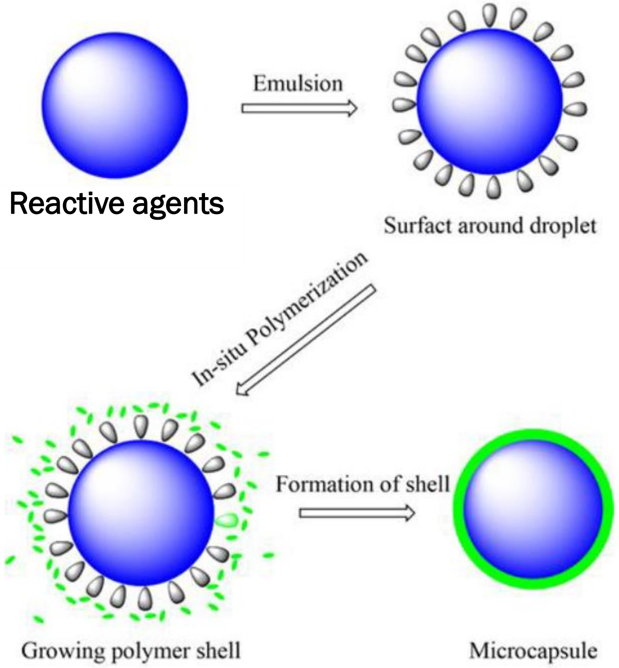
Feedback from industry partners

- CertainTeed: scale-up, technoeconomic analysis, commercialization requirements
- Bensonwood: ease of use at prefab plant and jobsite

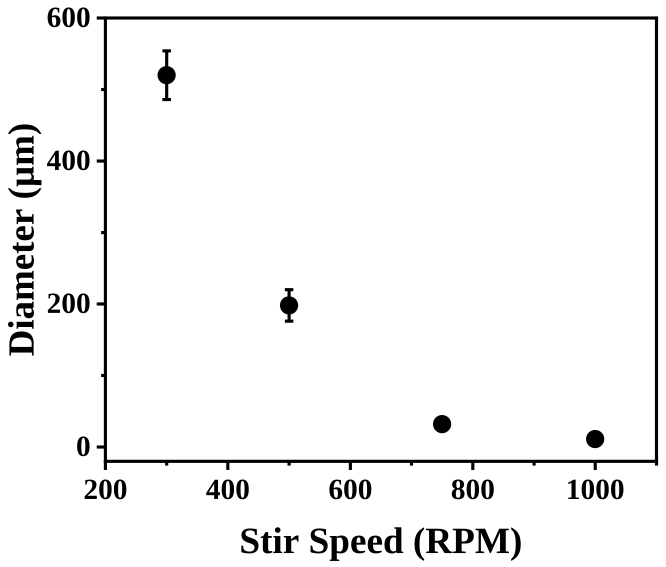
Progress: Encapsulation of Reactive Agent

- Goal: separate reactive and curing agents to delay curing until force is applied
- Requirements
  - Low cost and feasible
  - Easy to scale-up
  - Narrow distribution of microcapsule sizes
  - Tunable microcapsule breaking force

Fabrication via emulsion

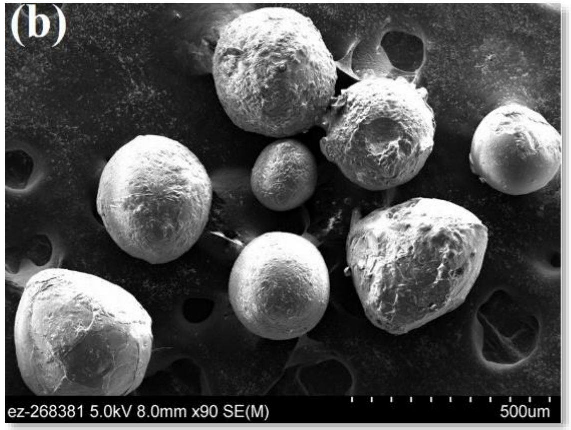


Prototypes

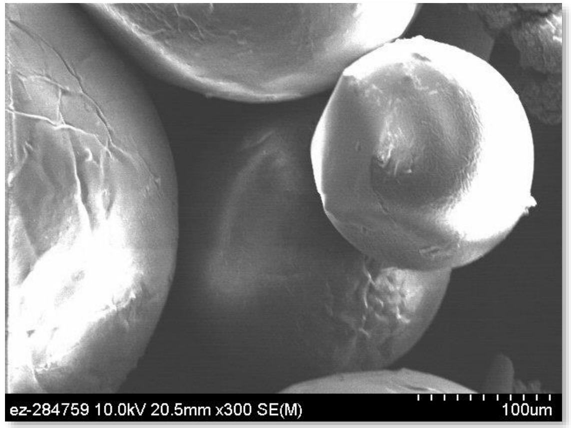


Demonstrated encapsulation of iso- and epoxy-based reactive agents with tunable diameters

Encapsulated iso-based reactive agent



Encapsulated epoxy-based reactive agent



Progress: Preinstalled Sealant Fabrication

Microcapsules (isocyanate or Epoxy)

~50%

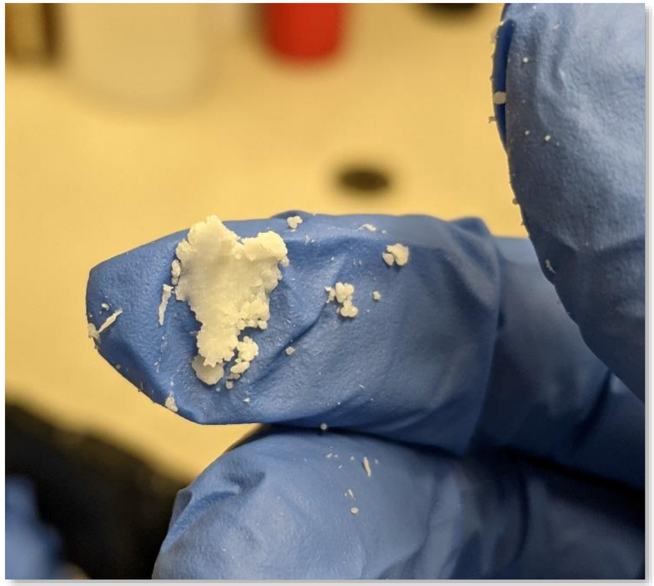
Crosslinking Agent

(Amine)

~45%

Self-healing Adhesive

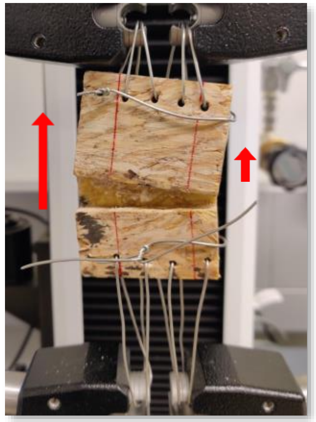
~5%



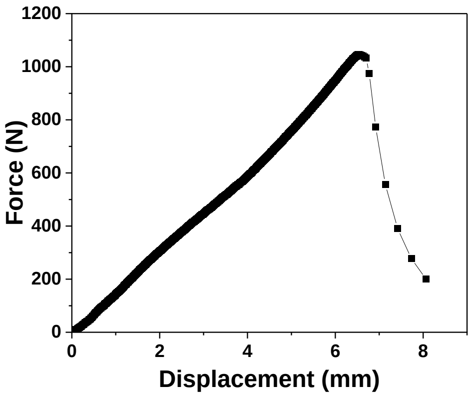
Microcapsules broken by hand

- Microcapsules well-dispersed in matrix, had uniform size, and squeezable
- Sealant formulations had medium viscosity and adhered to multiple substrates (e.g., wood, metal)

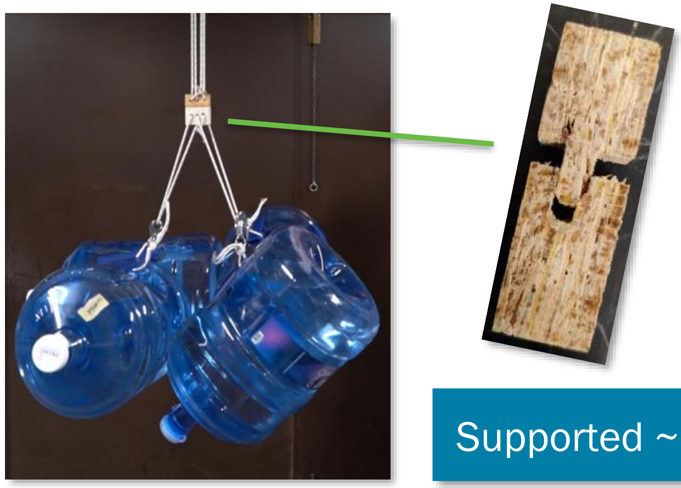
Progress: Performance of Preliminary Isocyanate-Based Sealant



50-mm wide test sample

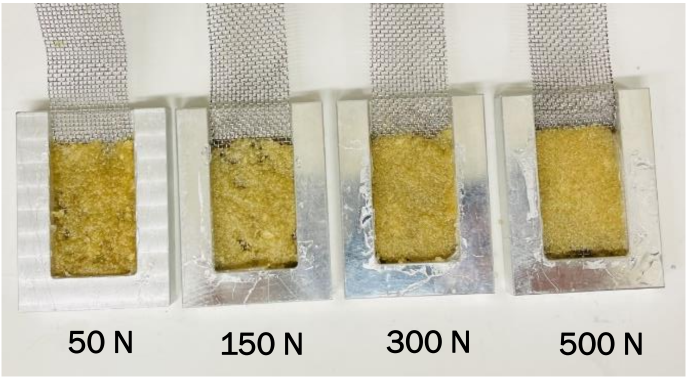


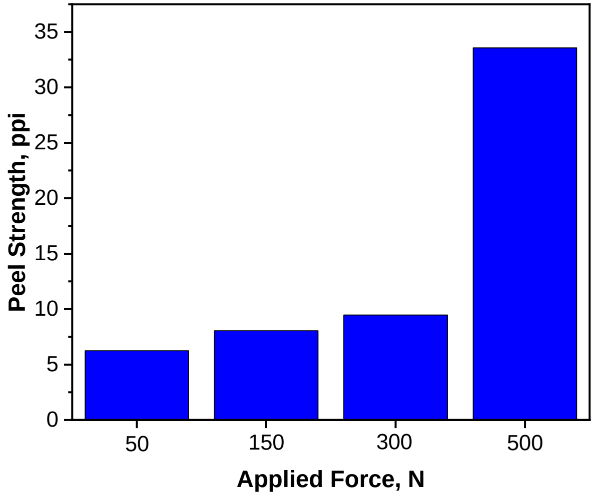
119 ppi peel strength after 75 psi trigger and 3-day curing



Supported ~80kg

Tailored triggering force by tuning shell thickness of microcapsules





- Iso-based sealant
  - High adhesion
  - Fast curing
  - Tunable

Submitted "Force Triggered, Ultra-Adhesive Elastomer" to Advanced Functional Materials journal

- Main drawback: 7-day max shelf life because isocyanate reacted with water vapor that penetrated the microcapsules' shell

Progress: Shelf Life of Preliminary Epoxy-Based Sealant

- Epoxy reactive agent
  - Widely available
  - Nontoxic
  - Not affected by water vapor
- 4 to 12 hours curing time

Shelf life

Pressure

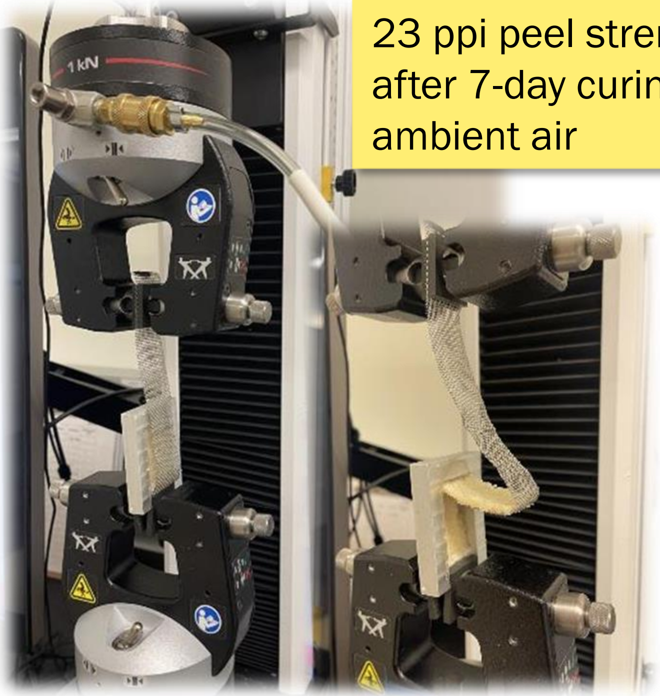
Right after preparation

After exposure to ambient air for 45 days

- Microcapsules still soft/reactive after 45 days
- Very likely that 1-year shelf-life can be attained because the epoxy shell and core are not sensitive to environmental triggers like moisture and light

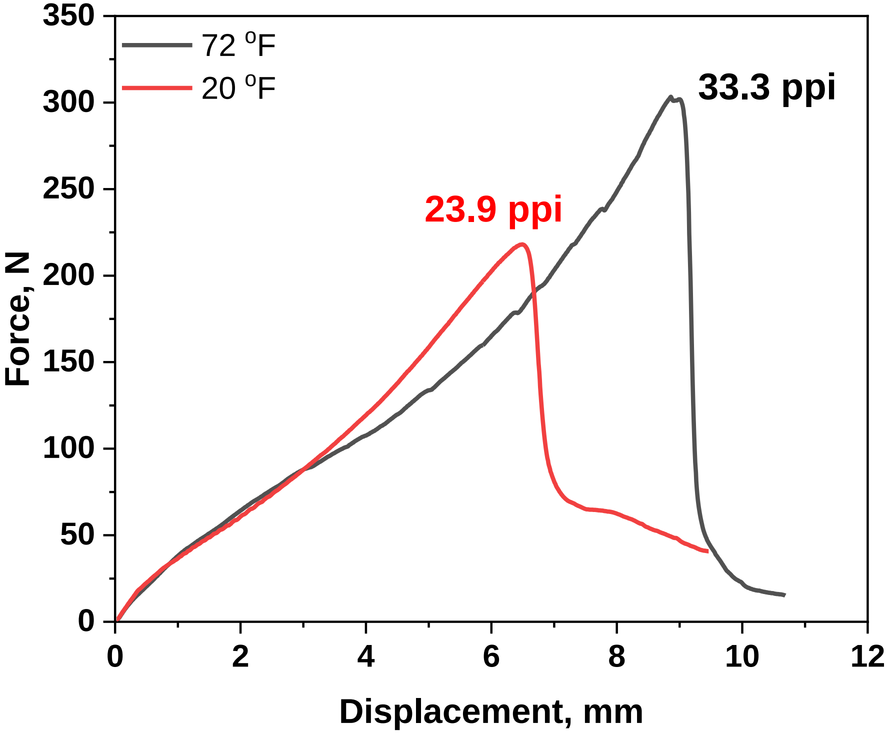
Progress: Adhesion Strength of Preliminary Epoxy-Based Sealant

ASTM C794 peel test



23 ppi peel strength after 7-day curing at ambient air

Alternate test setup



Nonoptimized epoxy-based formulation exceeded 20 ppi peel strength target after curing at ambient and 20°F for 21 days

Future Work

- Lower embodied carbon of epoxy-based formulation (out of scope work, 9-month no cost extension)
  - Reactive agent (i.e., epoxy resin) represents 60% of the formulation
  - Replace 50% of petroleum-based epoxy with biobased epoxy
  - Biobased epoxy can be synthesized with economical and readily available feedstocks
- ~60% biobased content → ≥50% lower embodied carbon
- Meet specs with low-carbon formulation

Future Work: Feedback from CertainTeed and Bensonwood

- CertainTeed
  - Validate ORNL's lab results
  - Technoeconomic analysis
  - Provide feedback on requirements for commercialization
- Bensonwood
  - Installation
  - Shelf-life
  - Curing time

Publications and Intellectual Property

- Publications
  - X. Zhao, J. Luo, J. Tian, B. Li, K. Cao, T. Saito, D. Hun, A. P. Sokolov, Z. Demchuk, and P.-F. Cao “Force Triggered, Ultra-Adhesive Elastomer” *Submitted to Advanced Functional Materials*
  - Future papers on
    - Sustainable Considerations in the Design of Pressure-Triggered Adhesives. To be submitted to *ACS Sustainable Chemistry&Eng.*
- Intellectual property
  - *Preinstalled Sealant for Prefab Components.* Non-provisional patent application #17/591,886

Thank you

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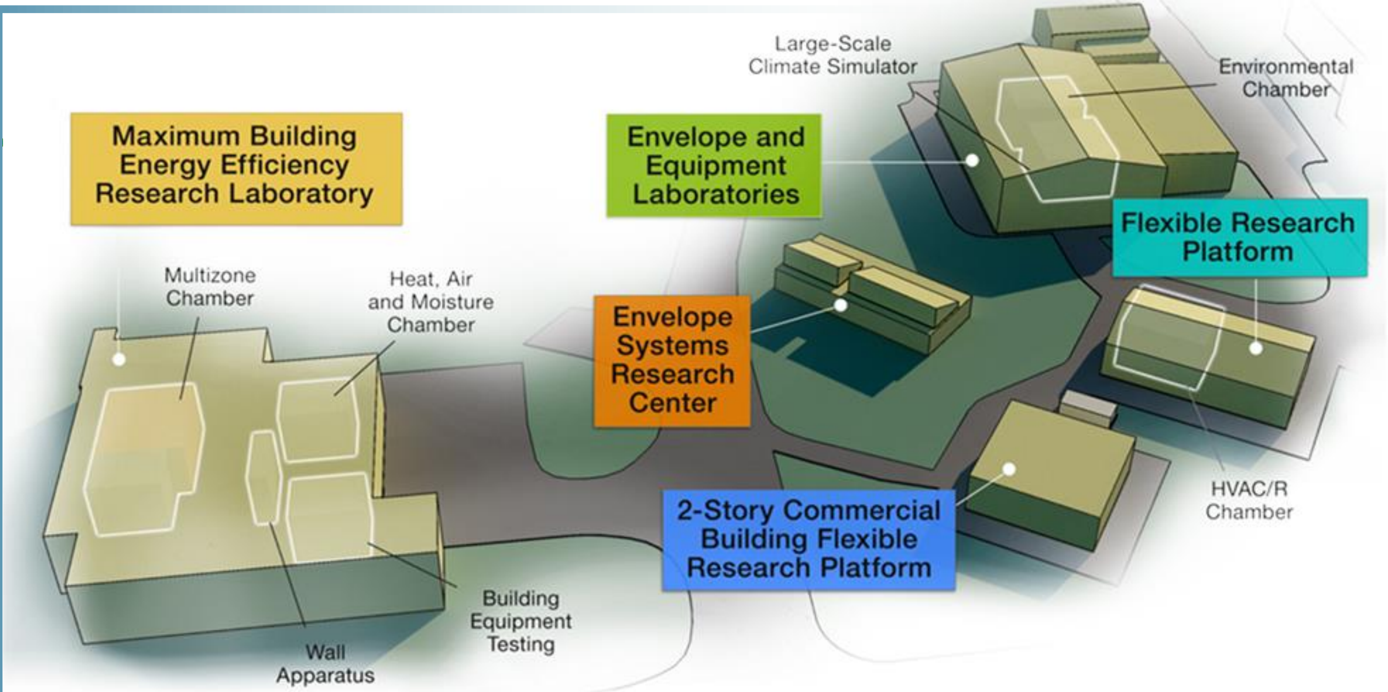


ORNL's Building Technologies Research and Integration Center (BTRIC) has supported DOE BTO since 1993. BTRIC is comprised of 60,000+ ft^2 of lab facilities conducting RD&D to support the DOE mission to equitably transition America to a carbon pollution-free electricity sector by 2035 and carbon free economy by 2050.

Scientific and Economic Results
236 publications in FY22
125 industry partners
54 university partners
13 R&D 100 awards
52 active CRADAs

BTRIC is a DOE-Designated National User Facility

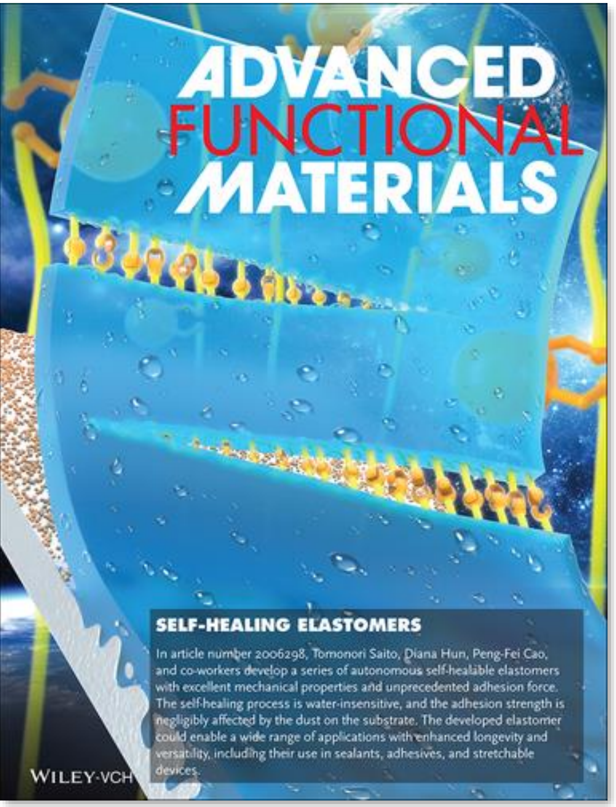
REFERENCE SLIDES

Project Execution

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	9/30/23	12/31/23	3/31/24
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 7 days at 20°F.															
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.															
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.															
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.															
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.															
M5.2	Developed a more robust pressure-triggered sealant that withstands the damaging scenarios presented by our industry partners, has the required triggering pressure and curing time according to the PRD, adhesion strength >10 lb/inch, with the elongation of 100%, and a shelf-life ≥ 45 days at ambient conditions.															
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%.															
Task 7. Reduce carbon footprint in pressure-triggered sealant formulations																
M7.1	Identified 2-3 biobased epoxy resins (>50% biocarbon content) that can gel in 24 h at ambient conditions (74 oF) in the specified formulation															
M7.2	Synthesize epoxy-based microcapsules with at least 50 % biobased content and formulate the pressure-trigged sealants using the established recipe															
M7.3	Evaluate biobased pressure-triggered sealant properties including sealing capabilities and stability and select the best-performed formulations with a peel strength of at least 10 ppi and shelf-life of 30 days															
M7.4	Optimize the resulting formulation of pressure-trigged sealant to reach the peel strength of ≥15 ppi and shelf-life of ≥ 45 days															
Task 8. Evaluate technology feasibility																
M8.1	Conducted a small-scale trial with at least 10 g of sealant at the prefab plant of one of our industry partners.															
M8.2	Issued a preliminary techno-economic analysis of the developed sealant.															
M8.3	Conducted a mid-scale trial with at least 50 g of the sealant at the prefab plant of one of our industry partners.															
M8.4	Perform a full-scale synthesis of the preinstalled sealant formulation in the amount of 500 g and provide it to our industrial partner															
M8.5	Issued a techno-economic analysis that demonstrates commercialization feasibility for the developed sealant.															
M8.6	Perform techno-economic analysis of biobased pressure-triggered sealant and examine the capabilities of biobased sealant to be commercialized															

Team

CertainTeed
SAINT-GOBAIN


ADVANCED FUNCTIONAL MATERIALS

SELF-HEALING ELASTOMERS

In article number 2006298, Tomonori Saito, Diana Hun, Peng-Fei Cao, and co-workers develop a series of autonomous self-healable elastomers with excellent mechanical properties and unprecedented adhesion force. The self-healing process is water-insensitive, and the adhesion strength is negligibly affected by the dust on the substrate. The developed elastomer could enable a wide range of applications with enhanced longevity and versatility, including their use in sealants, adhesives, and stretchable devices.

WILEY-VCH

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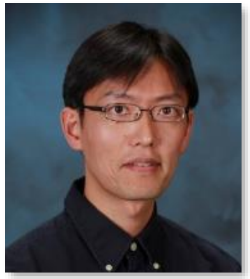
Zoriana Demchuk


Tomonori Saito

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