Potential of Materials to Impact Megawatt-Scale Electric Machines

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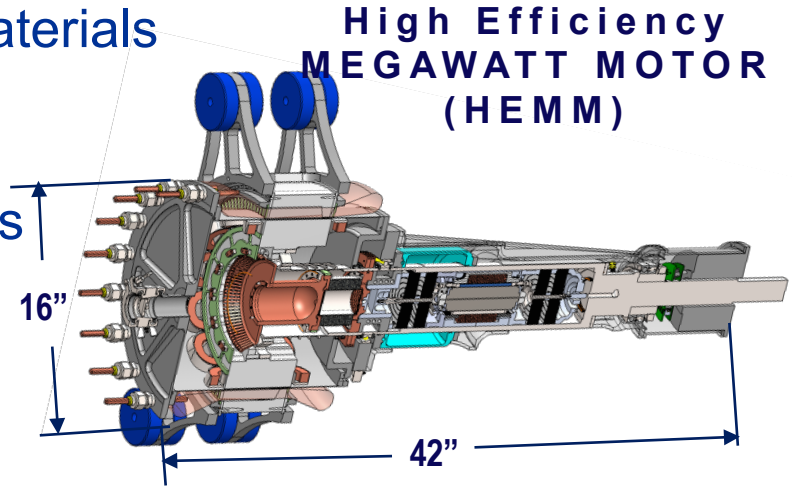
Introduction

Electric machine key performance parameters
- >1 MW, >13 kW/kg, >96% Efficient (< 40kW of waste heat/MW)
- Significant thermal management problem

Stator composition
- Thermally conductive electrical conductor
- Several nonthermally conducive potting and electrical insulation materials
- Multi-material systems is a composite material

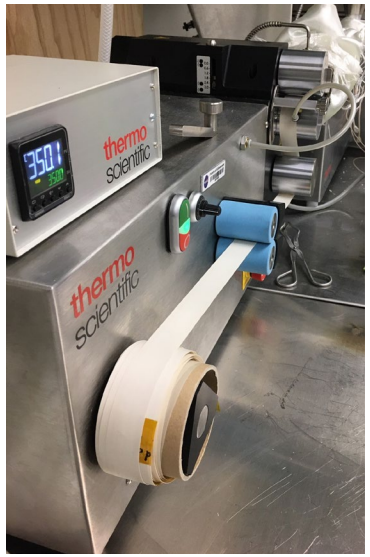
Targets
- Slot/slot liner (high voltage separator)-extruded polymer composites
- Wire insulation-polyimide/BNNS composites
- Potting materials and methods

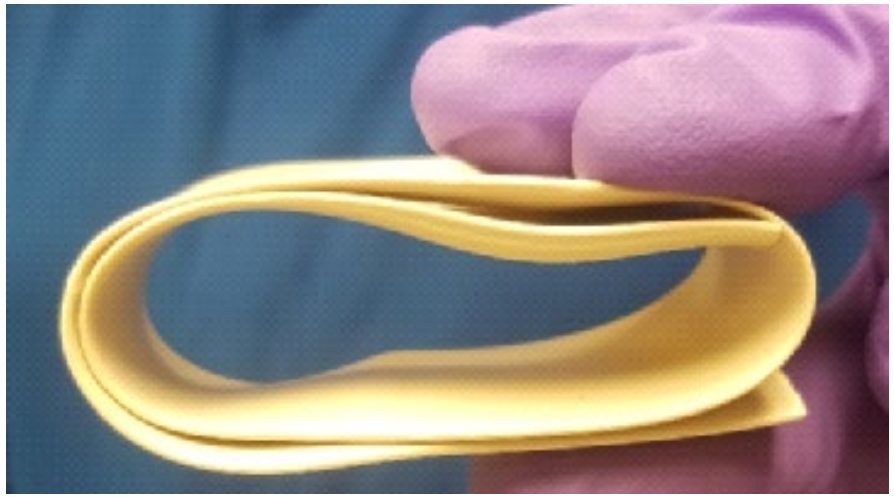


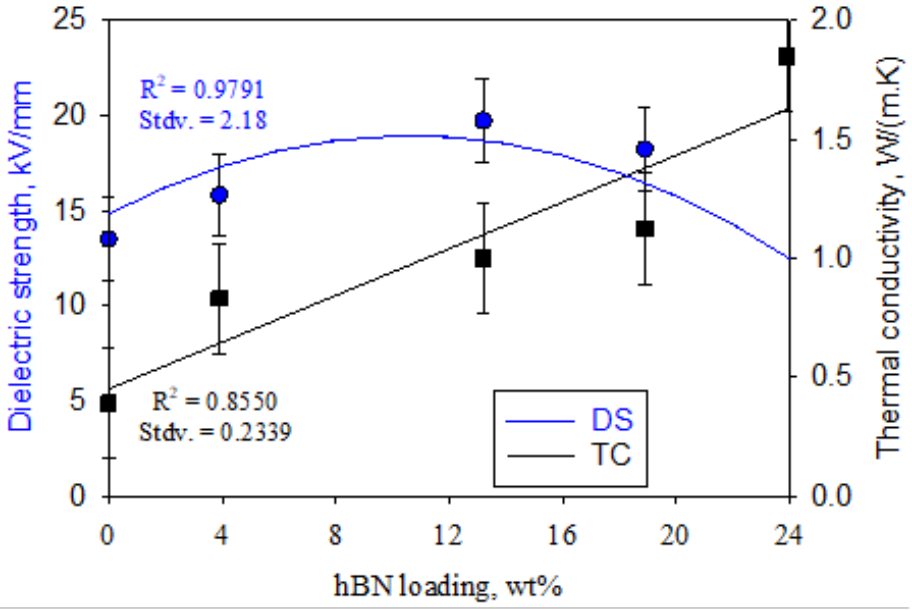
Limitation of cooling
- Dielectric fluids are a common way of cooling a stator
- Dielectric fluids are not as efficient at single-phase as water-based fluids for thermal transport applications
- Water based fluids have a relatively low dielectric breakdown
- A 3-D printable material that has significant dielectric strength and thermal conductivity would be of great interest

Extruded materials

- Extruded flexible polymer composite tapes have been demonstrated but other structures are possible
- Many different extrusion for possible including 3-D printer compatible filament extrusion possible
- 3-D printing of thermally conductive, electrically insulative heat exchanging stator teeth with integral fluid channels maybe useful







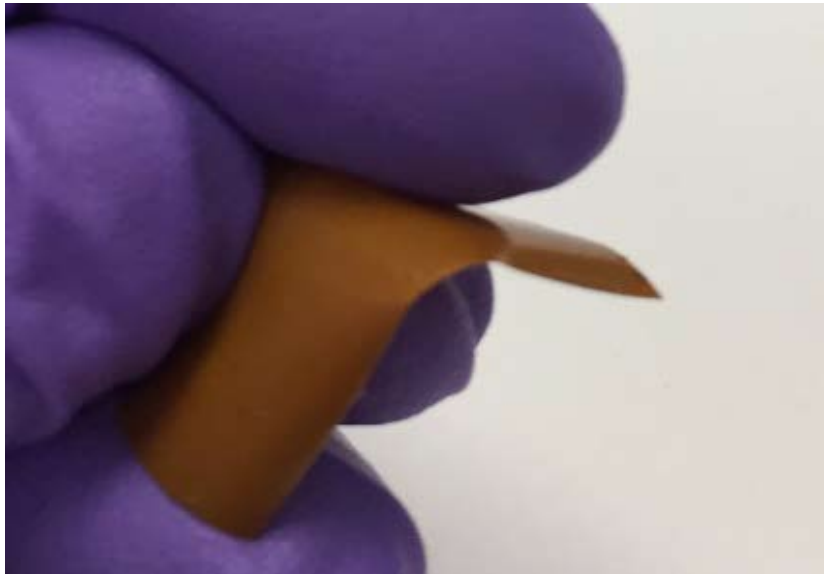
Flexible extruded PPSU (polyphenylsulfone)-hBN composite

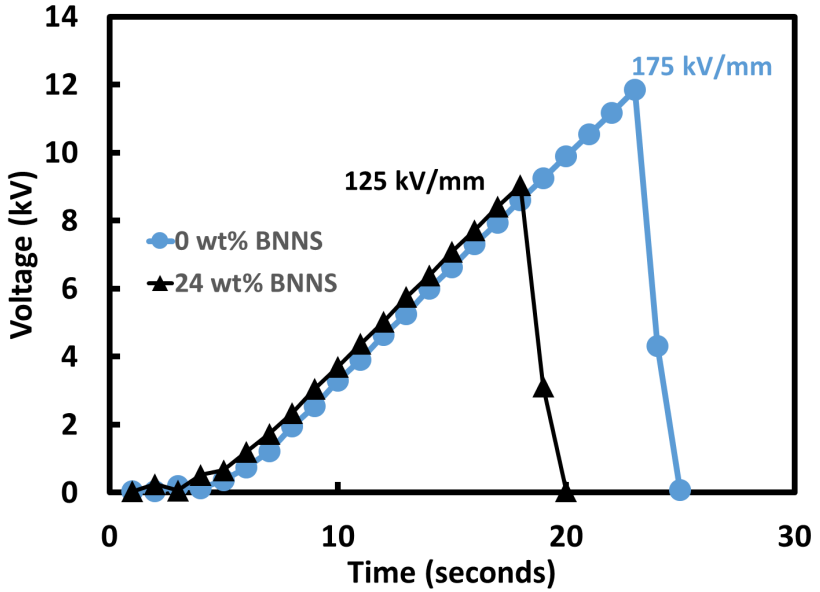
Take away: Flexible extruded polymer-hBN composites offer interesting solutions for electric machines

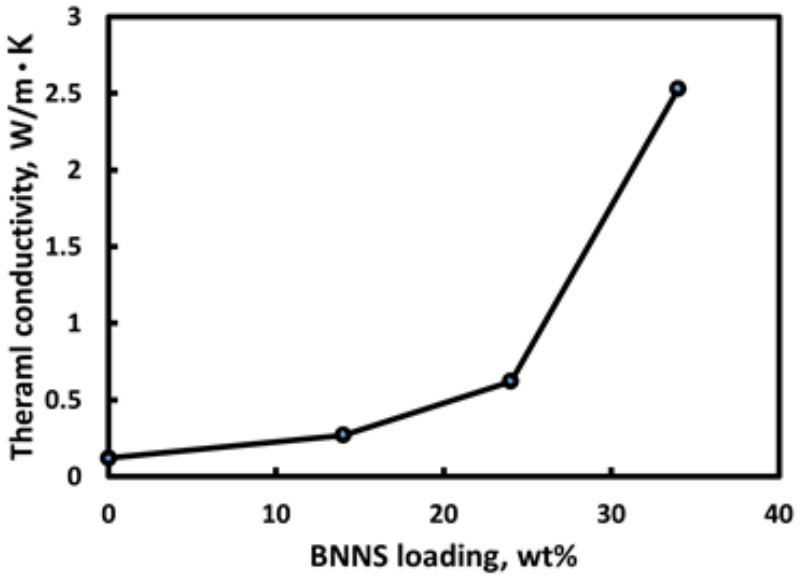
Williams, T., S, *et. al,* "Fabrication of Extruded Polyphenylsulfone-Boron Nitride Composite Tapes," *Society for the Advancement of Material and Process Engineering neXus*, Virtural, 2021.

Polyimide-BNNS composite

- Retention of flexibility is critical for wire coatings
- ~30% reduction in dielectric strength
- Order of magnitude increase in thermal conductivity





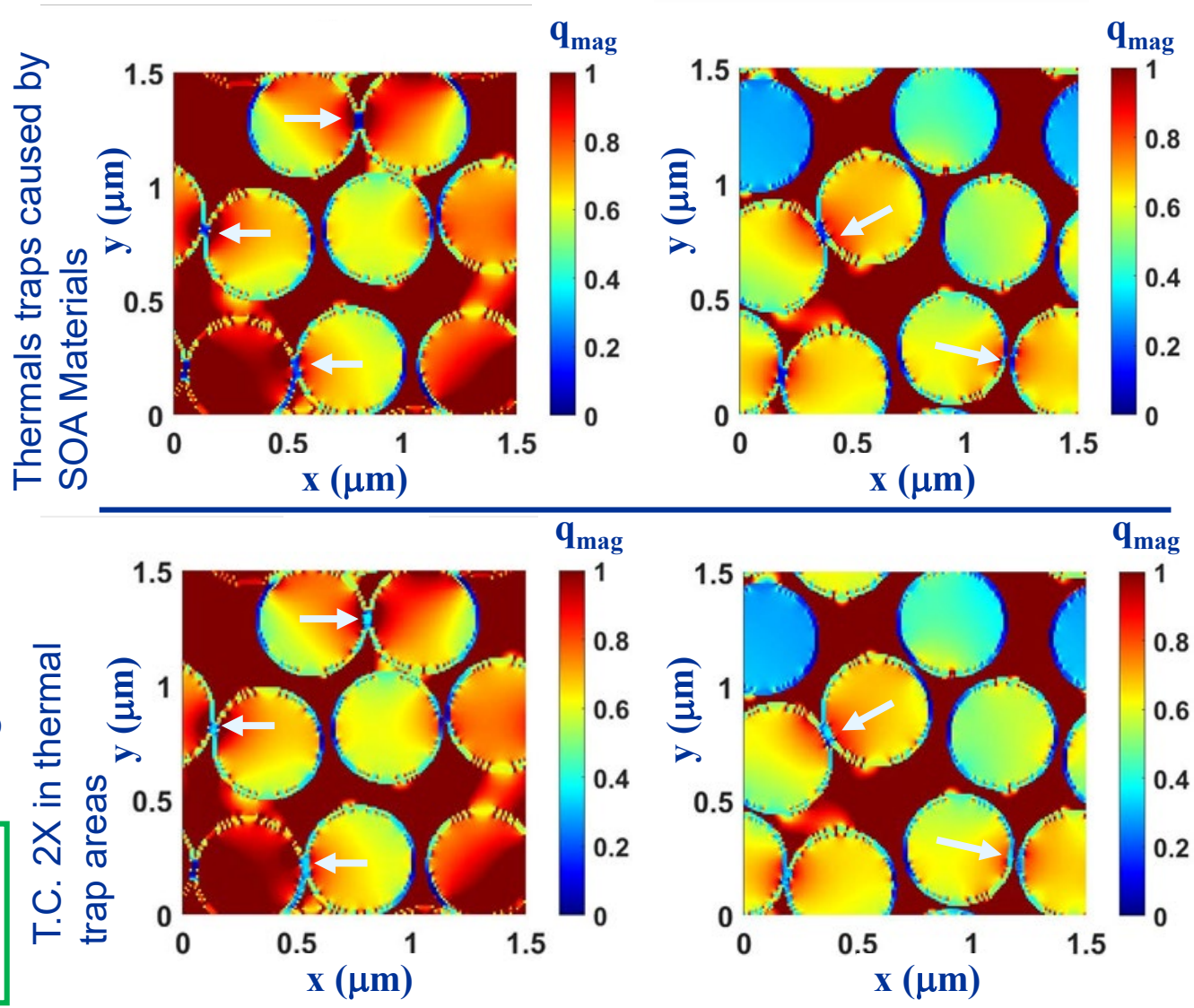


Take away: Polyimide-BNNS composites are a viable option for motor applications with improved thermal conductivity

Potting and Microthermal Analysis

- Vacuum-assisted axial injection potting (VaAIP) process
  - E. E. Shin, "Improved potting of Litz Wires for High Power Density Electric Motor," 2021 AIAA/IEEE EATS
  - Allows epoxy to flow along wires instead of through a bundle
- Thermal conductivity in potting materials
  - Usually achieved through micron sized fillers
  - Drives up viscosity
- Microthermal Analysis
  - Thermal traps (no heat flow) between conductors
  - Simple 2X improvement in trap aeras significantly improves heat flow
  - Need to channel high thermal conductivity materials to these locations

Take away: Combination of VaIP and low levels of nano fillers may enable significant thermal conductivity improvements

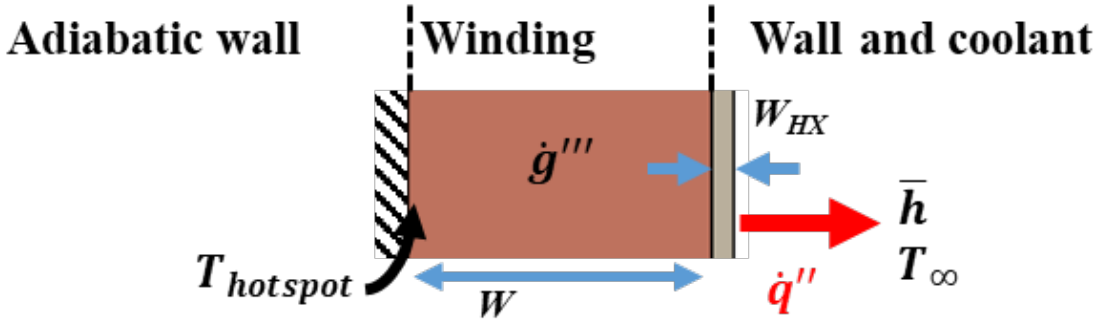


System Study

- 3-D printed direct winding heat exchangers
- BNNS infiltrated potting
- BNNS improved polyimide

Winding Insulation Component	Base Material	SOA Material (W/m-K)	Composite Material (W/m-K)
Encapsulation (Potting)	SOA Epoxy	1.3	1.7 *
Wire Insulation	Polyimide	0.1	2.5
Extruded 3D-DWHX**	PPSU	0.4	1.8

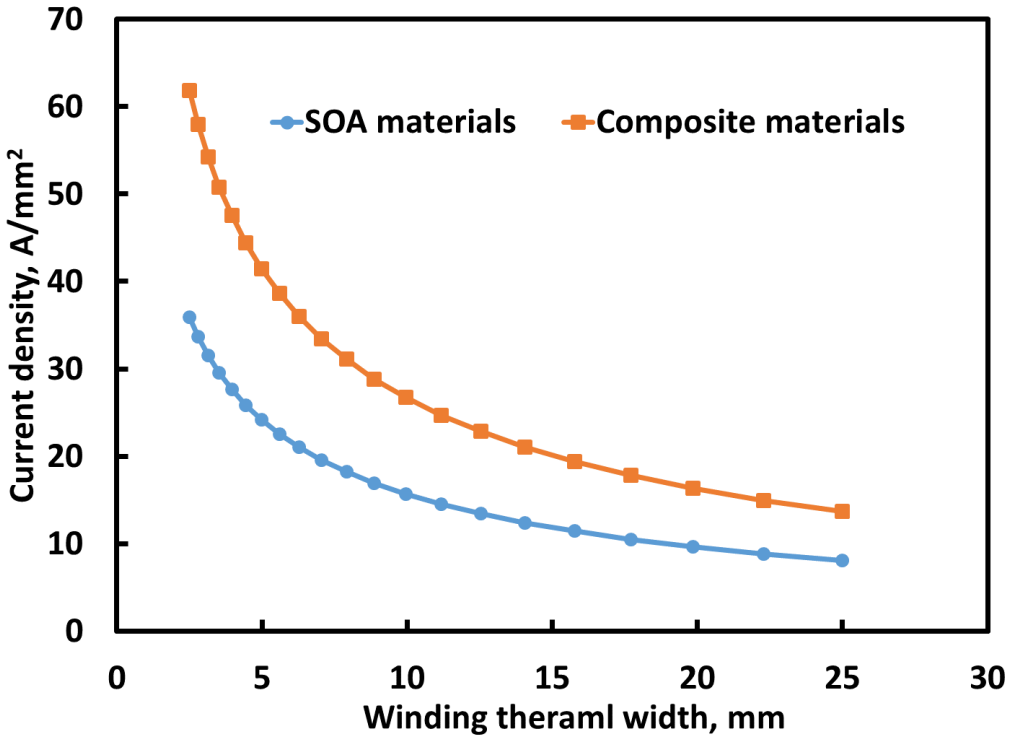
Printed direct winding heat exchangers (3D-DWHX 3-D)

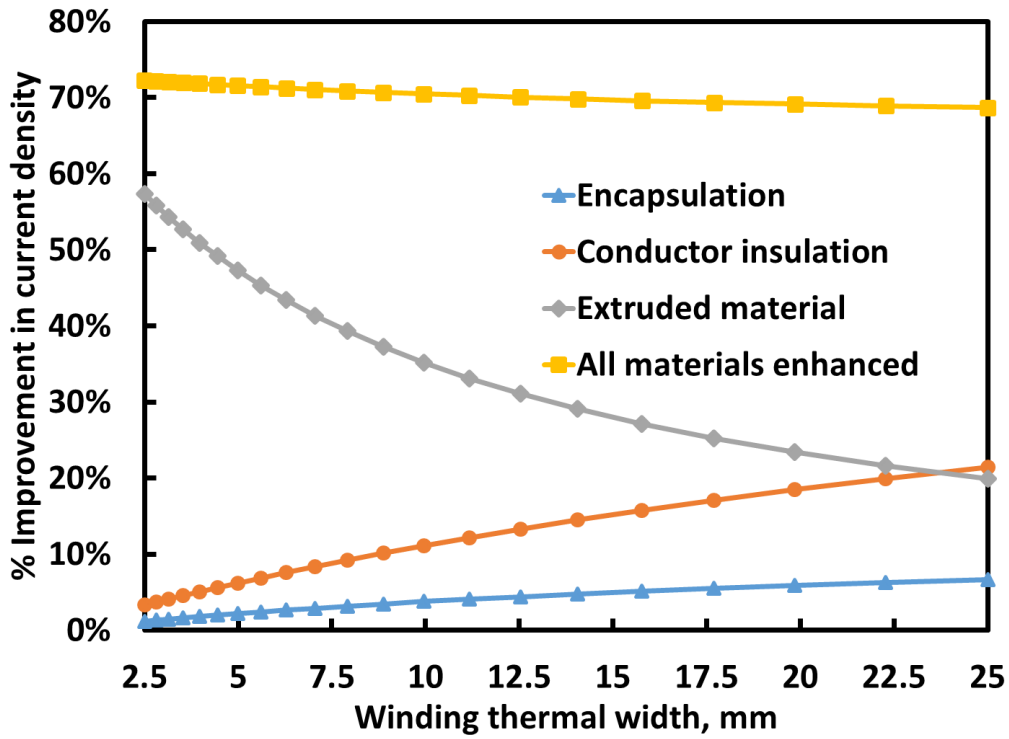


*Shin, E. E., "Improved potting of Litz Wires for High Power Density Electric Motor," 2021 AIAA/IEEE EATS
**Sixel, W., Liu, M., Nellis, G., and Sarlioglu, B., "Cooling of Windings in Electric Machines via 3-D Printed Heat Exchanger," IEEE Transactions on Industry Applications Vol. 56, No. 5, 2020, pp. 4718-4726.

System Study

- Maximum current density was reached when the $T_{hotspot}$ reached 220 °C





Takeaways

- Definite trade space between the number of turns and thermal performance
- Synergistic effects between the thermal conductivity individual components and system performance

Summary

- Flexible extruded polymer-hBN composites offer interesting solutions for electric machines
- Polyimide-BNNS composites are a viable option for motor applications with improved thermal conductivity
- Combination of VaIP and low levels of nano fillers may enable significant thermal conductivity improvements
- System Study
  - Definite trade space between the number of turns and thermal performance
  - Synergistic effects thermal conductivity effected between individual components and system

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Thank you!

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