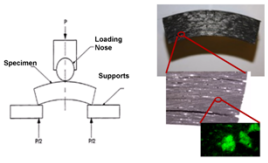

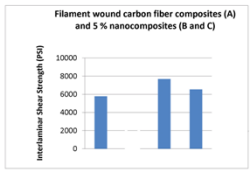

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Exceptional service in the national interest

Improved Properties of Nanocomposites for Flywheel Applications

September 2012

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Project: Improved Flywheel Materials

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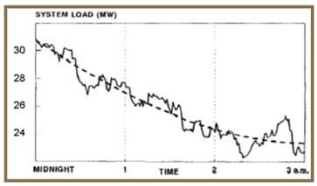
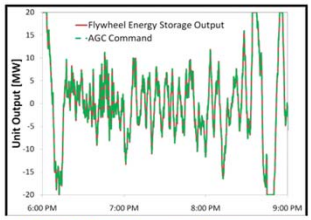


Problem: Small changes in the AC grid energy levels necessitates rapid and exact changes in the demand/surplus requirements to ensure energy leveling. Gas powered generators are lacking.

Approach: Flywheels are a clean and efficient method that can meet the energy leveling demands. To store more energy, flywheels need to spin faster, which requires stronger rims. Focused on the materials (C-fiber, glass fiber, resin) of composite flywheels. No major changes to basic design, processing parameters, and/or cost can be incurred.



A 20 MW flywheel energy storage resource accurately following a signal

Stationary Energy Storage Impact: The economics of flywheel-based energy storage might potentially be improved by a factor of 3 or more. The increased storage/supply will be necessary to meet expected future complications expected as alternative energies (i.e., solar, wind, etc.) are introduced.

The Need for Speed Kills

Goal: to explore nanocomposites as the rim material to produce improved flywheel performance.

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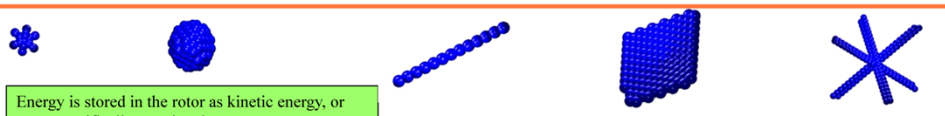
Low load levels of nanoparticle fillers have lead to dramatic property changes

Loading (wt %):	4	$Al_2Si_2O_5(OH)_4$:	*23%*	*storage, 113% flexural strength,*[1]
	3	Al_2O_3:	*75%*	*tensile strength,*[2]
	2	SiO_2:	*3%*	*hardness, 57% impact, 65 % flex, 88 % tensile strength,*[3]
	2	ZrP:	*52%*	*Youngs Modulus, 14% tensile strength 6 %, fracture toughness,*[4]
	0.4% CNT-2%	ZrP:	*41%*	*Youngs Modulus, 55% tensile strength.*[5]



Energy is stored in the rotor as kinetic energy, or more specifically, rotational energy:

$$E_k = \frac{1}{2} \cdot I \cdot \omega^2$$

ω = angular velocity, I = moment of inertia of the mass about the center of rotation

The amount of energy that can be stored is dependent on:

$$s_t = \rho \cdot r^2 \cdot \omega^2$$

s_t = tensile stress on the rim, ρ = density, r is the radius, ω is the angular velocity of the cylinder.

Polym Res (2008)
hem (2006)
al J. App Polym Sci
olym Sci B: Polymer
em Mater (2010)

Small % changes in the flywheel spin speed leads to magnified energy storage

16,000 rpm → *20,000 rpm*
25 kWh → *39 kWh*
of extractable energy

25 kWh/100 kW per unit = 21 kg TNT

FY12 Overall Objectives: defining nanoparticle fillers effects on the 'state-of-the-art' system

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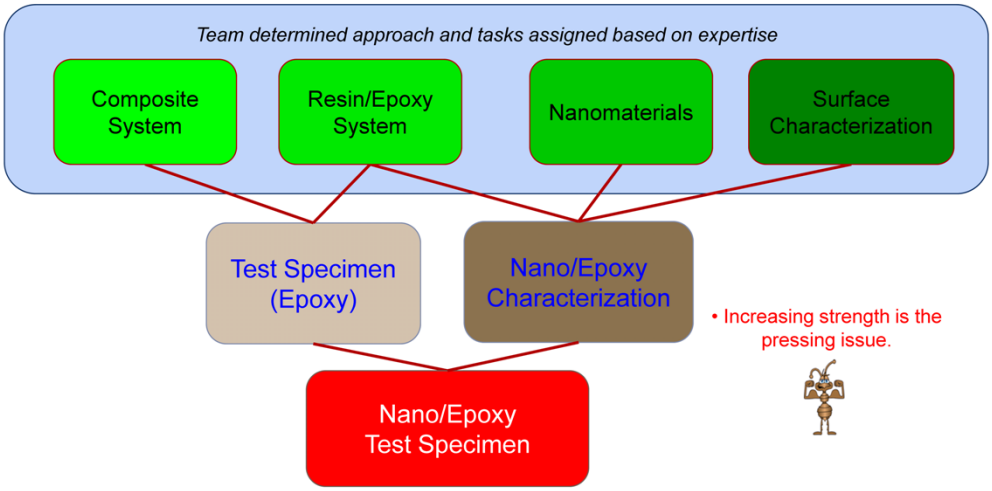
• Flywheel applications are interested in increasing the strength of the resin/C-fiber interaction to allow for faster spin speeds.



• Increasing strength is the pressing issue.

• Incorporation of suggested nanomaterials or resins will represent verification of our approach

Interlaminar strength of composite test specimens for different resin systems indicated that the….

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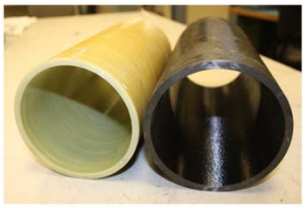
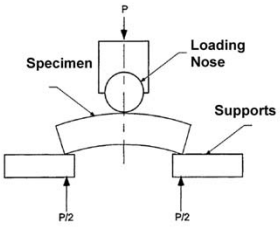
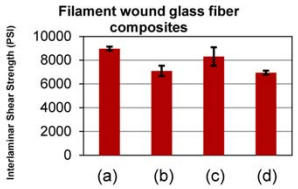


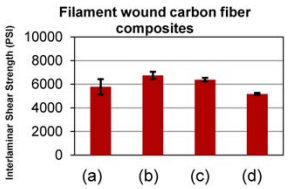
Filament wound glass and carbon fiber composite tubes

Arc 3-point bend specimens



Resin Systems
(a) Standard: epoxy anhydride /catalyst
(b) Epoxy anhydride/catalyst
(c) Epoxy anhydride/catalysts/modifier
(d) Epoxy amine





(i) system is good model to 'real-world materials' and allows for interpretation of NW additives

(ii) C-fiber/resin interaction needs increased

Nanocomposites show a < 30% increase in measured strength of C-fiber wound test specimen!

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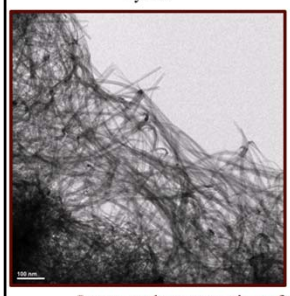
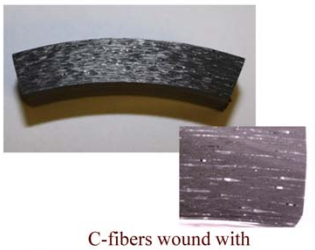
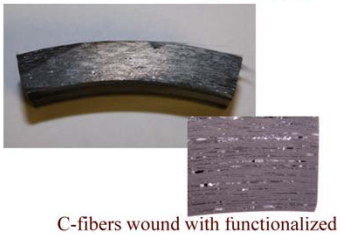
hybrid



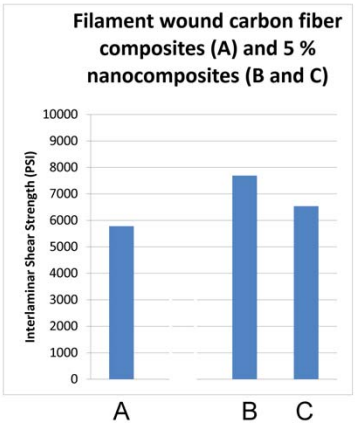
Large scale preparation of nanowires available



C-fibers wound with unfunctionalized nanoparticles (B)



C-fibers wound with functionalized nanoparticles (C)



(i) Sarwar et al. *J. Sol-Gel Sci Tech.* (**2007**) 44, 4.
(ii) Adler-Abramovich et al. Angewandte Chemie (**2010**) 49, 1-5.
(iii) Kane et al. J Appl. Cryst. (**2009**) 42, 925.
(iv) Sumfleth et al *Polymer* (**2008**) 49, 5105.
(v) Sangermano et al. Macromol. Mater. Eng. (**2006**) 291 517.

Increased shear and interlaminar-fracture strength of flywheel carbon fiber-epoxy composite by 30%, may enable 20-30% reduction in flywheel energy storage cost ($/kW-h).

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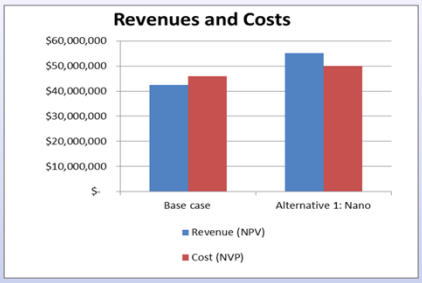
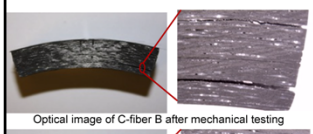
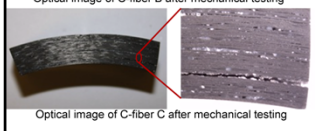


Case Study: 20-MW Beacon Power Facility (NY)

- Technology increases power capacity to 26 MW and energy capacity to 7.5 MW-service hours.
- Decreases average energy storage costs to $1500/kW and $6000/kW-h.
- After accounting for new-technology and additional production costs, return on improved-nanocomposite investment is 4%-6% per year over 20-year service life.

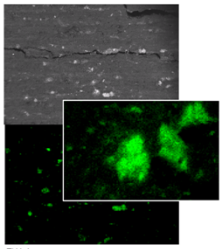


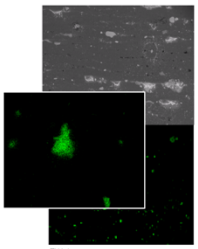
Optical image of C-fiber B after mechanical testing



Optical image of C-fiber C after mechanical testing

Poor distribution of nanomaterial observed, implies a minimal impact for the load levels used.





C-fiber resin interaction requires improvement, so functionalization of the C-fiber undertaken.

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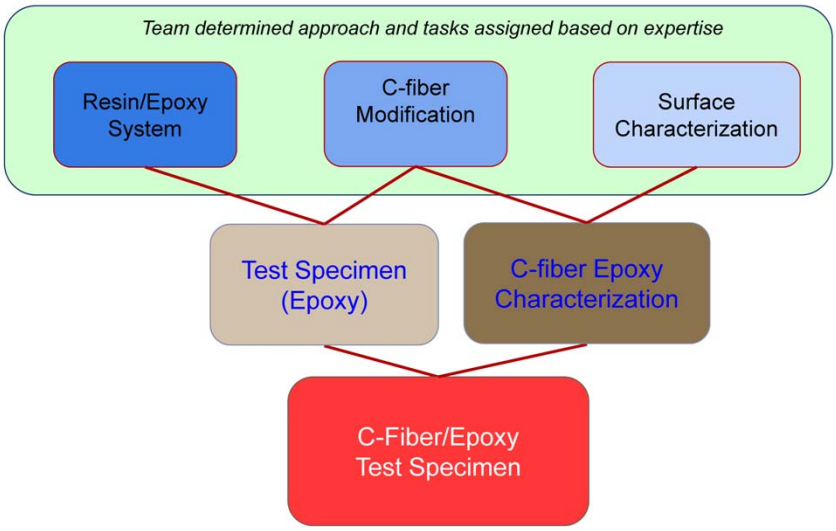

Several approaches to functionalize C-fibers were undertaken

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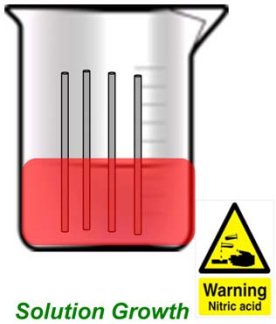
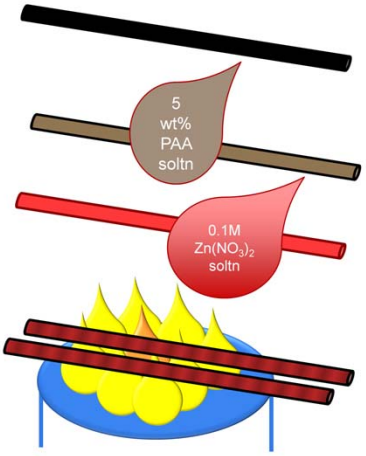
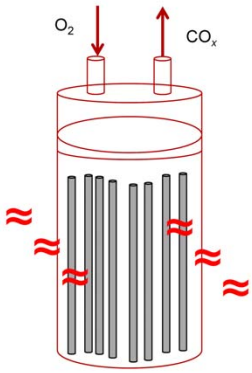


Solution Growth



Rapid Thermal Decomposition:



Thermal oxidation

C-fiber modification results promising

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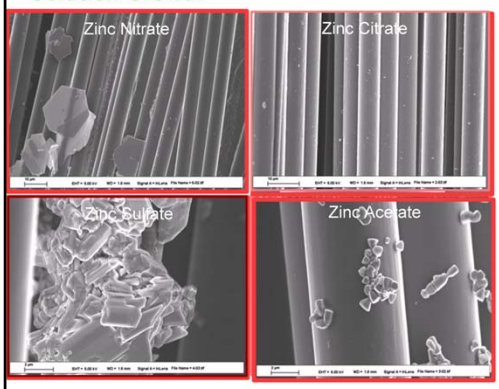
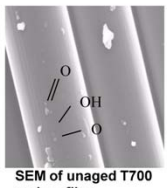
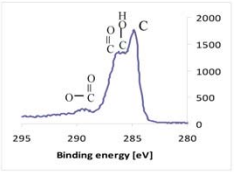
Solution Growth



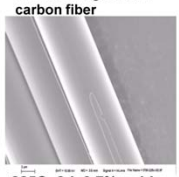
Thermal Oxidation



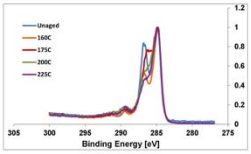
SEM of unaged T700 carbon fiber



XPS to probe surface oxidation of carbon Fiber exposed to 0.6% oxid. at 175°C

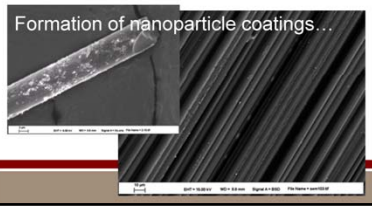


225C, 2d, 0.7% oxid.



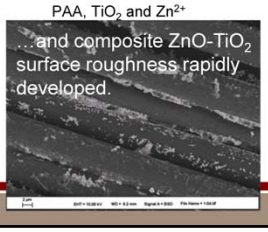
Rapid Thermal Decomposition

PAA-Zn^{2+} solution



Pechini formulation

PAA, TiO_2 and Zn^{2+}



Summary/Conclusions

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- Test Specimen Model identified:

(i) **good indicator of 'real world' properties,**

- Introduction of TiO_2 nanowires led to a 30 % increase in tested strength
- Economically correlates to a 20 % reduction in cost
- Better properties expected upon better distribution of poorly distributed nanowires in matrix.

(ii) **C-fiber/resin interaction needs increased.**

C-fiber modification underway:

(a) solution growth,

- surface modification shown with control indicated by anion

(b) thermal oxidation

- CO_x gas observed without substantial decomposition of C-fiber

(c) rapid thermal decomposition.

- rapid surface modification noted with bonding between fibers.

Future Tasks: Milestones for FY13

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- Retest resin at higher load levels consistent with test specimen.
- Functionalize/characterize TiO_2 nanowires for improved distribution.

- Re-evaluate distributed functionalized TiO_2 nanowires in test specimen.

- Optimize surface modification of C-fiber with ceramic nanomaterials.
- Determine interaction strength of C-fiber and ceramic NM.
- Introduction of optimized modified C-fiber into test specimen model system.

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Energy Storage Program Manager – Dr. Imre Gyuk

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