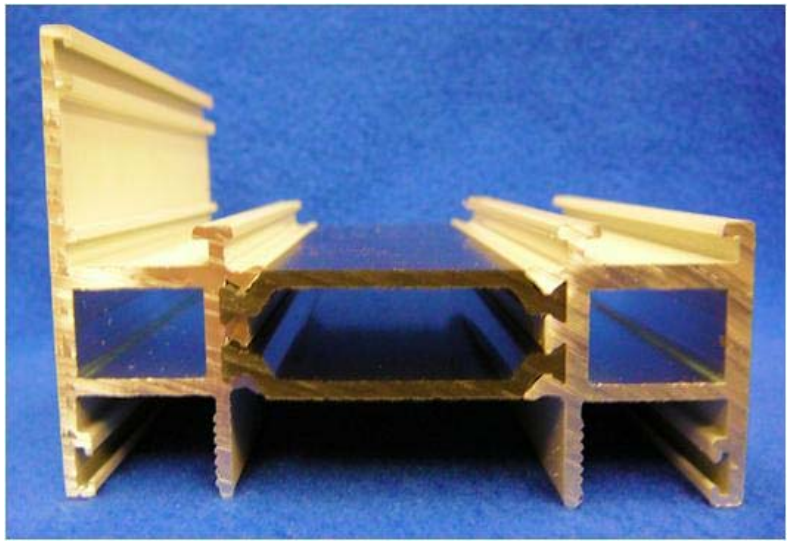
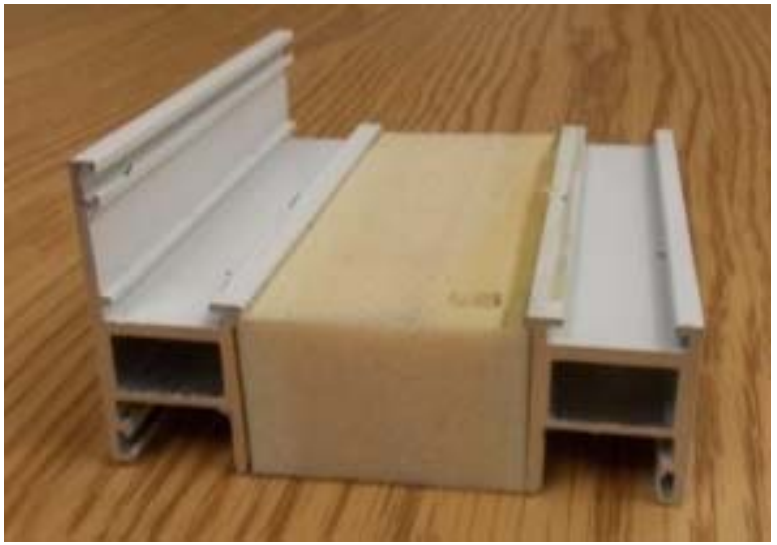
Novel Thermal Break with Simplified Manufacturing for R7 Commercial Windows (DE-EE0006716)

2016 Building Technologies Office Peer Review





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KAWNEER AN ALCOA COMPANY

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Project Summary

Timeline:

Start date: Oct 1, 2014

Planned end date: Dec 31, 2016

Key Milestones

1. Complete preliminary R7 product design and ID component for further evaluation, Feb 2015
2. Develop test specifications to evaluate the new thermal-break systems, May 2015
3. Complete validation testing of the new thermal-break composite system, Dec 2015

Budget:

Total Project $(Feb '16): $808,397

- DOE: $647,961
- Cost Share: $160,436

Total Project $: $1,404,798

- DOE: $1,123,838
- Cost Share: $280,960

Key Partners:

Alcoa Inc.
Kawneer / Traco
Others …

Project Outcome:

Develop best-in-class thermal-performance (R7) commercial windows and the manufacturing process based on novel thermal-break technology, at no additional cost compared to the incumbent Kawneer R5 OptiQ windows.

In addition, new Thermal break technology would also reduce Capital and Operation expense for thermal-break assembly process.

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Purpose and Objectives

Problem Statement: Improve Architectural Window performance (from R5 to R7) and reduce the manufacturing cost of thermal-break assembly system. *Improve Frame U-Factor by 20% and overall window U-Factor by 15% while lowering manufacturing cost when compared to the best commercial-window in the market today*

- Validate novel thermal-break technology feasibility
- Develop R7 architectural windows that meet **thermal** (R7), **structural** (AW-Rated), **durability** (20 year+) and **cost** (~R5 OptiQ windows) performances
- Demonstrate the manufacturing process to validate the cost assumptions.

Target Market and Audience: Architectural Windows for retrofit and new construction. Windows account for approx. 10% of commercial building energy use (~2 quads), $180B/Yr. energy cost

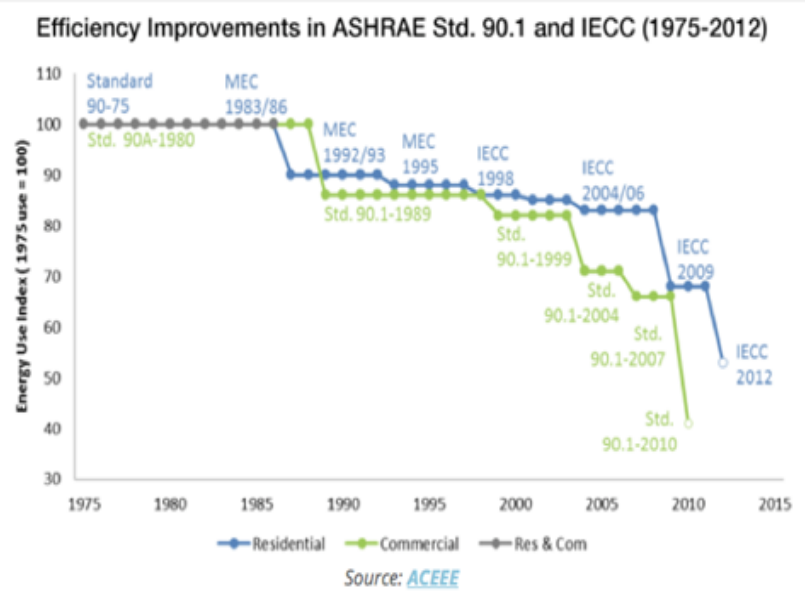
Impact of Project: Develop next generation of thermal break system to enable R7 architectural windows.

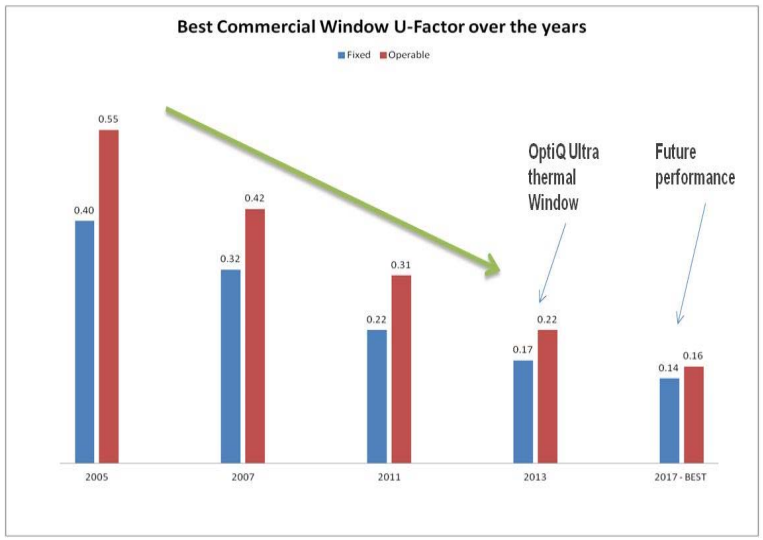
1. Industry's first**: R7 Architectural Grade** Aluminum window (R7 window @ R5 cost)
2. A **scalable thermal-break system** with **simplified manufacturing.**
3. Potential to significantly improve building performance with reduced energy consumption, energy cost, peak load, and greenhouse gas (GHG) emissions.
4. BTO's Goal is to achieve **cost effective R10** Architectural/Commercial window
    a. Validate new T/B technology with improved performance without cost increase
    b. Establish manufacturing capability and commercialize R7 window products
    c. Wider adaptation of high-performance windows leading to building energy intensity reduction

Project Impact: Driving Energy Efficiency

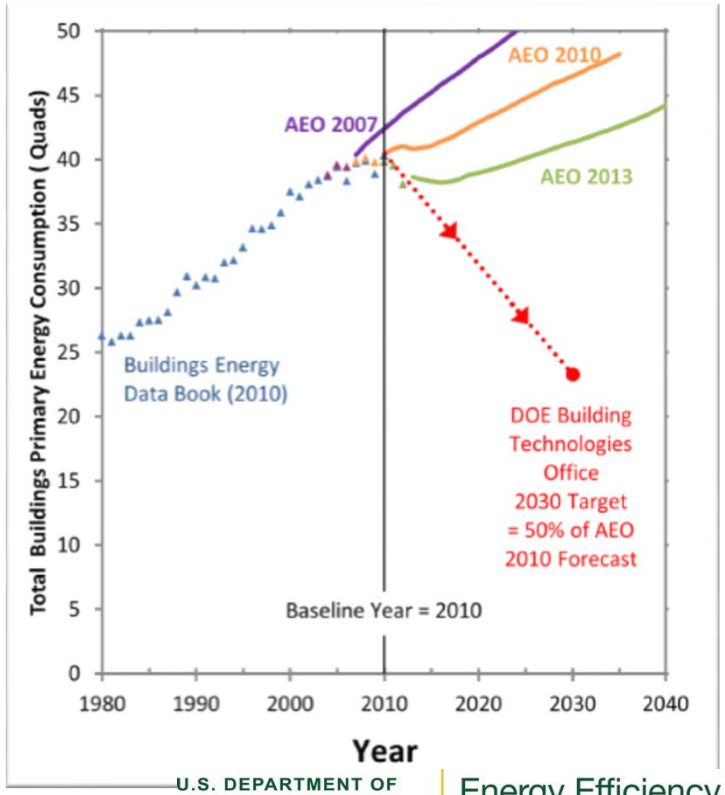
Building's Impact

40% 70% 40%





DOE Building Technology Office Goal:
Reduce Building energy use by 50% in 2030 compared to the "business-as-usual" energy consumption projected by the 2010 Annual Energy Outlook



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Approach

Approach:

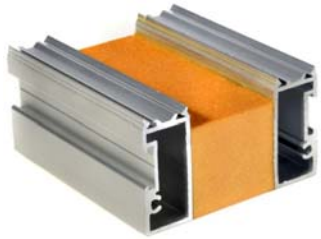
- **Technical** – systematical evaluation plan. Start with testing material properties, followed by coupons, them small composite, followed by lineal, then full-scale Window.
- **Tactical** – Diverse team with expertise in key area. Cast wider net for materials, conducted trade study of available materials, Identify partners willing to work with project timeline to modify material to fit performance needs

Key Issues:

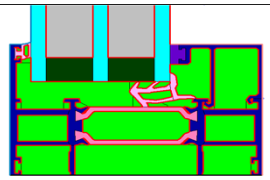
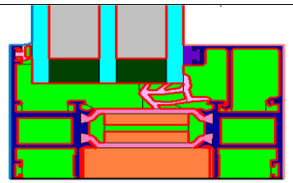
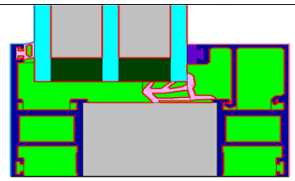
- **Lack of industry standard** for assessing the **long term durability** of the thermal break system
- Lack of **existing supply chain** for material supply or manufacturing
- Variation in advertised vs. actual properties

Distinctive Characteristics:

- **Adhesive bonded** thermal-break system, **Surface** dependent
- Simplified manufacturing, **reduced manufacturing steps**
- **Scalable-thermal-performance** , **lower Capex/Opex cost**
- First **R7 Aluminum Architectural Window**



Distinctive Characteristics

Description	High Performance R4 window (PA t/b)	OptiQ - Advance R5/R6 window (PA with foam)	Proposed foam t/b window
Frame cross-section Image	 Figure-2a	 Figure-2b	 Figure-2c
Frame U-Factor	0.44	0.31	0.25
CoG U-Factor	0.12	0.12	0.12
Window U-Factor (R-value)	0.23 (R4)	0.18 (R5/R6)	**0.14 (R7)**
Relative Cost	$$	$$$	$

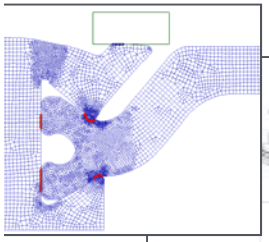


Exhibit 3: Manufacturing processes for current baseline windows (Knurling of aluminum, Insertion of thermal-break; and Mechanical Crimping of AL and thermal break Exhibit 3: Thermal Conductivity of Thermal Break Materials

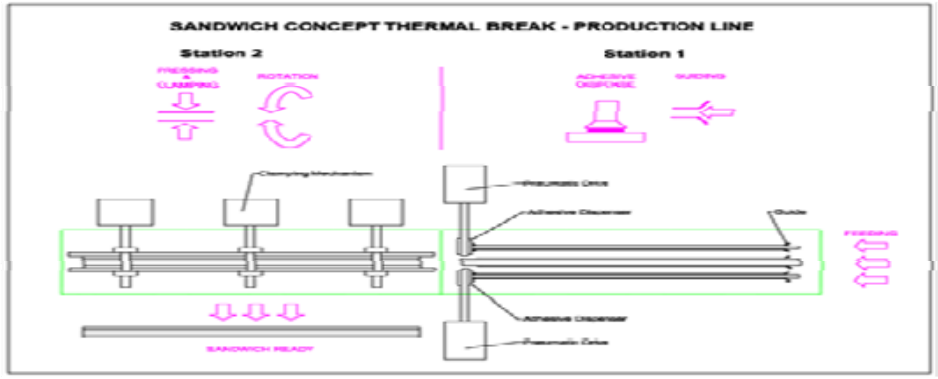
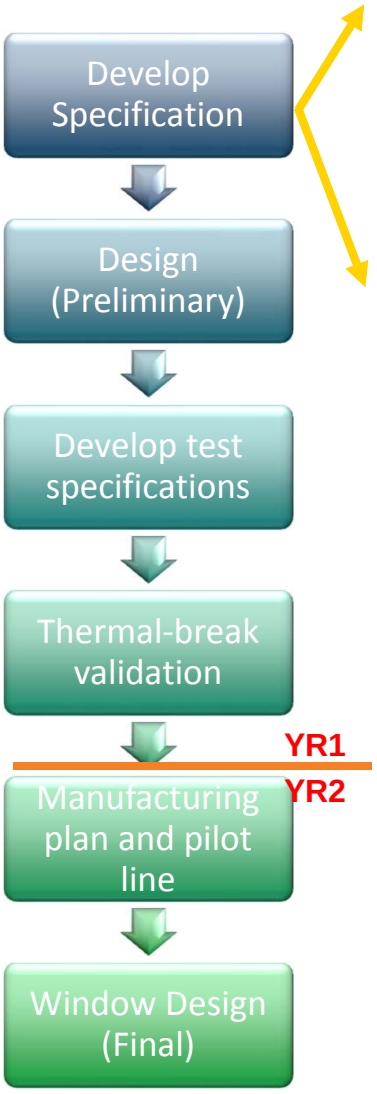


Exhibit 4: Pilot line concept for assembly the novel foam-thermal-break

Manufacturing process differences between the current and proposed technology

Progress and Accomplishments: Product Specification



- **Performance specification**
  - Fixed and operable windows
  - **Thermal**: R7 Window (Fixed Window)
    - (0.14 Btu/hr-ft^2-F; 0.8 W/m^2-K)
    - COG U-Factor =).12
    - NFRC 100 Standard
  - **Structural**:
    - Architectural Grade (AW-rated)
    - Per NAFS/AAMA Standard
  - **Environmental**
    - Life expectancy: 40 years
    - Custom test specification developed
    - Sustainability/LCA – TBD
    - Fire performance - TBD
  - **Cost**
    - Cost neutral compared to Kawneer OptiQ (R5) windows

- **Manufacturing goals**
  - Meet North America flow-path
    - Process conditions able to accommodate the foam T/B manufacturing
  - Ease of manufacturing
  - Throughput - comparable or better than current Polyamide Thermal break (min 35 lineal/hr)
  - Low-capex
  - Meet working time and fixture time to achieve throughput
  - Shelf life of materials (min 6 month)
  - EHS approved

Progress and Accomplishments: Product Design (Prelim)

Develop Specification

Design (Preliminary)

Develop test specifications

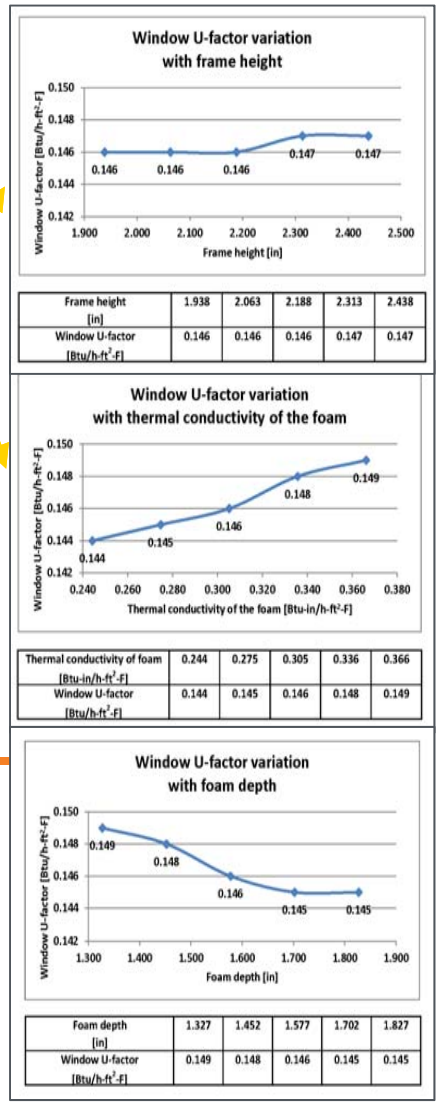
Thermal-break validation

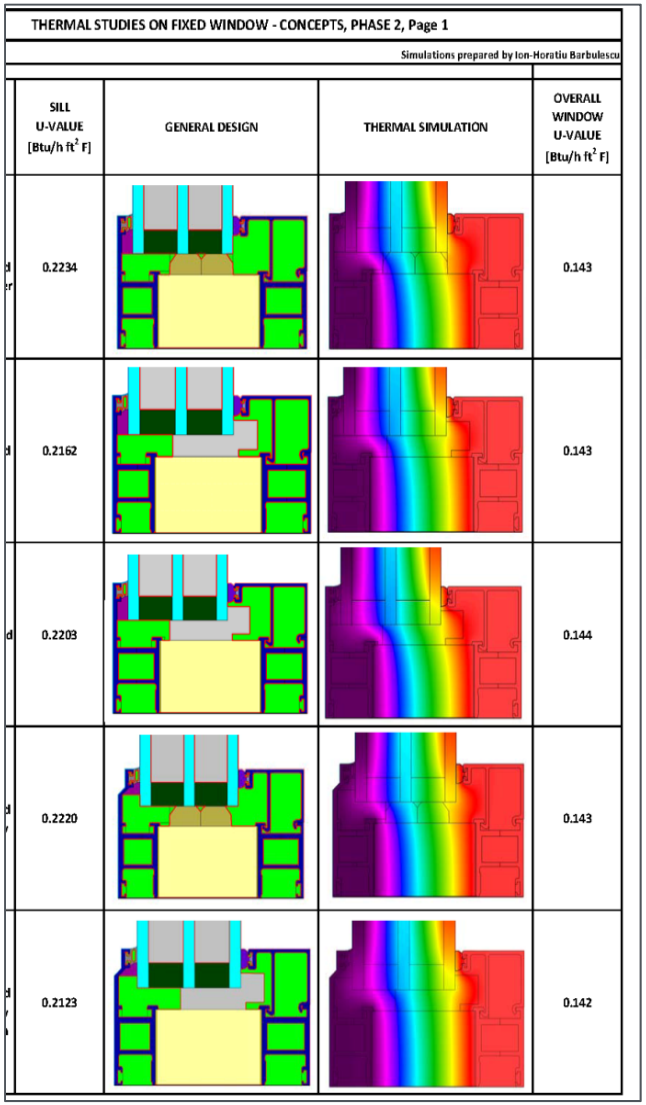
YR1

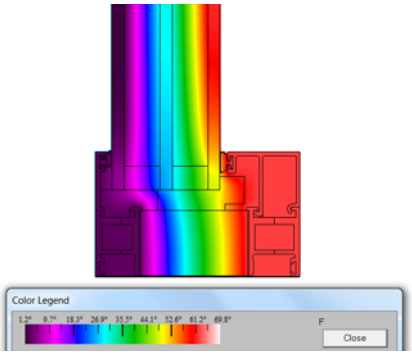
YR2

Manufacturing plan and pilot line

Window Design (Final)



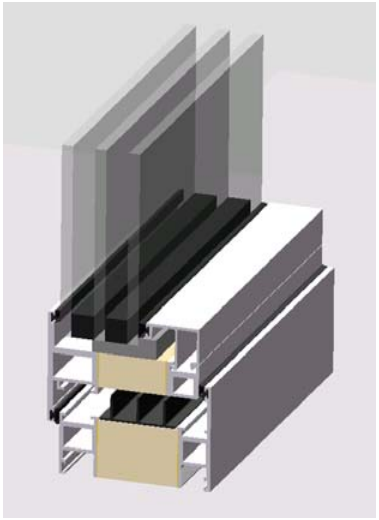




Fixed Window

Window U-Value = 0.14

C.O.G. U-Value = 0.12



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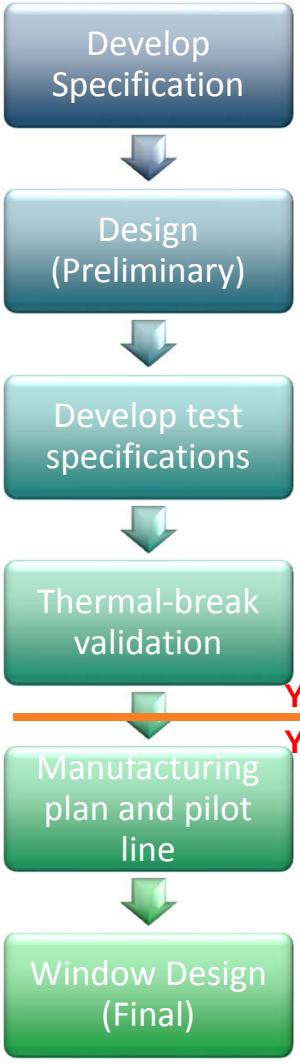
Progress and Accomplishments: Material Search– Foam & Adhesives



Reference guide for foam properties			
Physical Properties	**SI Units**	**Imperial Units**	**Test Procedure**
Thermal conductivity	Maximum: 0.040 W/mK (less is better)	Maximum: 0.275 Btu·in/(ft^2·h·°F) (less is better)	ASTM C518 or EN 12667
Density	For reference only: 160 kg/m^3 or higher	For reference only: 10.0 lb/ft^3 or higher	ASTM D1622 or ISO 845
Tensile strength	Minimum: 5.4 MPa (higher is better)	Minumum: 783 psi (higher is better)	ASTM D1623
Tensile modulus	Minimum: 205 MPa (higher is better)	Minimum: 29,730 psi (higher is better)	ASTM D1623
Shear strength	Minimum: 2.6 MPa (higher is better)	Minimum: 377 psi (higher is better)	ASTM C273
Shear modulus	Minimum: 73 MPa (higher is better)	Minimum: 10,590 psi (higher is better)	ASTM C273
Coefficient of linear expansion	Maximum: 40 ·10^{-6}/°C (lower is better)	Maximum: 22.2 ·10^{-6}/°F (lower is better)	ASTM D696
Continuous temperature range	-200°C to +70°C (higher is better)	-328°F to 158°F (higher is better)	
Heat distortion temperature	125 °C (higher is better)	257°F (higher is better)	DIN 53424

Other Properties	**Required (Preferred): Yes/No**
UV resistance	Preferred: Yes
Compatibility with silicone and adhesives	Required: Yes
Water absorption	Required: Very Low or No water absorption

	Thermal Conductivity [W/mK]	Density [kg/m^3]	Compressive Modulus [MPa]	Tensile Modulus [MPa]	Tensile Strength [MPa]	Shear Modulus [MPa]	Shear Strength [MPa]	Coefficient of Linear Expansion [1/C]
	0.038	160	54.60	92.70	1.81	19.63	1.36	0.000053
	0.043	192	80.33	126.44	2.47	27.95	1.81	0.000053
	0.050	240	128.86	184.85	3.50	43.06	2.63	0.000053
	0.056	288	189.60	N/A	4.92	61.31	3.46	0.000053
	0.061	320	237.00	301.65	5.89	75.19	4.09	0.000053
	0.038	160	51.85	65.00	2.02	19.72	1.64	0.000056
	0.042	192	75.79	N/A	2.65	26.50	2.15	0.000056
	0.047	240	113.09	N/A	3.68	38.02	2.97	0.000056
	0.052	288	156.84	N/A	4.81	51.08	3.87	0.000056
	0.056	320	189.47	175.00	5.61	60.58	4.51	0.000056
	0.031	160	60.65	80.20	2.21	19.94	1.68	0.000061

Chemistry	Part	Mix Ratio	Shelf Life	Working Time (min)	Fixture Time (min)	Tensile Strength (psi)	Shear Strength (psi)	Elongation (%)	Young's Modulus (psi)	Flash Point (°F)	Temperature Range min (°F)	Temperature Range max (°F)	Surf. Prep Req?	Trade Study Score
	3	2	1	3	3	9	10	7	7	4	8	8	2	
methacrylate	2	10:1	12mon	4-6	9-13	2300	2800	45-50	-	51	-67	250	N	91
	2	2	1	1	1	1	1	2	1	2	1	1	1	
methacrylate	2	1:1	6mon	5-6	9-10	3500	-	15	-	51	-40	250	N	97
	2	1	2	1	1	1	1	3	1	2	1	1	1	
methacrylate	2	4:1	6mon	6-10	12-17	4650	2650	80	180000	59	-40	300	N	97
	2	2	2	1	2	1	1	2	1	2	1	1	1	
urethane	1	-	9mon	35-45	>50	475	330	500	-	201	-75	350	Y	110
	1	1	1	3	3	2	1	1	1	1	1	1	2	
methacrylate	2	10:1	6mon	6-10	16-24	2200-2400	2776	12		39			N	104
	2	2	2	1	2	1	1	3	1	2	1	1	1	
methacrylate	2	4:1	9mon	6-8	20-24	2800	2410	10	108778	59	-40	300	N	103
	2	2	1	1	2	1	1	3	1	2	1	1	1	
	2	1:1	7mon	4-6	12-15	3000-3500	3000-3800	15-25	155,000	51	-67	250	N	

Progress and Accomplishments: Material Search - Adhesive

Develop Specification

Design (Preliminary)

Develop test specifications

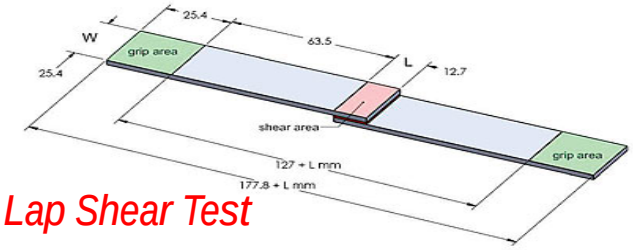
Thermal-break validation

YR1

YR2

Manufacturing plan and pilot line

Window Design (Final)

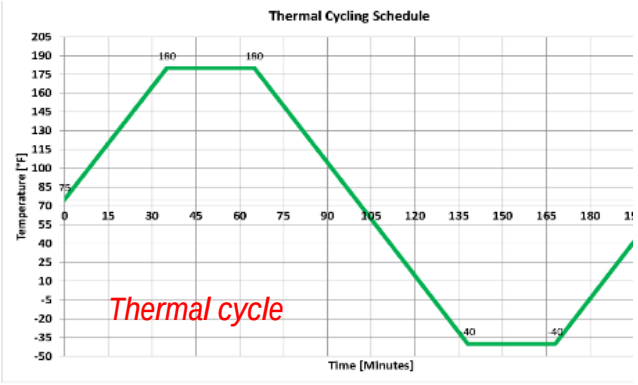


Lap Shear Test

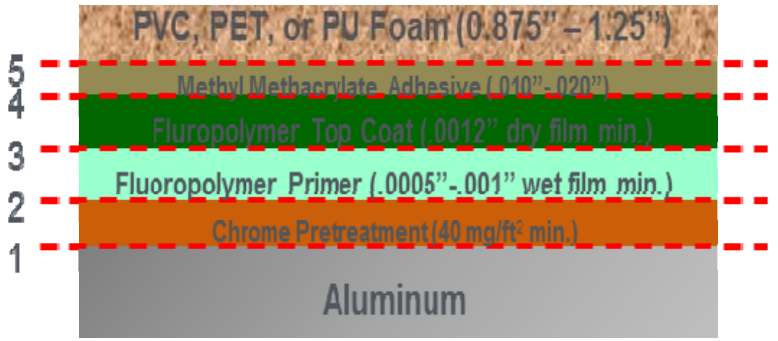
DOE R7 - THERMAL TEST CONDITIONS

Test Conditions						
Time [min]	0	35	65	138	168	206
Temperature [°F]	75	180	180	-40	-40	75

Thermotron Ramp Rate

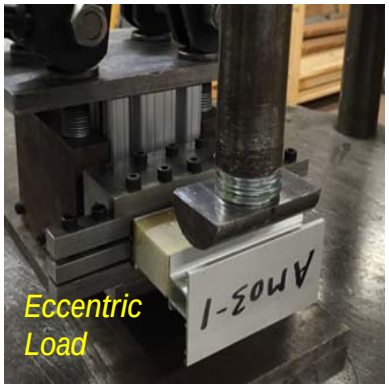


Thermal cycle

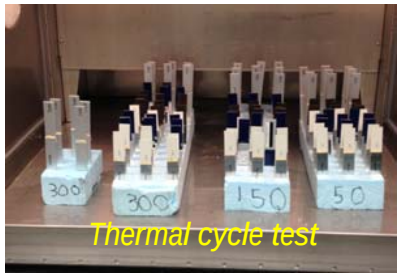


Surfaces under play in Composite

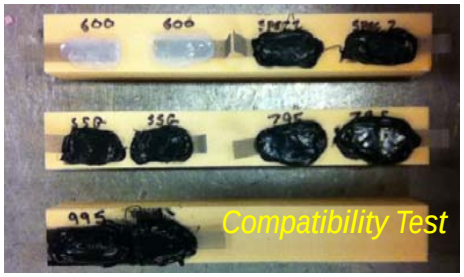
Shear Test



Eccentric Load



Thermal cycle test



Compatibility Test

Flexural Test

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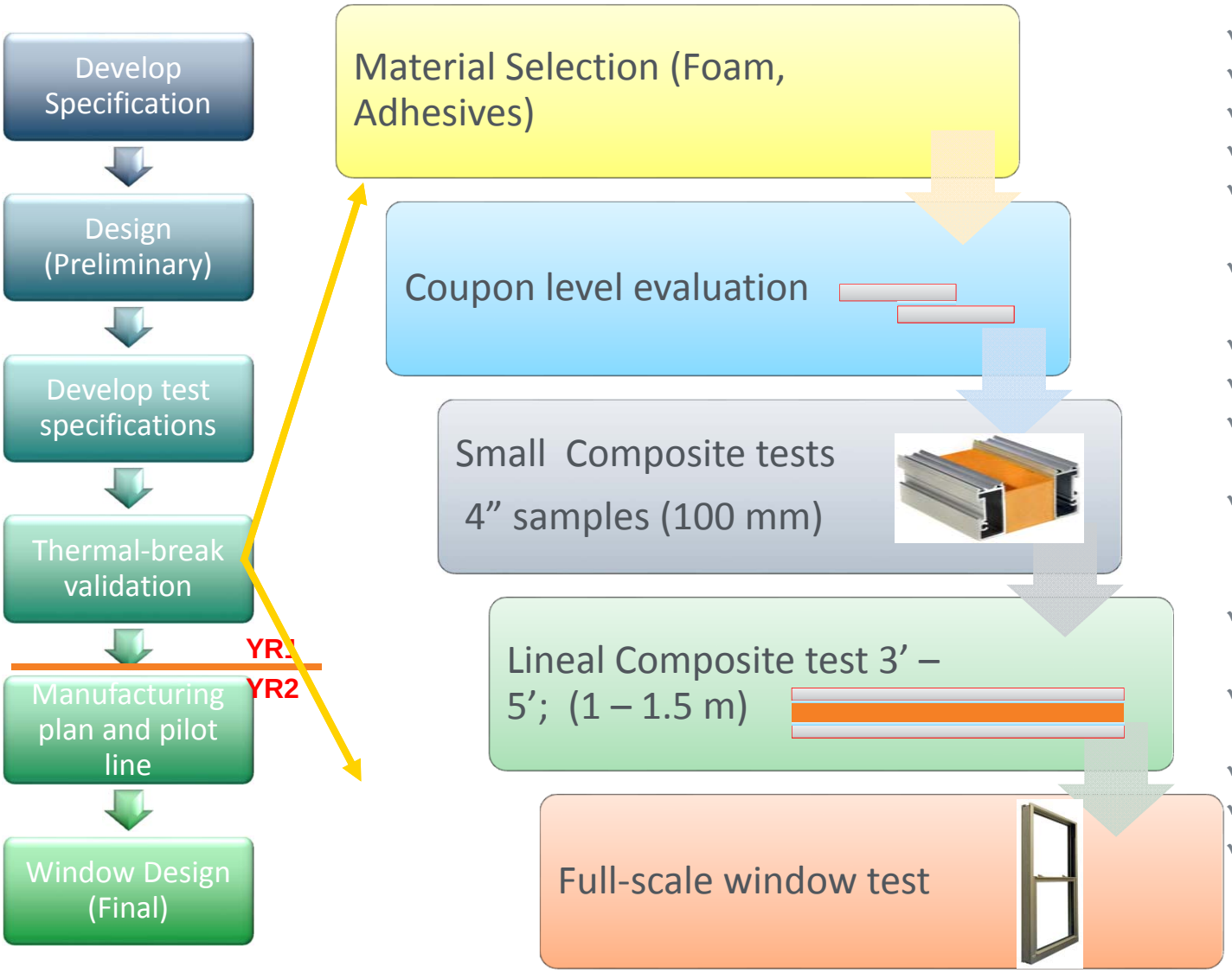
Approach: Key Deliverables and Flow-path



- ✓ Material trade study
- ✓ UV exposure
- ✓ bending Stiffness
- ✓ Moisture absorption
- ✓ Aesthetics

- ✓ Shear test at cold, room, hot Temp
- ✓ Thermal Cycling
- ✓ Moisture conditioning
- ✓ Water exposure at elevated Temp
- ✓ Extreme Temperature Shear tests

- ✓ Compatibility tests

- ✓ Mechanical testing and characterization
- ✓ Flexural / MOI Tests
- ✓ Fatigue Test
- ✓ Thermal cycling – through structural loading

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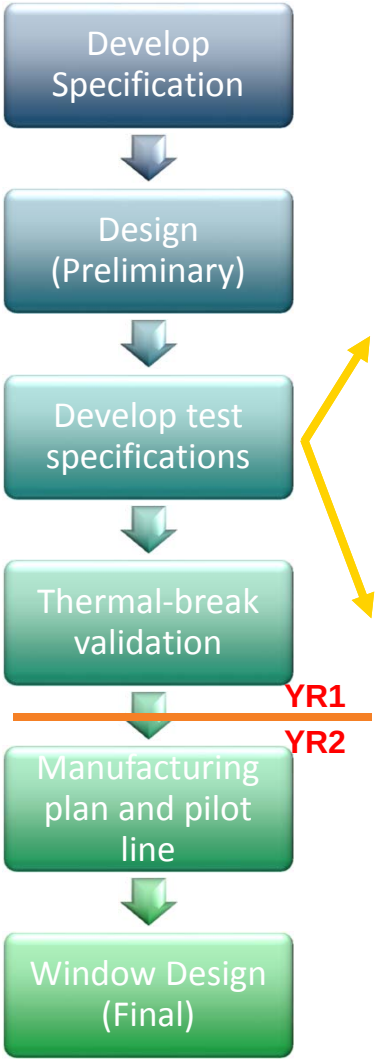
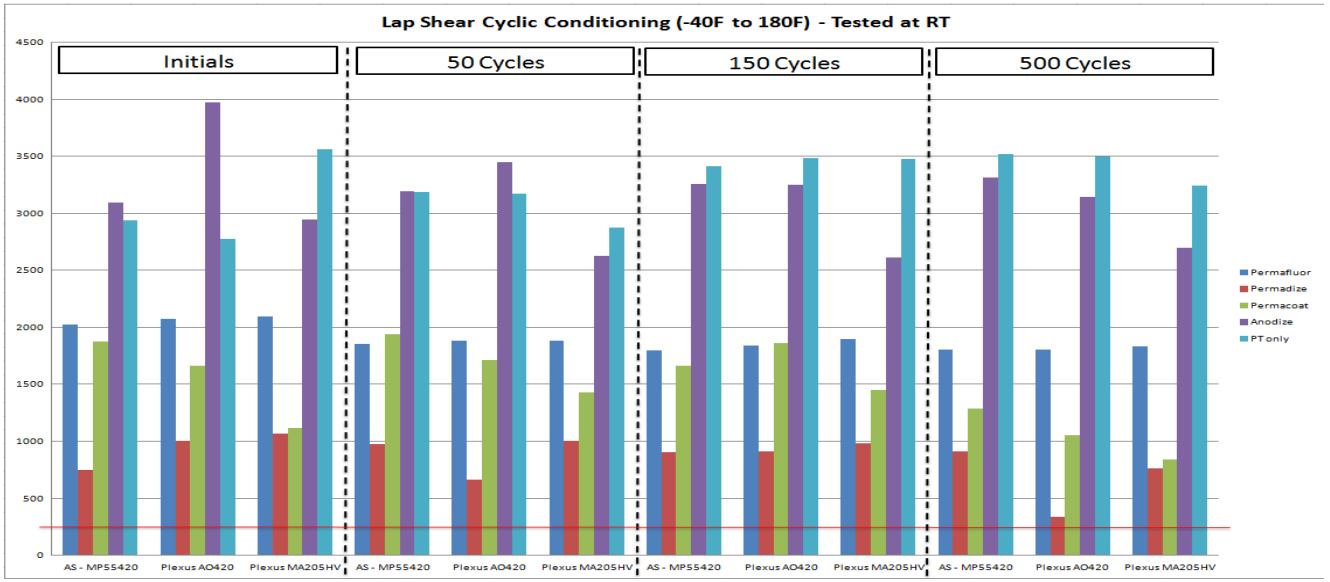
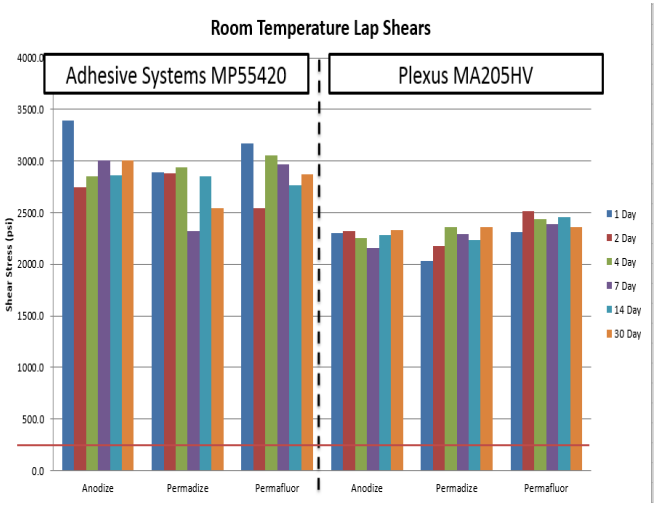
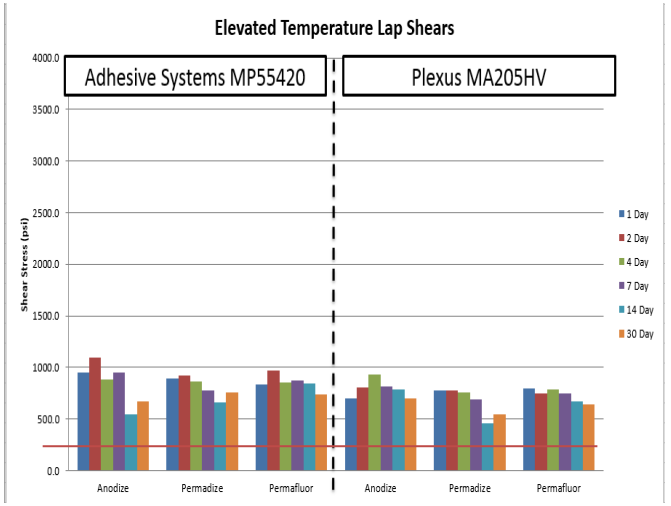
Progress and Accomplishments: Results of Lap Shear Tests









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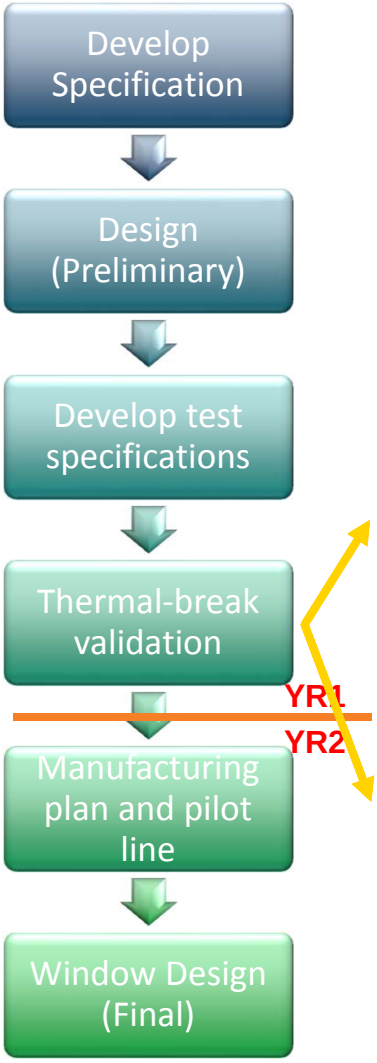
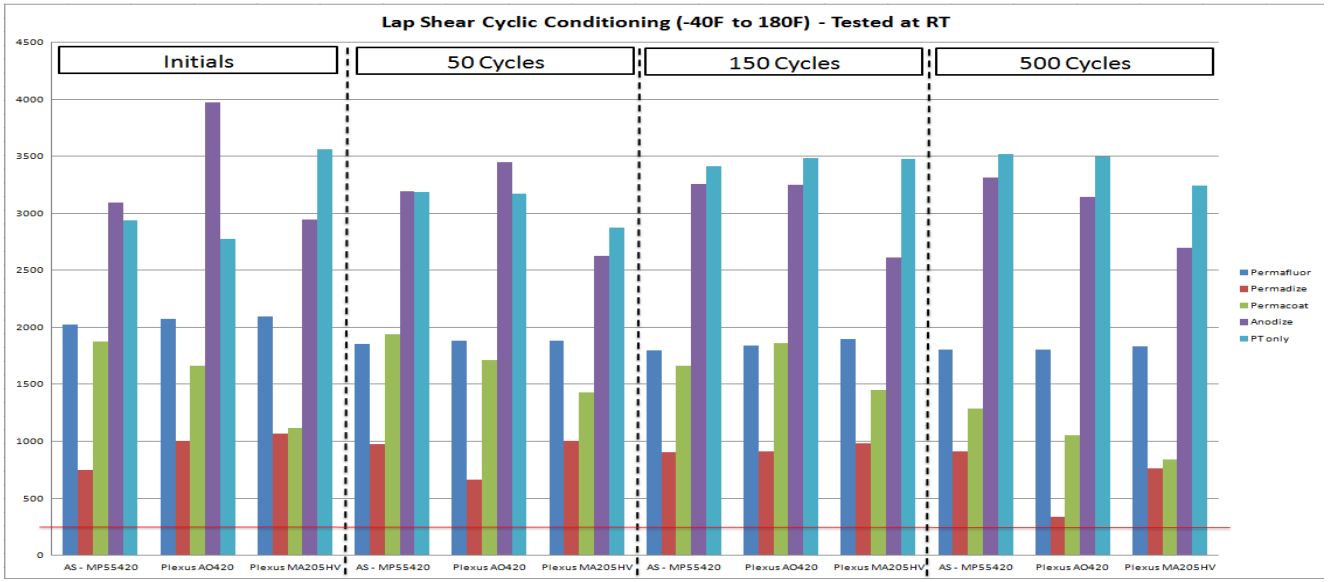
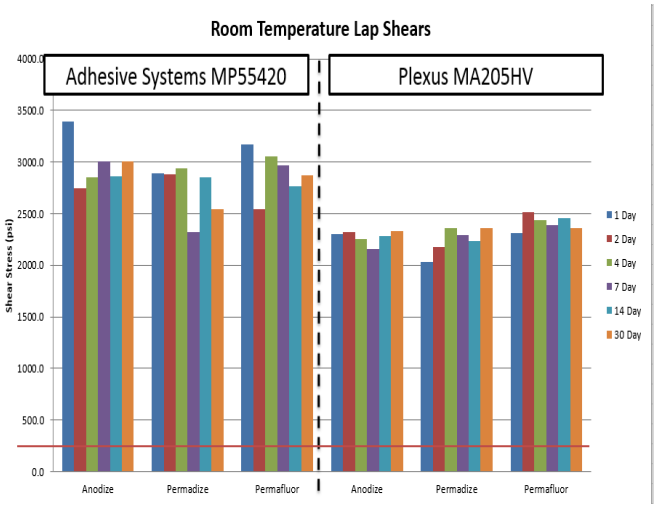
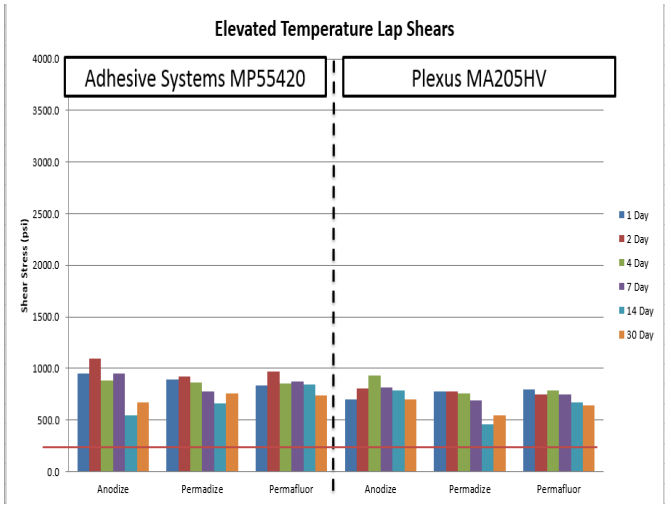
Progress and Accomplishments: Results of Lap Shear Tests









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Progress and Accomplishments: Results of Composite Tests

Develop Specification

Design (Preliminary)

Develop test specifications

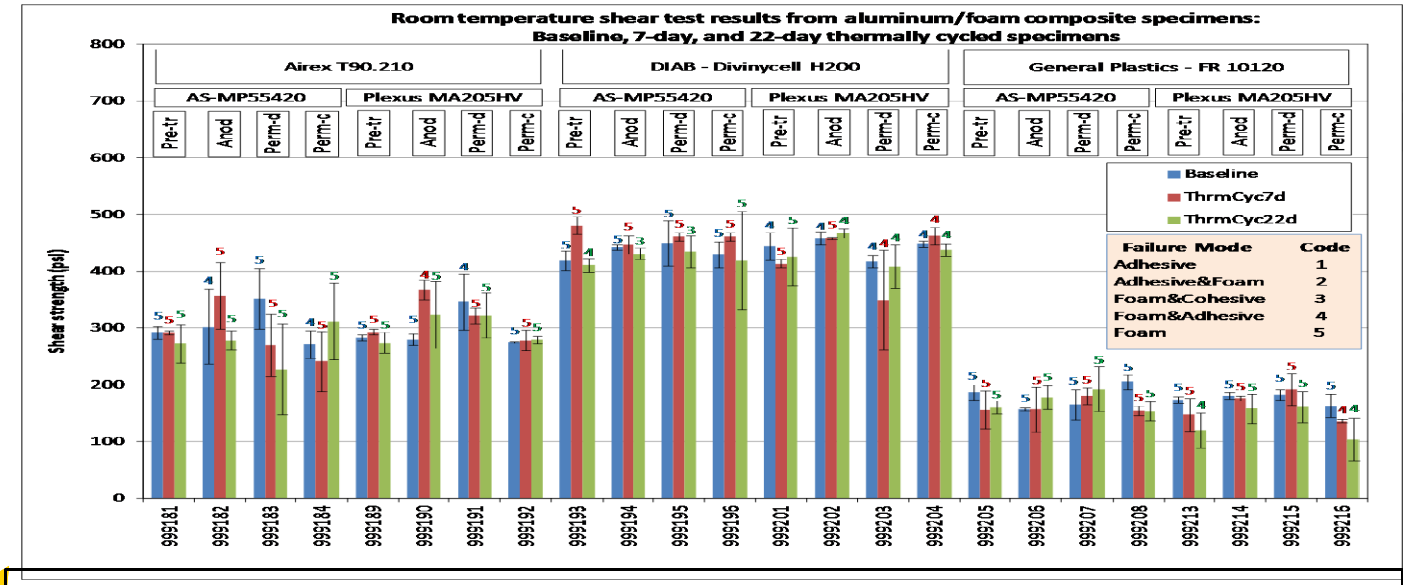
Thermal-break validation

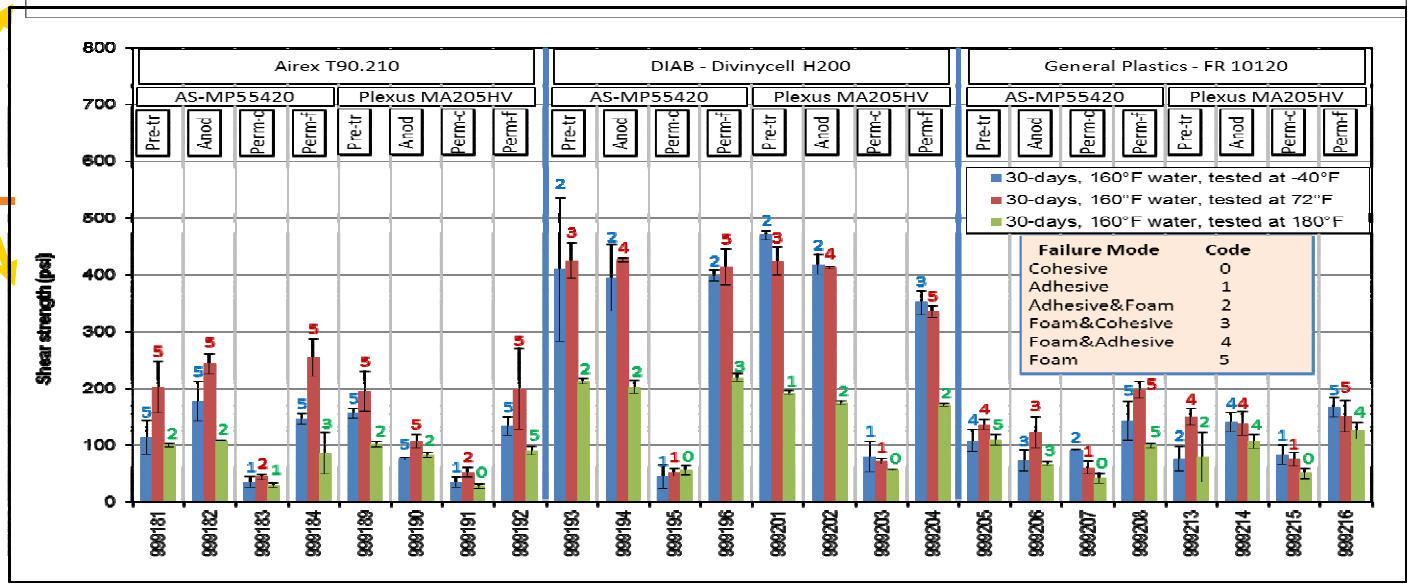
YR1

YR2

Manufacturing plan and pilot line

Window Design (Final)





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Progress and Accomplishments

Accomplishments:

- Completed preliminary product design of R7 commercial windows per specification
- Conducted study to selected materials (foam, adhesives) for thermal-break validation
- Developed test specification and protocol to evaluate the new t/b systems
- Identified impact of aluminum surface condition on T/B performance
- Completed validation of the new thermal-break system – identified materials to move forward towards final design

Market Impact: Possibility of First R7 Architectural Window in the market. New Thermal break system improves Frame U-Factor by 20% and overall window U-Factor by 15% while lowering manufacturing Capex and Opex . Potential to significantly reduce ~2 Quad of energy used in commercial buildings

1. Developing supply-chain to commercialize this technology through partnerships
2. On track to achieve the initial project goals of R7 Architectural windows at no incremental cost

Awards/Recognition: None.

Lessons Learned: Understanding of manufacturing is essential to developing viable solutions.

Project Integration and Collaboration

Project Integration:

- Active engagement between Alcoa, Kawneer, key material partners, and line integrators.
- Weekly Team meetings, project management and oversight.
- Executive Sponsorship.

Partners, Subcontractors, and Collaborators:

- Several Material suppliers e.g. Foam and Adhesive. Willingness to develop custom solution to meet product performance and manufacturing needs
- Currently identifying Manufacturing Line integrator Partners.

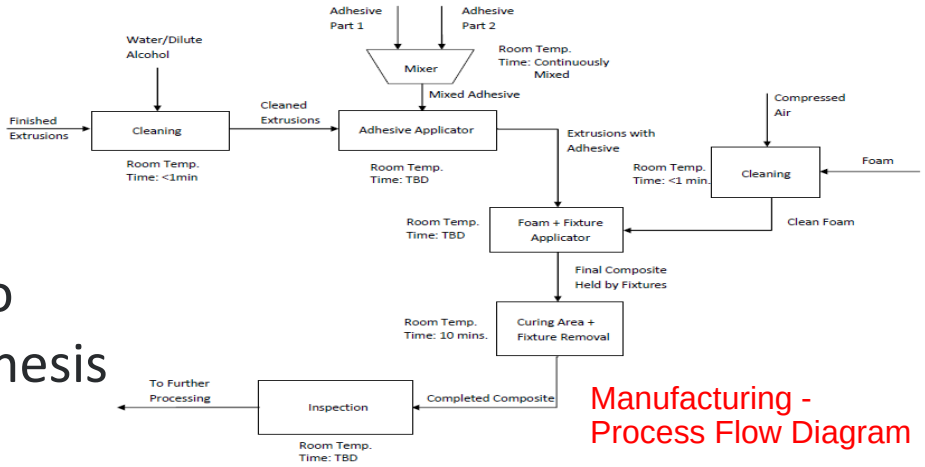
Communications:

- Summary Slide on this project presented at Federal Energy Exchange Conference in Phoenix on Aug 12th, 2015
- Shared the Product concept with key customers at the Annual Kawneer Customer Meeting in Jan 2016

Next Steps and Future Plans

Key 2016 Deliverables

- **Manufacturing Task:**
  - Develop Manufacturing Line Specification (Apr 2016)
  - Build and Install a Pilot Line to validate Manufacturing hypothesis (Dec 2016)
- **Product Development**
  - Finalize Product Design (April 2016)
  - Build Full-Scale prototypes (Jul 20160
  - Conduct validation test (Oct 2016)
- **Develop Marketing and commercial Assessment**
  - Detailed Cost Analysis (Nov 2016)
  - Technology-to-Market Strategy & Commercialization Plan (Dec 2016)



Manufacturing - Process Flow Diagram

Project Budget

Project Budget: Total $1,404,798
80% DOE: $1,123,838
20% Alcoa: $280,960

Variances: N/A.

Cost to Date: 58% ($808,397)

Additional Funding: N/A.

Budget History					
Oct 1, 2014– FY 2015 (past)		FY 2016 – Dec 31, 2016 (current/Planned)		FY 2017 – Dec 31, 2016 (planned)	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
$647,961	$160,436	$475,877	$120,524	-	-

Project Plan and Schedule