

# IACMI 9 Meter Prototype Blade

Dana Swan

Business Development Manager

Arkema



# IACMI 9m Demonstration Blade Purpose



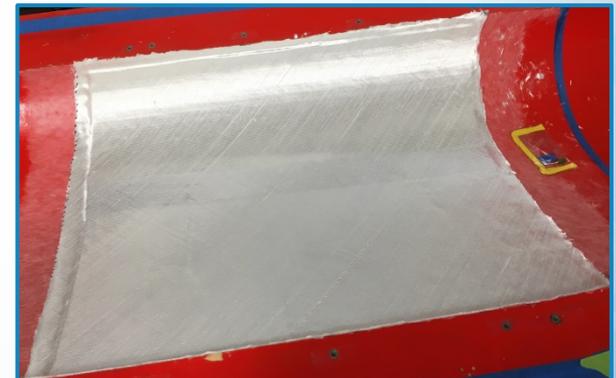
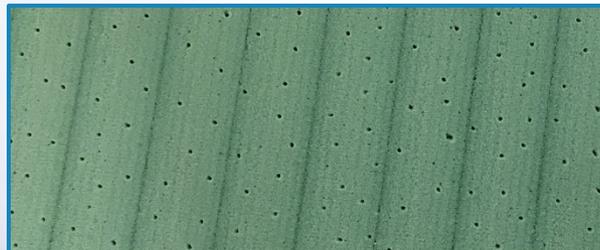
- ◆ Demonstrate scale-up of blade material and processing technologies
- ◆ Identify lower cost blade materials
- ◆ Identify path to reduction of embodied energy
- ◆ Demonstrate potential reduction of in-mold cycle time versus baseline epoxy
- ◆ Lead to larger scale projects with wind OEMs and blade suppliers
- ◆ Augment path to commercialization for innovative composite materials



# IACMI 9m Demonstration Blade Technology



- ◆ Low cost carbon fiber
- ◆ Textile PAN carbon fiber
- ◆ Polyurethane pultrusion
- ◆ ELIUM<sup>®</sup> thermoplastic resin system
- ◆ Room temperature cure
- ◆ Thermoplastic sizing
- ◆ Recycled PET foam



# IACMI 9m Demonstration Blade Industry Partners



ELIUM® Thermoplastic Resin System  
On-site Manufacturing Support



Specialty Sized Fiberglass  
On-site Manufacturing Support



Epoxy Adhesive System  
On-site Manufacturing Support



Blade Tooling and Fixtures  
Technical Analysis



Polyurethane Resin System  
Pultrusion Die  
On-site Manufacturing Support



Pultrusion Trials  
On-site Manufacturing Support

# IACMI 9m Demonstration Blade Industry Partners



On-site Manufacturing Support

## CHOMARAT

Carbon Fiber Conversion  
And Re-Spooling  
On-site Manufacturing Support



## DOWAKSA

Carbon Fiber



Recycled PET Foam

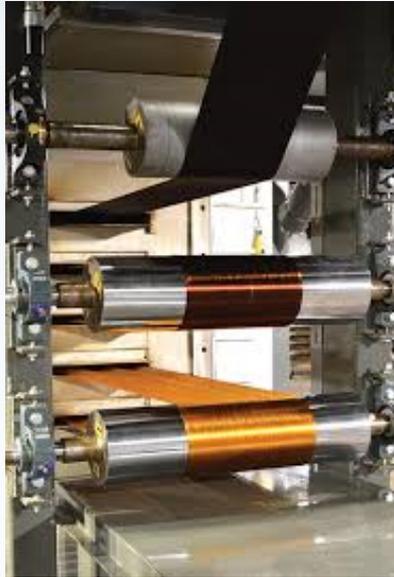


Mold Sealants and  
Release Agents



# Spar Cap Pultrusion

# Textile PAN-based Carbon Fiber



- ◆ Uses low cost industrial precursor
- ◆ Carbonized at ORNL Carbon Fiber Technology Facility
- ◆ Potential for significant cost reduction of carbon fiber
- ◆ Wide band requires some adaptation



# Carbon Fiber Properties (nominal)



	<b>DowAksa A42</b>	<b>CFTF Textile PAN</b>
Tow size	24K	457K
Tensile Strength	610 ksi (4200 Mpa)	399 ksi (2750 Mpa)
Tensile Modulus	34.8 Msi (240 Gpa)	37.1 (256 Gpa)
Strain	1.8%	1.08%
Density	1.78	1.77
Yield	1.6 g/m	14.35 g/m
Sizing	1.0 – 1.5%%	1.35%

Sources: DowAksa A42 Data Sheet, Oak Ridge National Labs

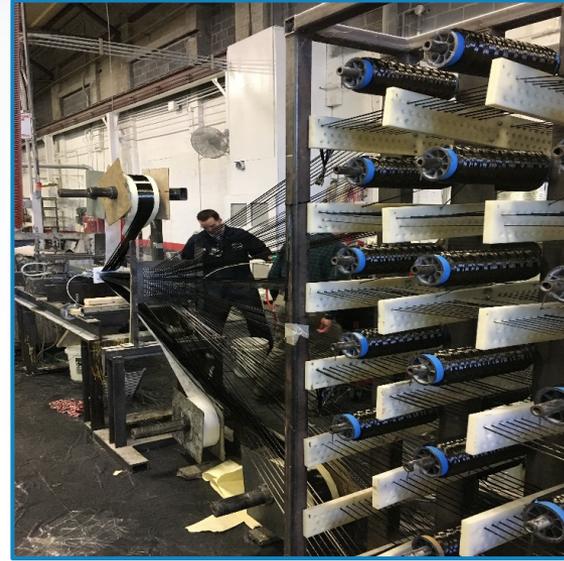
# Polyurethane Resin for Pultrusion



- ◆ Huntsman Polyurethanes provided the resin system used for the spar cap pultrusion trials:
  - ◆ RIMLINE® SK97018 (polyol blend with internal mold release)
  - ◆ SUPRASEC® 9701 (MDI-based isocyanate)
- ◆ Key resin features:
  - ◆ Low initial mixed viscosity (450-500 Cps), designed for efficient wet out of carbon fiber and high fiber volume glass fiber profiles
  - ◆ Long open time for ease in processing and elimination of viscosity build up in pultrusion injection box
  - ◆ Snap cures at high pultrusion die temperatures permitting fast line speeds
- ◆ Huntsman also furnished 3mm x 100mm die and injection box, mixing/pumping system and on-site technical assistance at Strongwell.

# Second Pultrusion Trial – December 7, 2016

- ◆ Combination of textile PAN and DowAksa A42 fiber
- ◆ Glass veil top/bottom
- ◆ Three textile PAN tows beneath and over veil
- ◆ 146 tows A42 in center of laminate
- ◆ Overall fiber volume fraction 58%
  - ◆ 27% Textile PAN CF
  - ◆ 73% DowAksa A42 CF
- ◆ Line speed 18 inches/min
- ◆ Die temperatures 300-325°F
- ◆ Produced 93 meters (305 feet) of pultruded stock before textile PAN fiber ran out





# 9 Meter Blade Fabrication



# What is ELIUM<sup>®</sup> Resin?

## ELIUM<sup>®</sup> - Liquid Thermoplastic Resin

- Two-part reactive resin
- Low viscosity: 100-500cps
- Capable of RT cure
- High modulus and toughness
- Thermoformable
- Recyclable
- Styrene Free



**ELIUM**  
BY ARKEMA

**Infusion**  
**RTM**  
**Pultrusion**  
**Casting**  
**Hand Lamination**

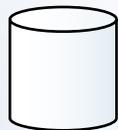
## Designed for a wide range of applications

- Aesthetic parts
- Structural mechanical parts



**ELIUM<sup>®</sup> Resin**  
(100- 500 cPs)

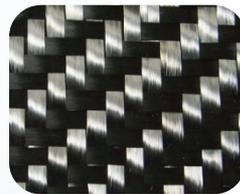
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**Initiator**

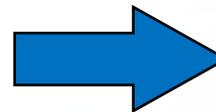
(ex. LUPEROX<sup>®</sup> AFR40)

+



**Fiber**

Glass / Carbon  
or other



- Low pressure injection (RTM, Infusion)
- High MW fiber-reinforced parts.
- No tooling changes

# Properties of ELIUM<sup>®</sup> Resin Composites



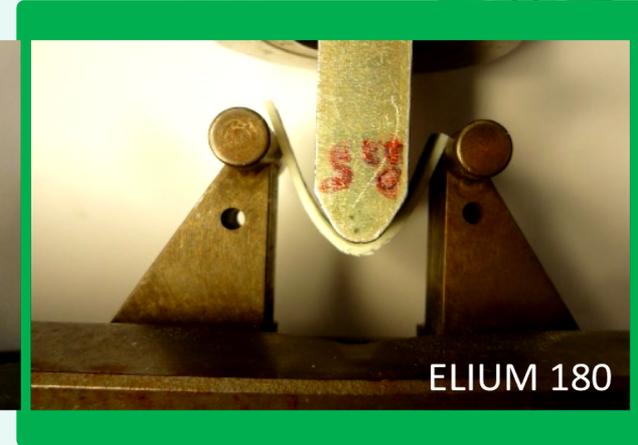
	Pure ELIUM <sup>®</sup> Resin		ELIUM <sup>®</sup> Resin with Carbon (structural parts)		ELIUM <sup>®</sup> Resin with Glass (structural parts)		ISO Method
Tensile strength	<b>76</b>	MPa	<b>1280</b>	MPa	<b>557</b>	MPa	<b>527</b>
Tensile modulus	<b>3300</b>	MPa	<b>59</b>	GPa	<b>27</b>	GPa	
Flexural strength	<b>130</b>	MPa	<b>870</b>	MPa	<b>700</b>	MPa	<b>14125</b>
Flexural modulus	<b>3250</b>	MPa	<b>65</b>	GPa	<b>27</b>	GPa	
Compressive strength	<b>130</b>	MPa	<b>480</b>	MPa	<b>347</b>	MPa	<b>14126</b>
Compressive modulus	-		<b>54</b>	GPa	<b>28</b>	GPa	

Details: ELIUM<sup>®</sup> RT-300 resin, room temperature RTM process | Carbon – T700SC 12K NCF 53%vol. | Glass - Chomarat 600T PW fabric 600GSM, 53%vol.

**Basic mechanical properties similar to epoxy**  
with same reinforcement loadings

Function	Flex Modulus	Applications
<b>Aesthetic</b>	<b>10 - 15 GPa</b>	Marine, Transportation, Heavy Equipment, etc.
<b>Structural</b>	<b>20 - 45 GPa</b>	Automotive, Aeronautic, Wind Blade, Sport, etc.

# High Modulus and Toughness



## EXCELLENT STIFFNESS

## SUPERIOR TOUGHNESS

	Max Stress (MPa)	Modulus (GPa)	Elongation at Break (%)
UPR	210	13	2.7
Epoxy	250	9	4.8
ELIUM® resin	343	11	> 20

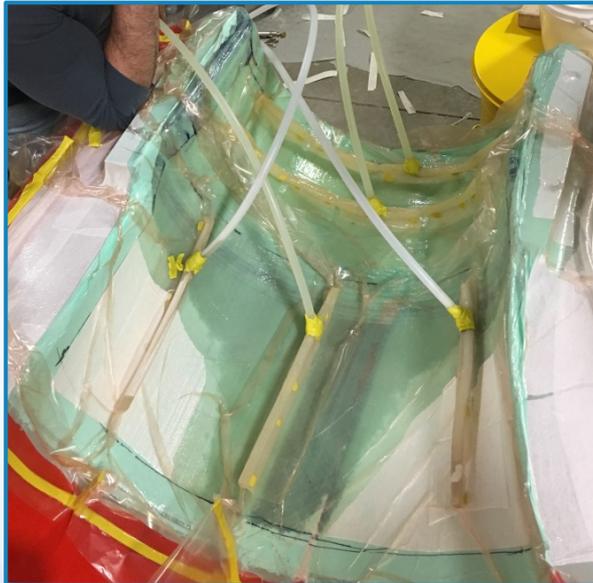
### Details

ISO 14125 Flexural Test  
Vacuum infusion process  
2 plies of GF BX45 1200GSM  
Sizing SE2020 for epoxy and  
SE4740 for UPR and ELIUM® 180

# ELIUM<sup>®</sup> Molding Trials at CoMET National Renewable Energy Laboratory – Colorado, USA



- ◆ Combined elements:
- ◆ Thick root section
- ◆ Transition to thin airfoil sections
- ◆ Spar cap
- ◆ Max chord



# IACMI 9m Demonstration Blade Specifications



## ◆ Blade Dimensions:

- ◆ Length: 8.325 m [27'-3.75"]
- ◆ Root Diameter: 0.535 m [21.05"]
- ◆ Max Chord: 0.789 m [31.06"]
- ◆ Root Laminate Thickness: 32.25 mm [1.27"]

## ◆ Blade Weight and Center of Gravity

- ◆ Weight: 116.82 kg [257 lbs]
- ◆ Spanwise CG 2.197 m [7'-2.5"]



# LP and HP Skin Fabrication: Laminate Schedule



4	Pultruded Carbon Uni	Spar Cap	0150	7,875
5	Pultruded Carbon Uni	Spar Cap	0230	5,000



# LP and HP Skin Fabrication: Laminate Schedule

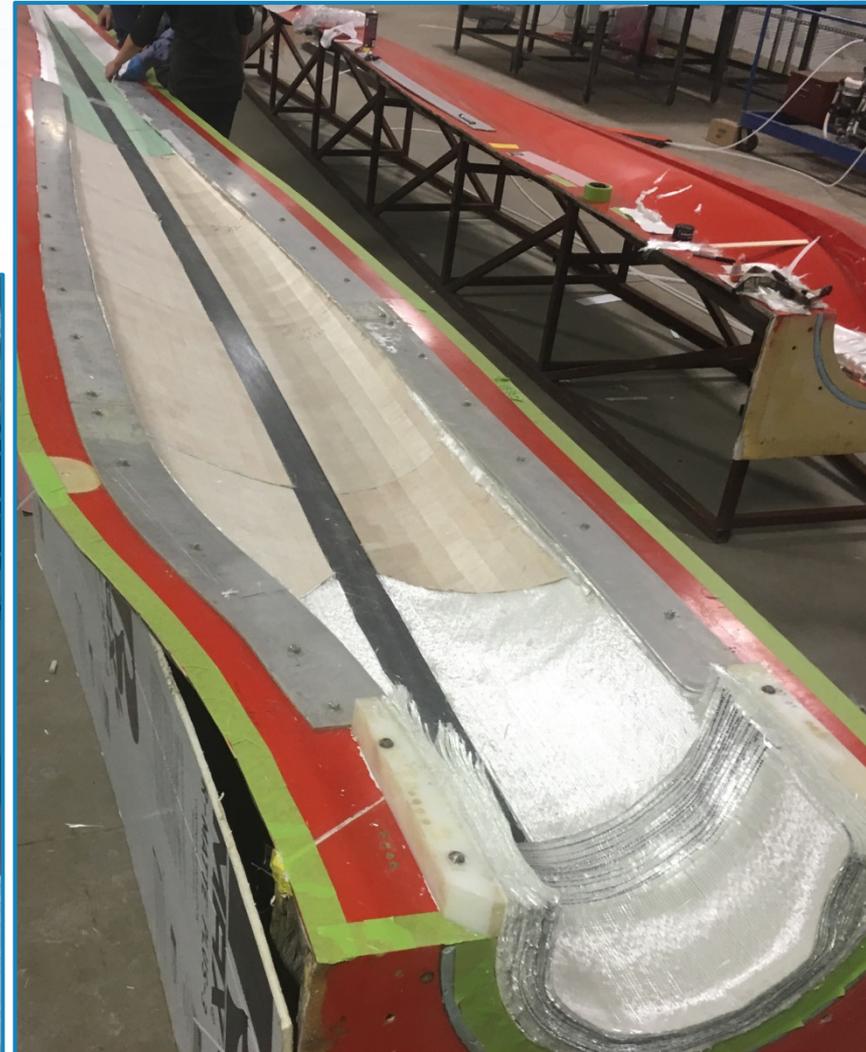
13	Saertex Triax	Root Build-Up	0000	381
14	Saertex Triax	Root Build-Up	0000	375
15	Saertex Triax	Root Build-Up	0000	369
16	Saertex Triax	Root Build-Up	0000	363
17	Saertex Triax	Root Build-Up	0000	357
18	Saertex Triax	Root Build-Up	0000	351
19	Saertex Triax	Root Build-Up	0000	345
20	Saertex Triax	Root Build-Up	0000	339
21	Saertex Triax	Root Build-Up	0000	333
22	Saertex Triax	Root Build-Up	0000	327
23	Saertex Triax	Root Build-Up	0000	321
24	Saertex Triax	Root Build-Up	0000	315
25	Saertex Triax	Root Build-Up	0000	309
26	Saertex Triax	Root Build-Up	0000	303
27	Saertex Triax	Root Build-Up	0000	297
28	Saertex Triax	Root Build-Up	0000	291
29	Saertex Triax	Root Build-Up	0000	285
30	Saertex Triax	Root Build-Up	0000	279
31	Saertex Triax	Root Build-Up	0000	273
32	Saertex Triax	Root Build-Up	0000	267
33	Saertex Triax	Root Build-Up	0000	261
34	Saertex Triax	Root Build-Up	0000	255
35	Saertex Triax	Root Build-Up	0000	249
36	Saertex Triax	Root Build-Up	0000	243
37	Saertex Triax	Root Build-Up	0000	237
38	Saertex Triax	Root Build-Up	0000	231
39	Saertex Triax	Root Build-Up	0000	225



# LP and HP Skin Fabrication: Laminate Schedule



40	Balsa, 1/4"	Inboard Aft Panel Balsa		4182
41	Balsa, 1/4"	Inboard Fwd Panel Balsa		4182
42	Balsa, 1/4"	Flatback Panel Balsa		
43	Foam, 1/4"	Outboard Aft Panel Foam	4182	
44	Foam, 1/4"	Outboard Fwd Panel Foam	4182	



# LP and HP Skin Fabrication: Infusion



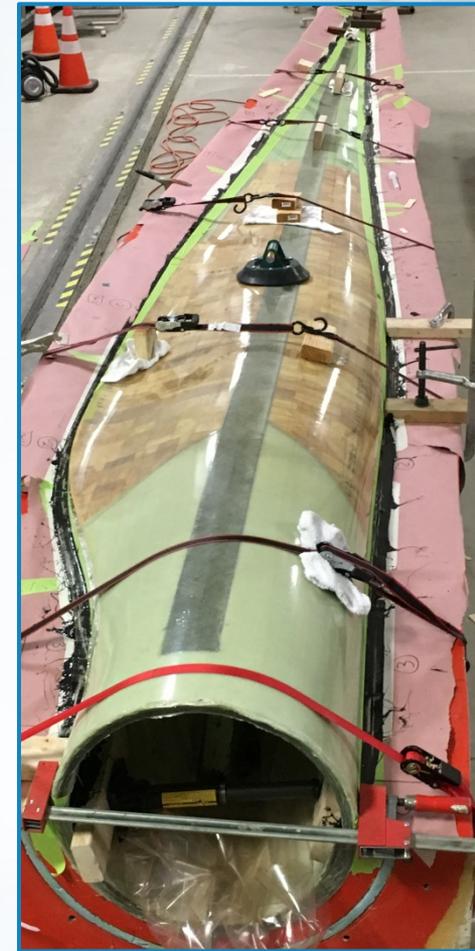
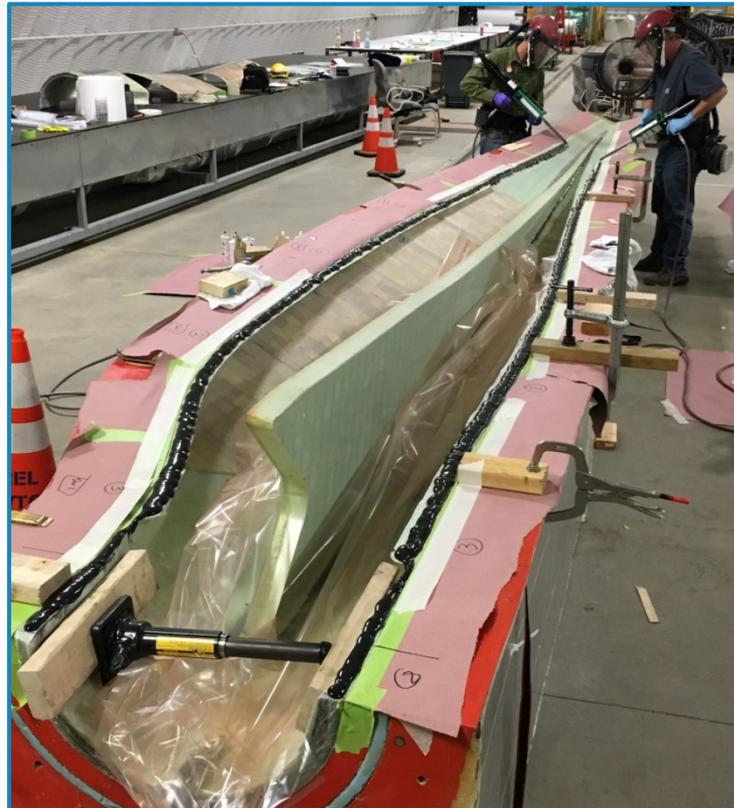
- Wet-out: 60 min
- Gel: 120 min
- Demold: 4 hr (from start of infusion)



# LP and HP Skin Fabrication



# Blade Bonding and Finishing: Assembly



- ◆ SikaAxson Adekit A140 Epoxy Adhesive

# IACMI 9 meter Demonstration Blade





# Conclusions

# IACMI 9m Demonstration Blade Achievements



- Assembled broad supply chain for blade fabrication trials
- Fostered collaboration between IACMI industry partners, government laboratories and IACMI technology areas
- Demonstrated innovative composite material and processing technologies at blade scale
- Demonstrated potential reduction of cure time and in-mold cycle time for ELIUM<sup>®</sup> versus baseline epoxy
- Successfully produced a full-scale 9 meter technology demonstration wind turbine blade with advanced composite materials to be displayed at the CoMET Ribbon Cutting, the IACMI Colorado Members Meeting and other venues
- Augmented the path to commercialization for several of the innovative materials and processes

# Unique Innovative Blade Technology

Thermoset  
Resins



Thermoplastic  
Resins

- Reduced Cycle Time – by up to 20%
- Decrease tooling capital costs – by up to 30%
- Decrease over wind turbine blade cost – by approximately 5%
- Enable cost effective blade recycling
- Future Impact: thermal welding of wind turbine blades

Standard  
Carbon Fiber



Low Cost  
Carbon Fiber

- Reduce cost of carbon fiber for wind turbine blades from ~\$13/lb. to ~\$7/lb.



# Special Thanks to:



**COLORADO**

Office of Economic Development  
& International Trade



U.S. DEPARTMENT OF  
**ENERGY**