DOE Office of Electricity TRAC

Peer Review

U.S. DEPARTMENT OF ENERGY | OFFICE OF ELECTRICITY

PROJECT SUMMARY

Robust Insulation for Transformers and Power Electronics

Developed and compared various materials electrical performance at varying temperatures, electrical frequencies and voltages, as well as their mechanical properties

PRINCIPAL INVESTIGATORS

Dr. Bjorn Vaagensmith, Power Systems researcher, INL

WEBSITE

www.INL.gov

The Numbers

DOE PROGRAM OFFICE:
OE – Transformer Resilience and Advanced Components (TRAC)

FUNDING OPPORTUNITY:
XXX

LOCATION:
Idaho Falls, Idaho

PROJECT TERM:
09/15/2019 to 06/03/2020

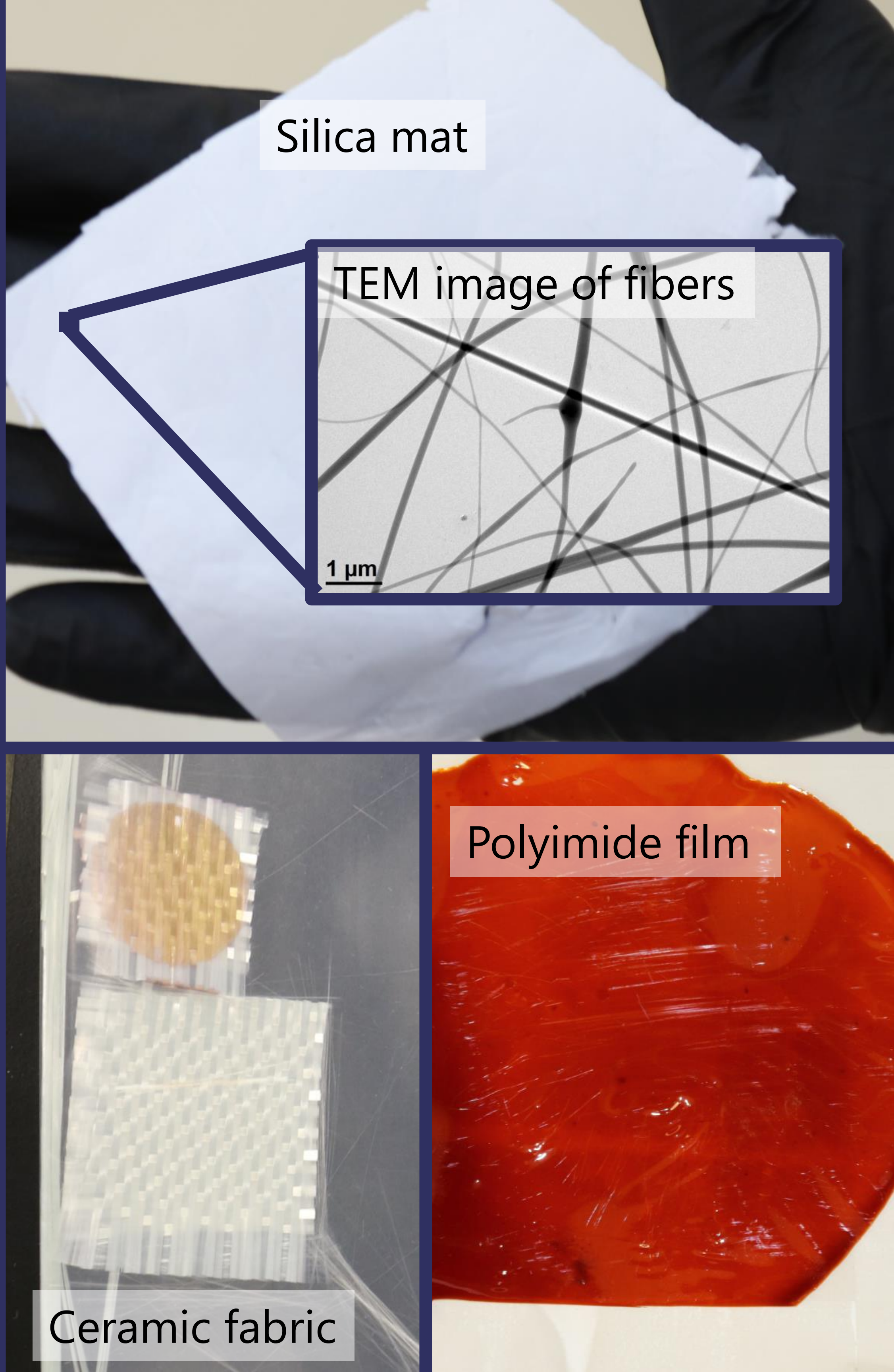
PROJECT STATUS:
Incomplete/Completed

AWARD AMOUNT (DOE CONTRIBUTION):
$500,000

AWARDEE CONTRIBUTION (IN KIND):
$30,000

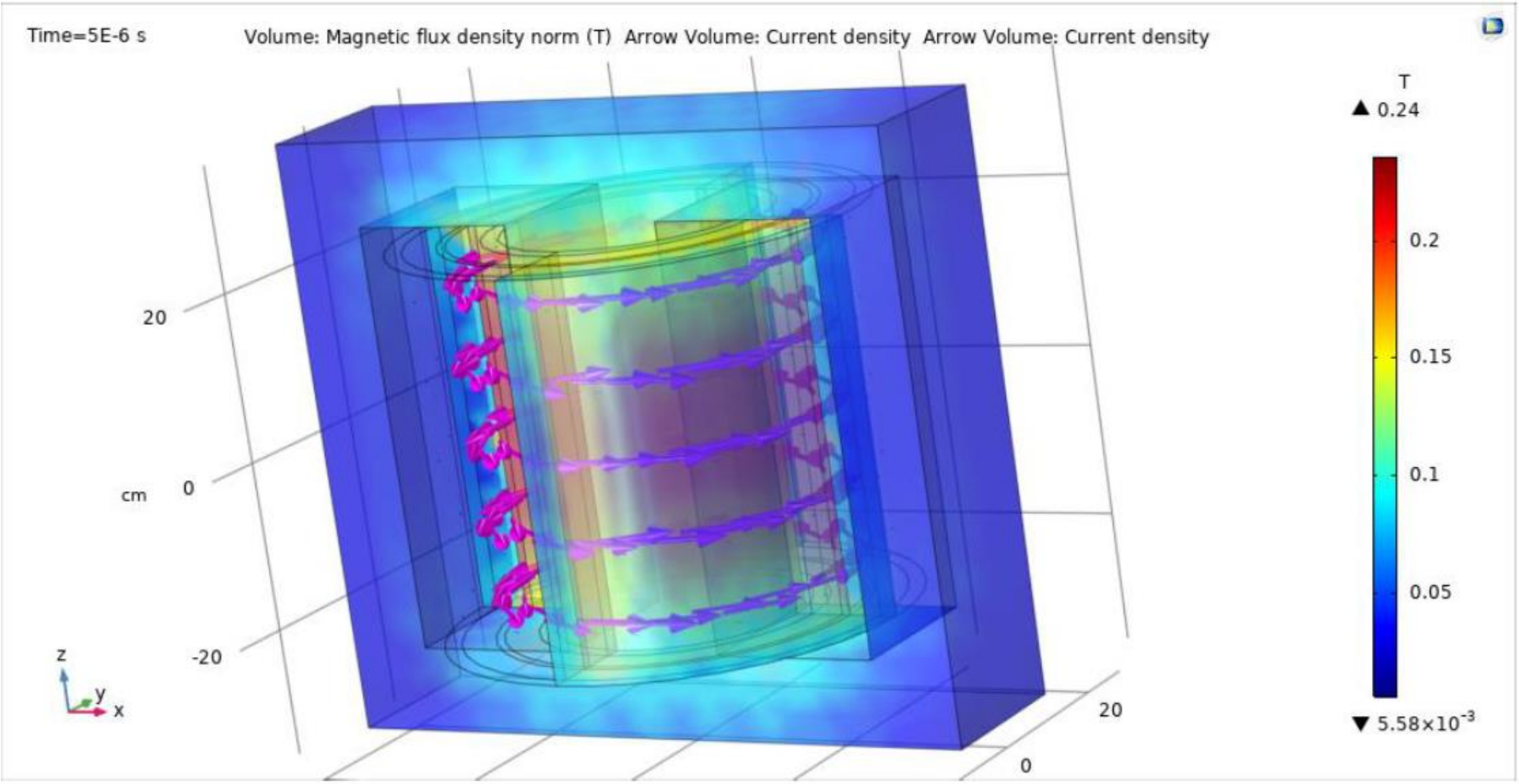
Primary Innovation

- Tested high temperature tolerant binders to improve the machinal strength of fibrous silica mats.
- Explored the effects of nanoparticle additives effects to polyimide composites.
- Explored material insulation performance in transformers via simulation.



Impact

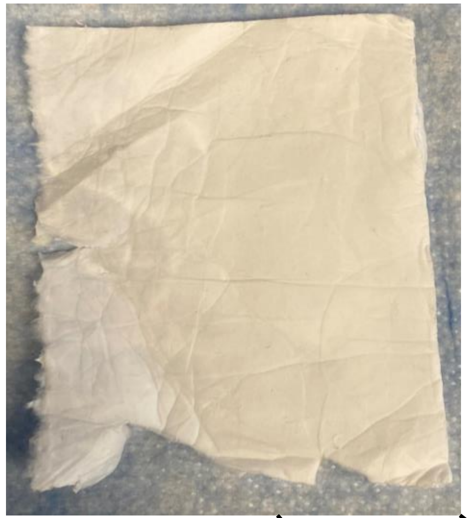
- Enable robust solid state transformer designs by advancing transformer electrical insulation material
  - Withstand the confluence of high voltage, temperature, and electrical frequency
- Advance the science behind high temperature insulation materials



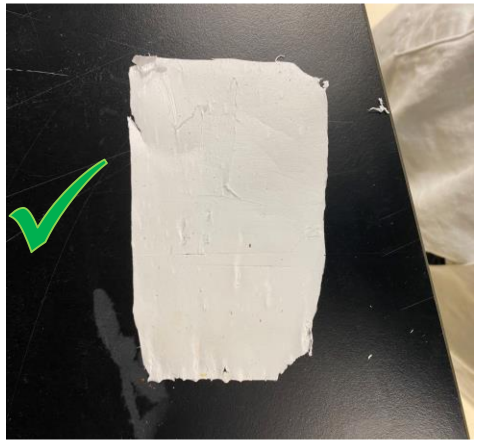
Innovation update

Silica mats with Ren 50 binder

Tensile Strength of Silica Mats with Ren 50



Spray coat with compression



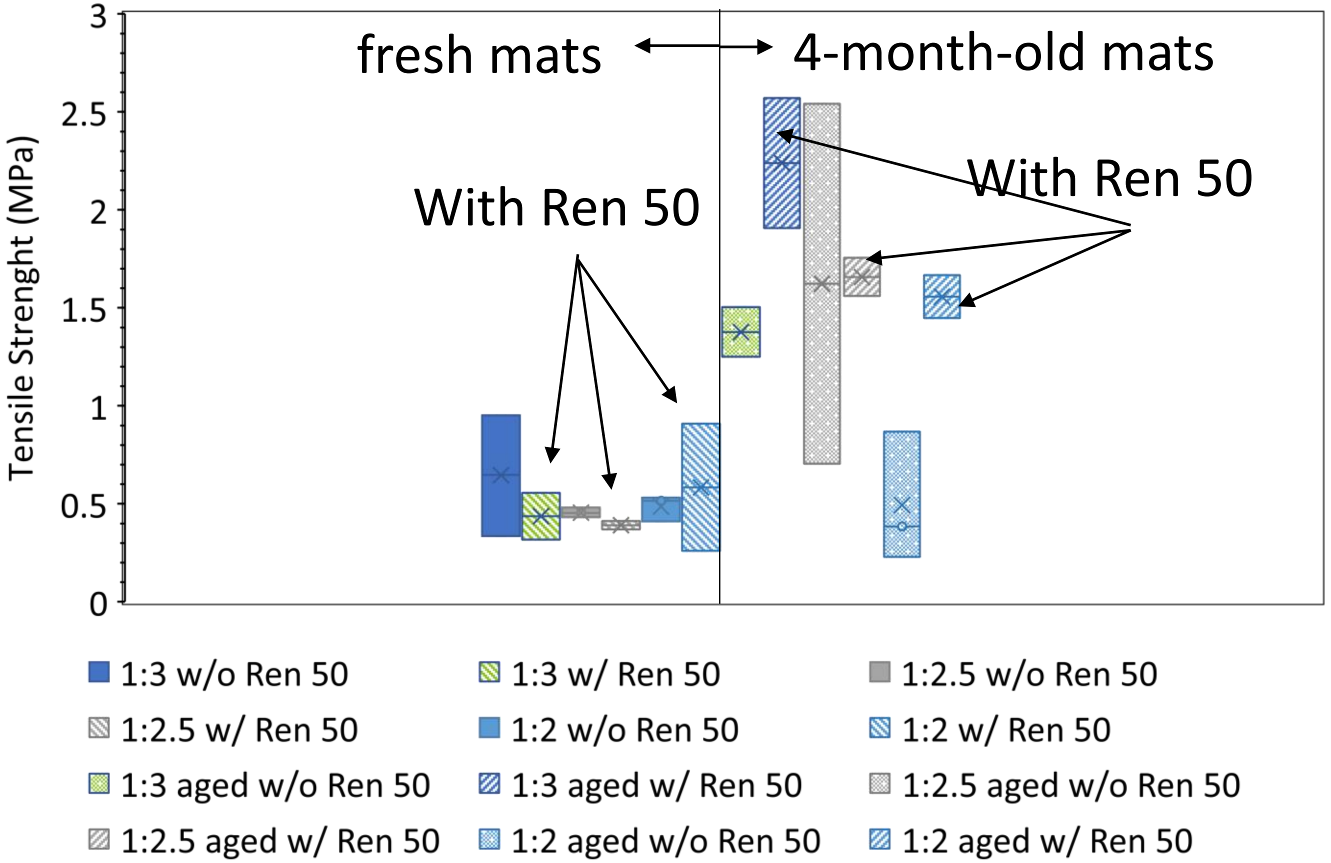
Was flexible

Meyer Rod

Soak

Pour

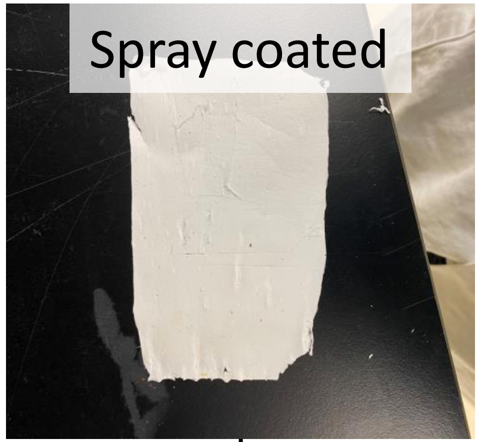
Was brittle after curing

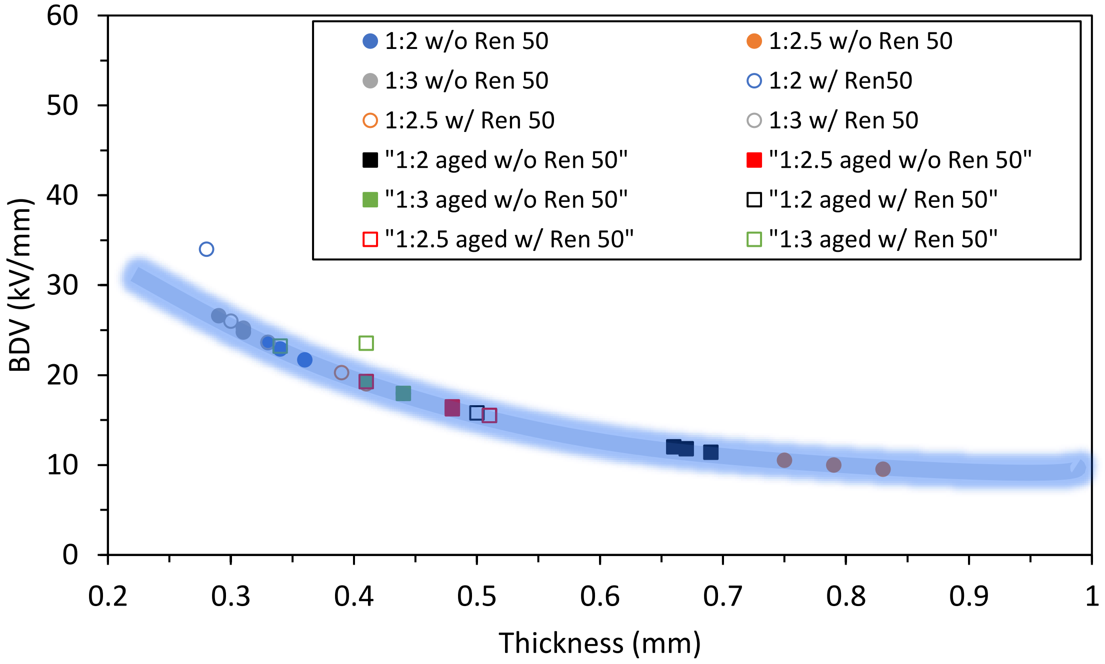


- Tensile strength of mats with and without binder was not significantly different
- Aged mats showed increase in tensile strength

Break down voltage of silica-Ren 50 mats

- Weigh ratios of 1:2-1:3 mat:Ren 50 wt. ratio did not affect breakdown voltage
- Conductivity ranged from 10^9-10^{13} Ω-cm
- ***New discovery:*** *Indicates Ren 50 has good electrical properties*
- Break down voltage of 26 kV/mm at 0.3 mm thickness
  - Suitable for transformer applications
- Ren 50 can withstand temperatures up to 650 °C
  - DSC results indicate operating temperatures above 500 °C should be avoided for silica-ren 50 mats





Innovation update

Polyimide films with nanoparticle additives

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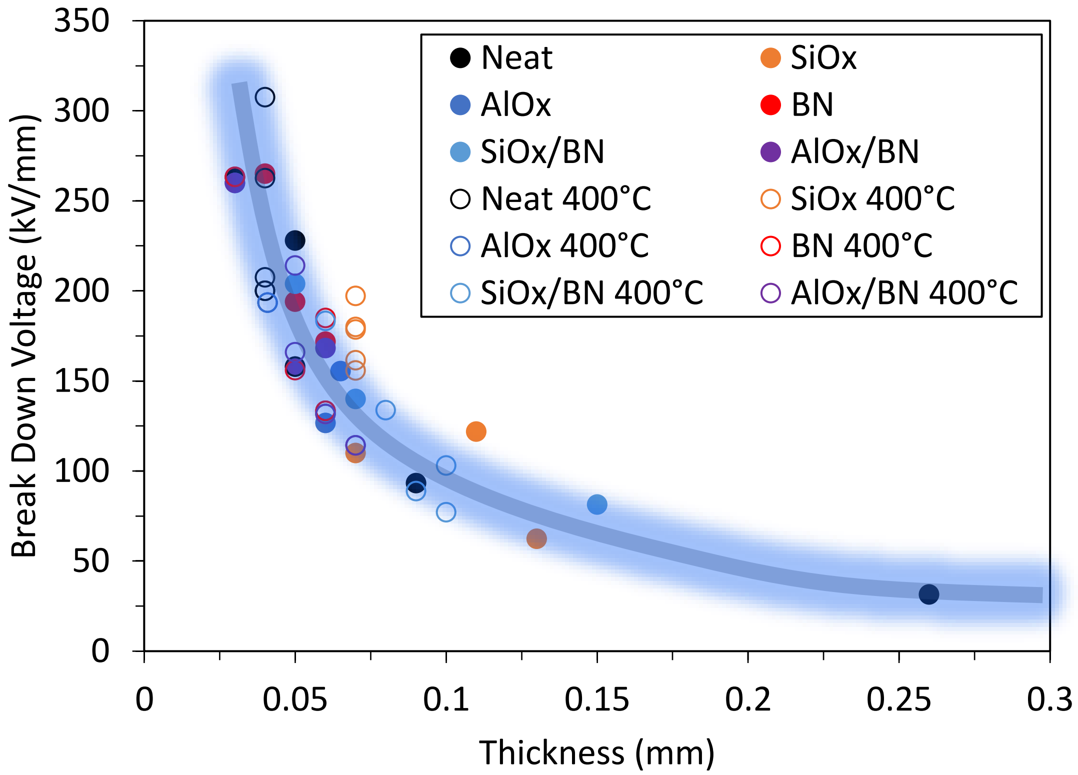
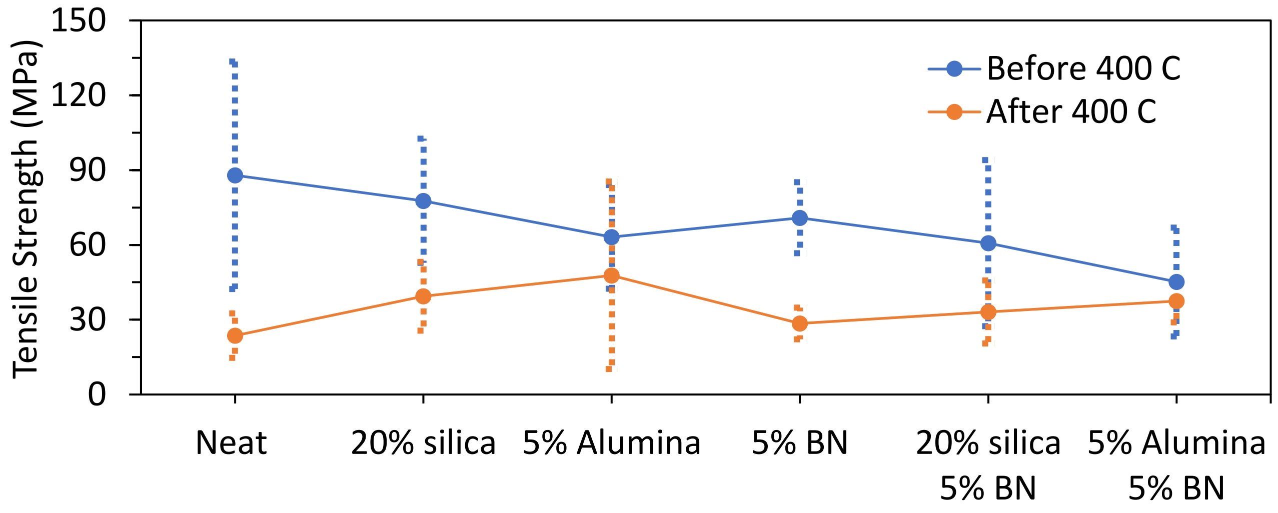
Break down voltage of Polyimide

- No significant deviation from exponential decay relationship after:
  - Varying additive type
  - After 400 °C heat treatment for 12 hours
- Additive type nor heat treatment affected breakdown voltage within the films
- Breakdown voltage 31.5 kV/mm at 0.26 mm
  - Good for transformer applications



Mechanical Strength of Polyimides

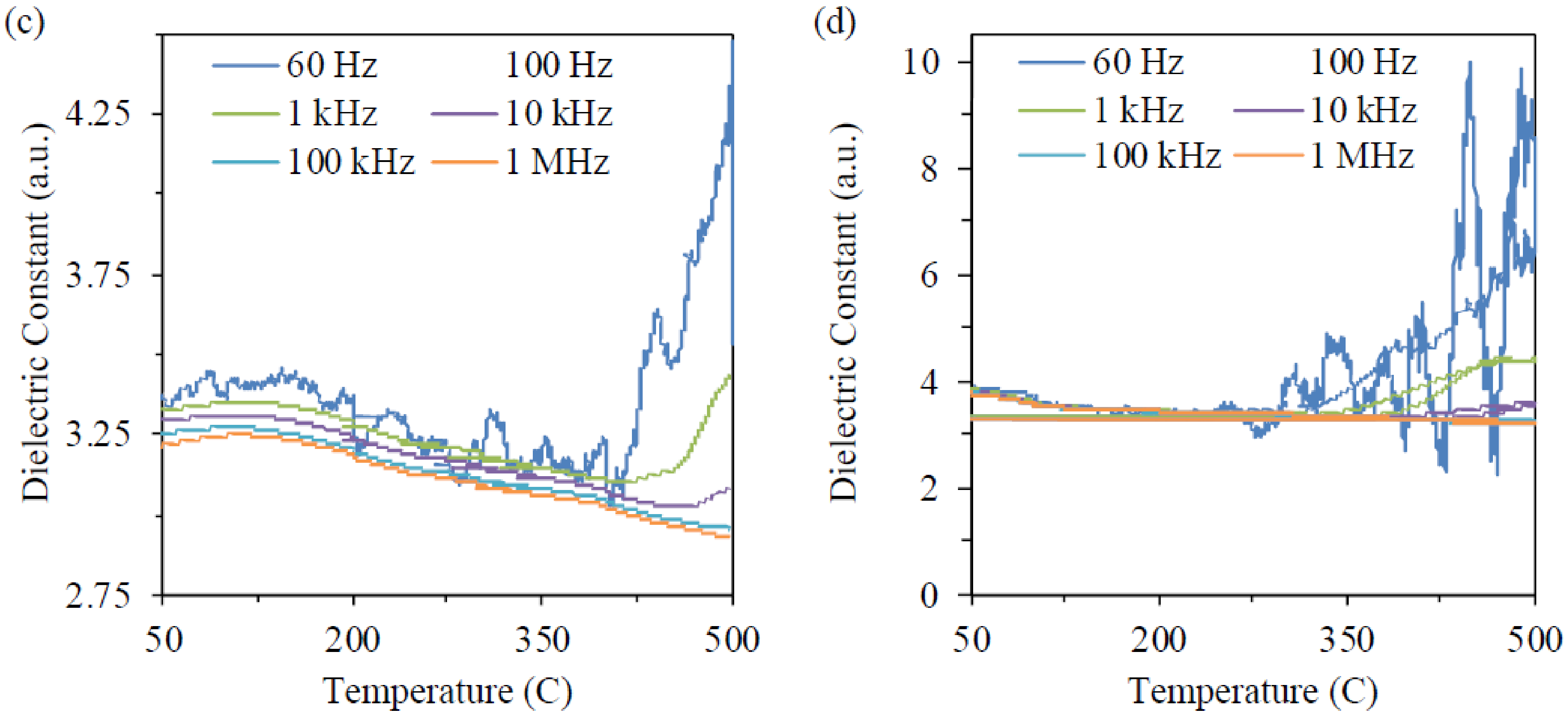
- Tensile strength degraded with 12 hours of 400 °C heat treatment
- MIT fold endurance reduced by 50-99% after heat treatment



MIT fold endurance	Neat	20% silica	5% Alumina	5% BN	20% silica 5% BN	5% Alumina 5% BN
Before 400 °C	370±179	6841±4274	3514±1034	1059±588	153	1006±448
After 400 °C	180±146	7±7	368±276	134±63	146±70	57±52
% Change	51.35%	99.90%	89.53%	87.35%	4.58%	94.33%

Temperature tolerance of Polyimides

- TGA and DSC showed a glass transition temperature ranging from 380-460 ℃
  - Should operate transformers below this temperature
- Films dielectric constant decreased by 50 ℃ after heat treatment
  - from 400 ℃ to 350 ℃



Films with 5% Al_2O_3 additives shown as a representative sample

Innovation update

Transformer insulation modeling

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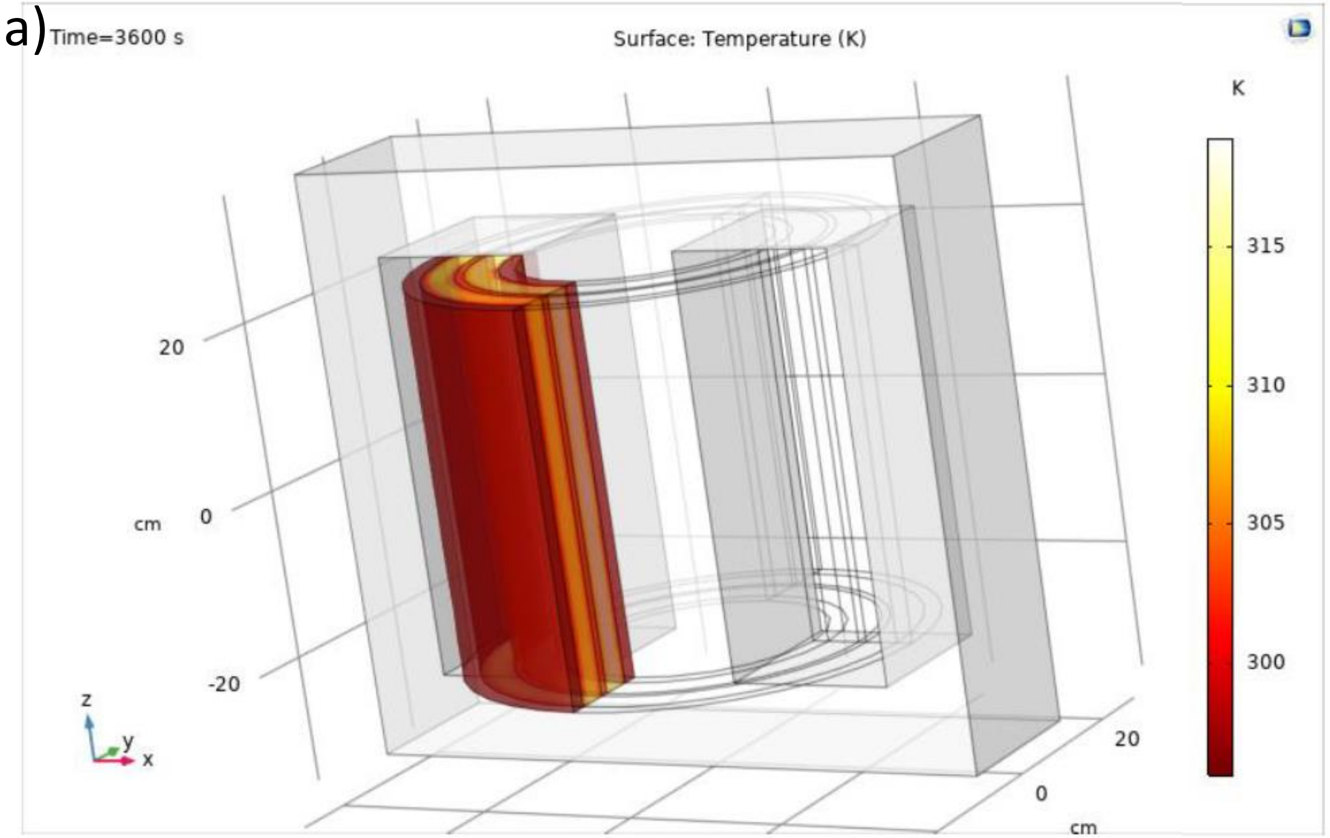
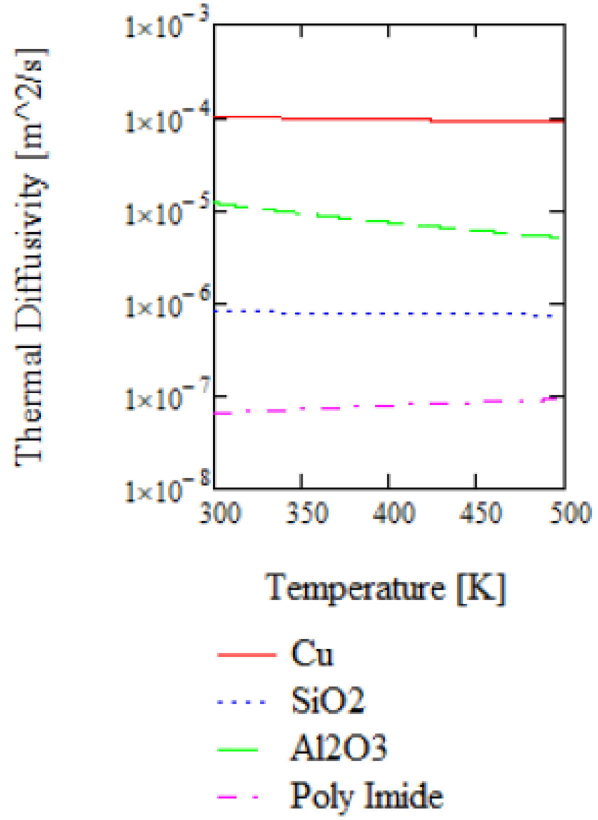
COMSOL model of transformer insulation

(a)



(b)



- (a) Transformer model with various insulation materials operated at 100 kHz achieved temperatures of
  - PI: 7000 K
  - Silica: 650 K
  - Alumina: 320 K
    - Attributed to the higher thermal diffusivity of the material
- (b) Thermal diffusivity of various materials used for the insulation

Innovation update

Summary

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Summary

- Electrospun silica mats with exhibited good electrical and thermal properties but had weak mechanical properties
  - Silres Ren 50 was discovered to not negatively impact silica mats electrical properties
- Polyimide films had good mechanical and electrical properties but limited operating temperatures at 350 ℃
  - Due to changes in the dielectric constant above this temperature
- Transformer insulation simulations showed thermal diffusivity is an important variable
  - Alumina exhibited the best performance for a transformer operating at 100 kHz reaching only 320 K (47 ℃)

Acronyms

SST

- *Solid State Transformers*

Wt.

- *Weight*

DSC

- *Differential scanning calorimetry*

TGA

- *Thermal gravimetric analysis*

SiOx

- *Silica*

BN

- *Boron Nitrate*

AlOx

- *Alumiuna*

THANK YOU

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