

Advances in Motor Encapsulation

Presented by
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HEXION™

Hexion is a specialty chemicals company with a leading position in the development and production of systems, products and services for the global energy, transportation and construction markets.

At a glance ...

Columbus, Ohio
\$3.6 billion ⁽¹⁾
4,300 Employees
~50 Global Production &
Manufacturing Sites

Technology Platforms

Epoxy
Phenolics
Versatic™ Acids
Formaldehyde

Automotive Applications

Exterior
Structural
Suspension
Under-the-hood
Coatings
New Energy Vehicles

AUTOMOTIVE

WIND ENERGY

AEROSPACE

RAIL

Hexion has developed thermoset solutions for EV applications

**Suspension
Components**

**Electrical
Motors**

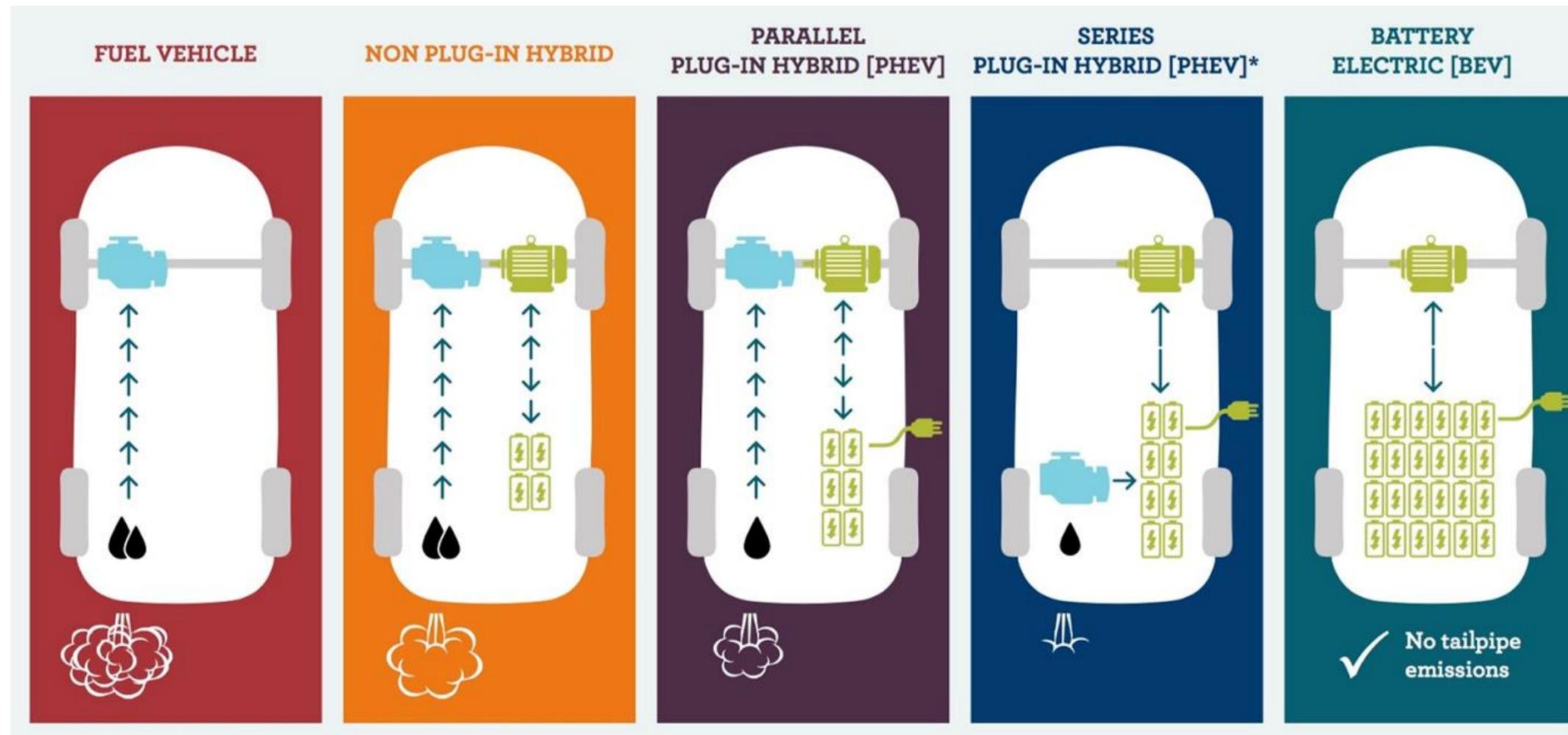
**Battery Floor
and Cover**

**Battery Thermal
Management**



The automotive industry is shifting towards electrification

Reduced emissions and improved fuel economy



*Source: The Electric Vehicle Car Guide - http://www.leadingthecharge.org.nz/nz_electric_car_guide

Many design options to build an electric drive

- In all traction motors a turning magnetic field is electrically generated by AC current in the stator windings.
- The necessary coils are typically insulated with a wire enamel followed by an impregnation (varnish) or encapsulation as a secondary insulation
- The constant magnetic field in the rotor is generated by permanent magnets or induction.

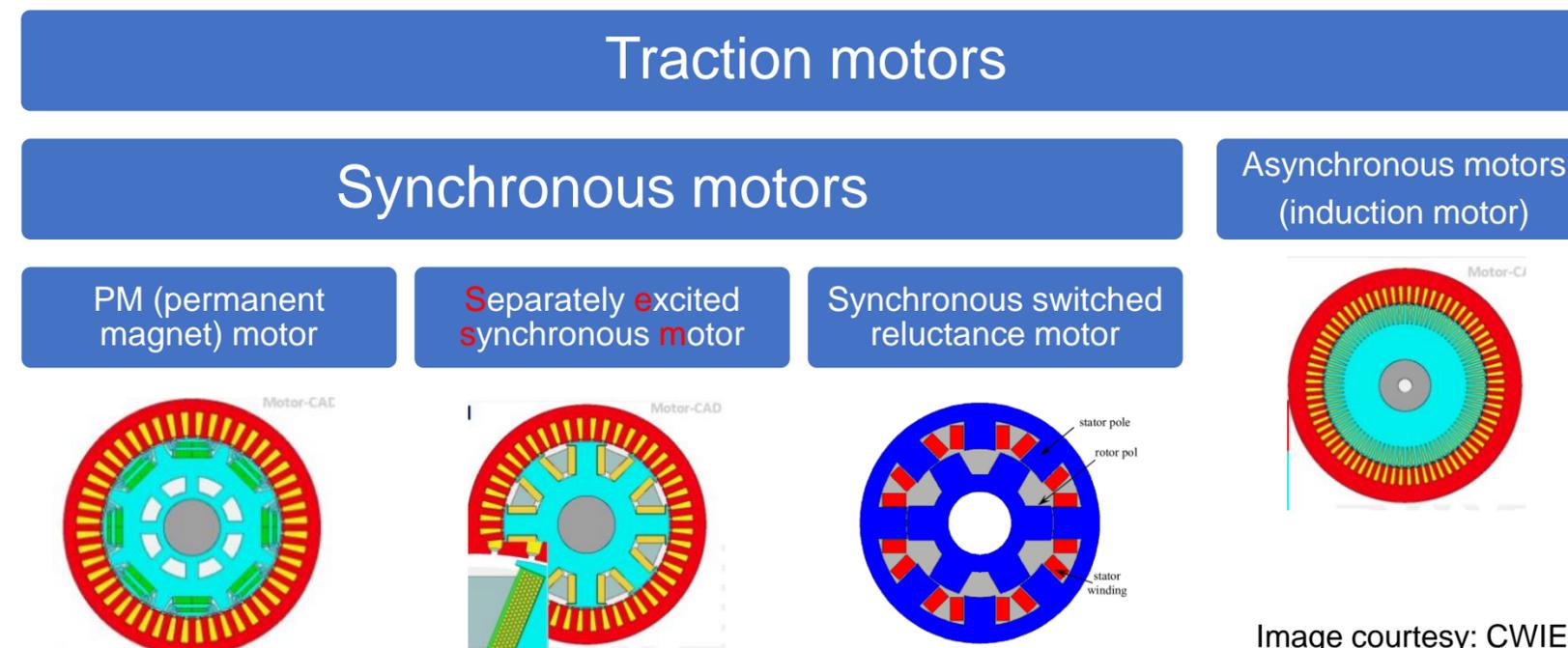
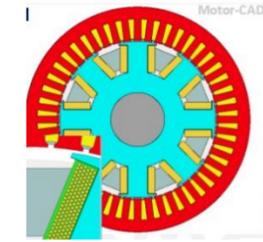


Image courtesy: CWIEME 2018 James Goss Motor Design Ltd.

SESM encapsulation requires high Tg and excellent crack resistance

- SESM and induction motors are the preferred option to avoid rare earth based permanent magnets.
- The motor efficiency increases with the rotational speed (rpm) that can go up to 20000 rpm.
- It is necessary to fix the rotor coil wires to avoid unbalance and motor destruction.
- The coil temperature in operation reaches 150 to 200 °C depending on the current density applied.
- A high Tg system providing a minimum mechanical strength at operation temperature with excellent crack resistance is required.



Separately Excited
Synchronous motor



Asynchronous induction
AC motor

With new toughening technology performance requirements can be met

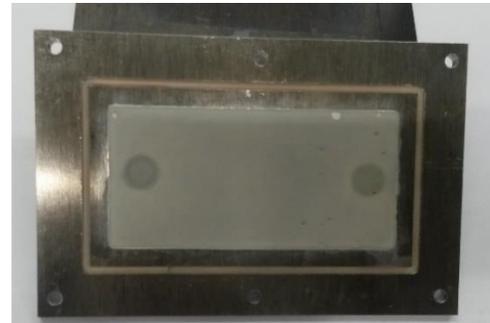
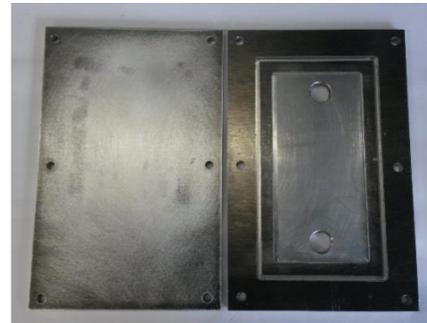
- Often product performance requirements are conflicting:

Performance need	Adjustment	Side effect
mechanical strength at high operation temperature	Tg ↑	low temperature crack resistance ↓
small gaps to be filled require a low viscosity	filler load ↓	CTE ↑ thermal conductivity ↓ low temperature crack resistance ↓
fast curing	reactivity ↑	impregnation capability ↓

- New to the world toughening technology allows to manage these challenges

Permanent magnet rotor encapsulation for noise dampening and heat release

- In case PM motors are targeted encapsulation plays a role too.
- Although the magnets are fitted into the iron core with fairly small gaps, it is highly appreciated, for noise dampening and heat release reasons to encapsulate them.
- Due to prior explained differences in CTE and big temperature changes (-40 up to 160°C) drives are exposed to, the mechanical performance (crack resistance) is of high importance.
- Using encapsulation systems containing mineral fillers is highly advisable.



- Proven gap filling capability at 0.2 mm with EPIKOTE™ Resin 05555 / EPIKURE™ Curing Agent 05556

Stator insulation with epoxy encapsulation brings benefits

- Why using an Epoxy encapsulation system?
 - Protect the winding against water & salt, especially for in-wheel motors
 - Fixation of the winding to control vibration, reduce noise & protect primary wire insulation
 - Support thermal management of the motor by heat absorption

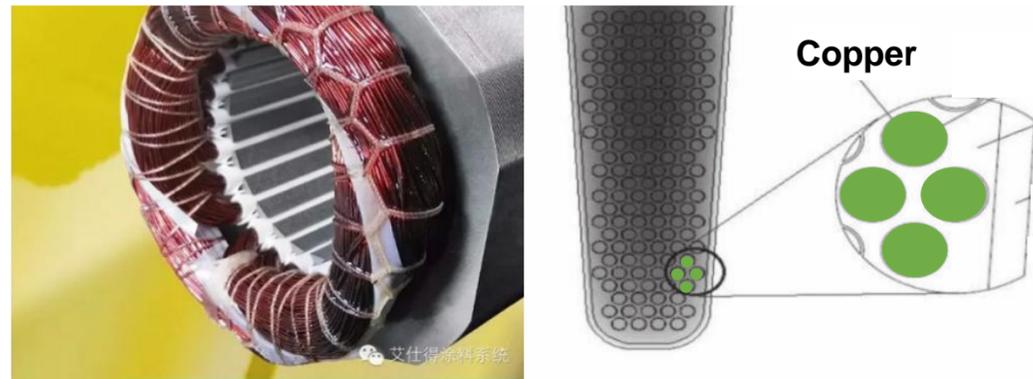


In-wheel motor

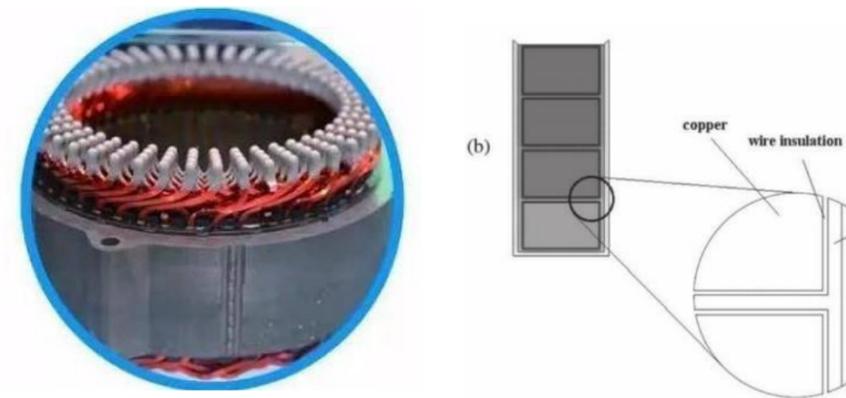
Flat wire stator winding increases the E-motor power density

- Two main technologies for the stator windings:

**Stranded round wire winding
(Slot filling ~ 45%)**



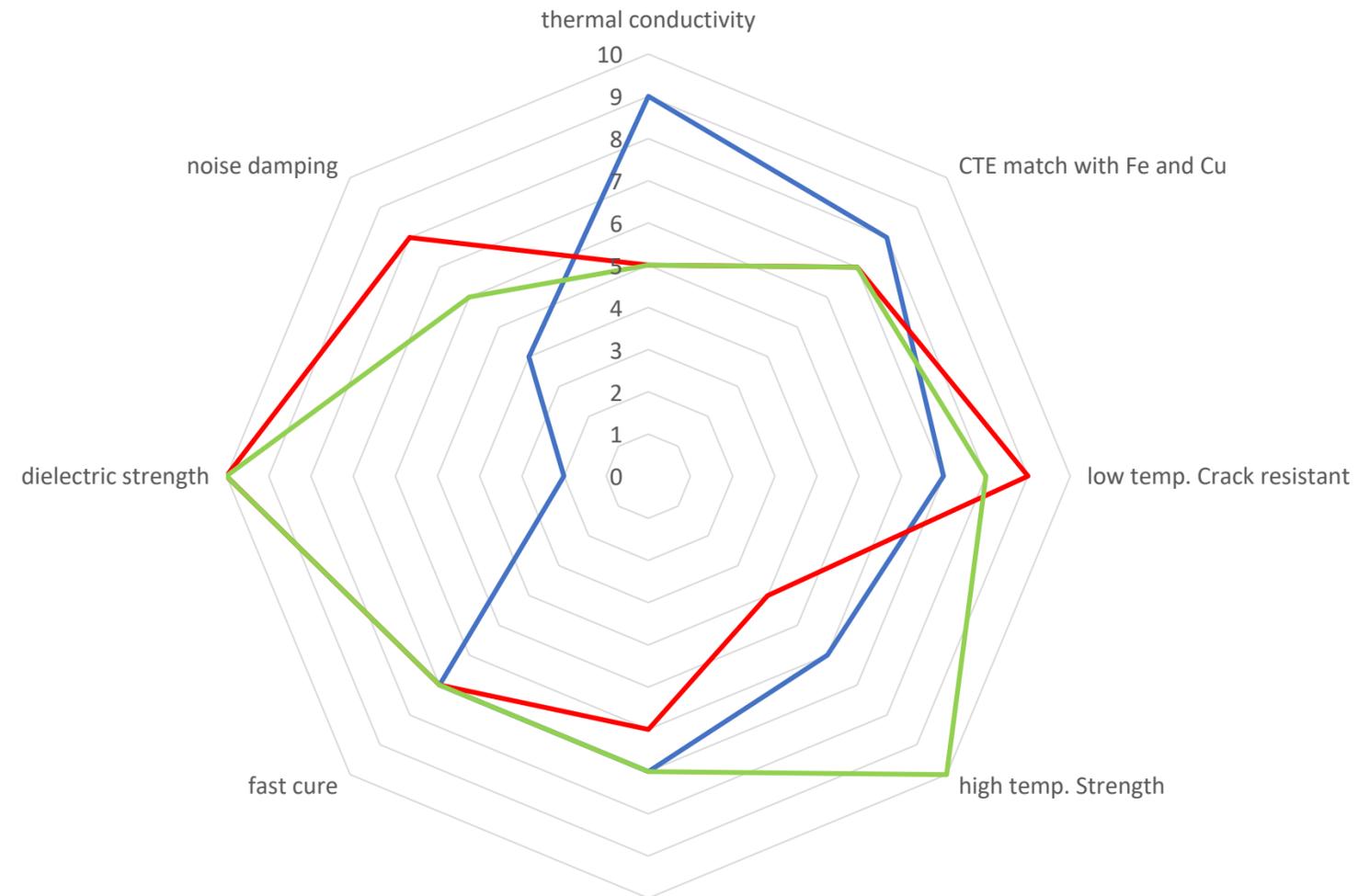
**Flat Hairpin winding
(Slot filling ~ 60%)**



- The secondary insulation primarily is a varnish. In some cases highly thermal conductive encapsulation systems are used to support heat release.

- The secondary insulation primarily is a varnish. The welded connections require a robust electrical insulation. An encapsulation (dipping or casting) is commonly used.
- With increased Voltage levels (~ 800 V) and design dependent higher electric field, encapsulation systems might be considered to prevent partial discharges.

Hexion's encapsulation systems for E-motor applications



-- Epikote™ Resin 850 / Epikure™ Curing Agent 850

-- Epikote™ Resin 870 / Epikure™ Curing Agent 879

-- Epikote™ Resin 05555 / Epikure™ Curing Agent 05556

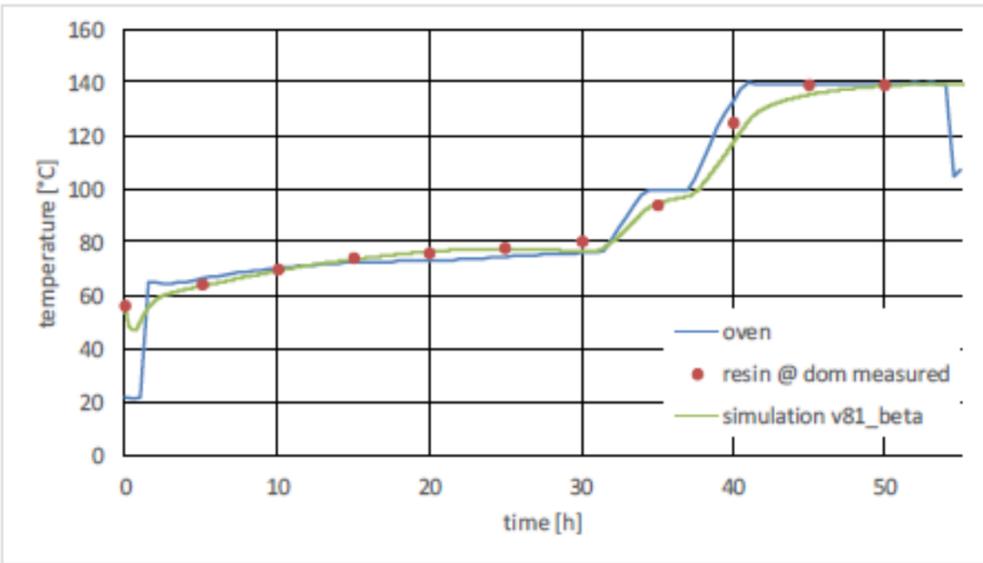
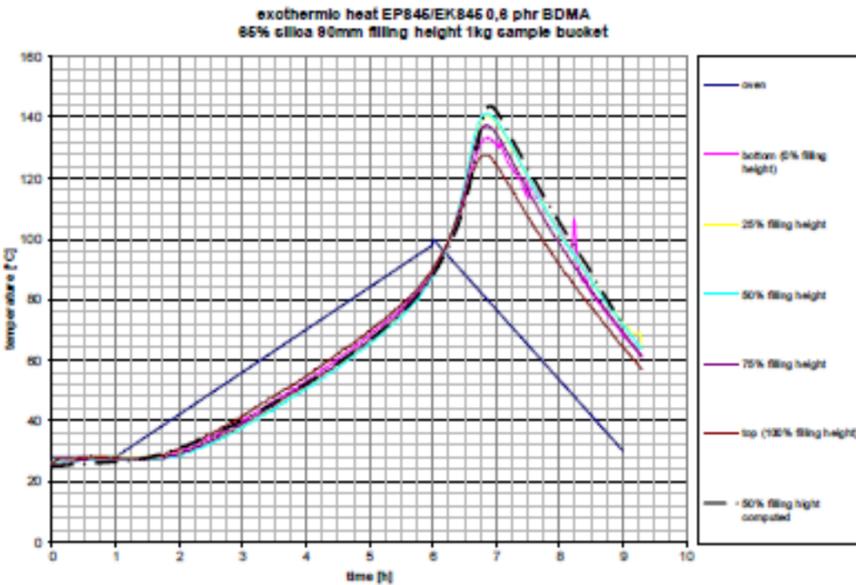
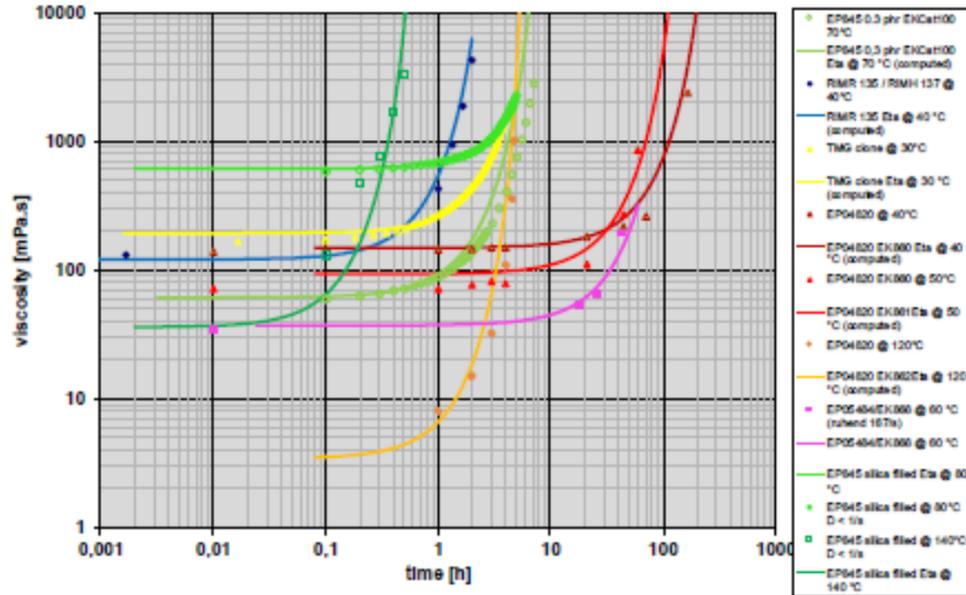
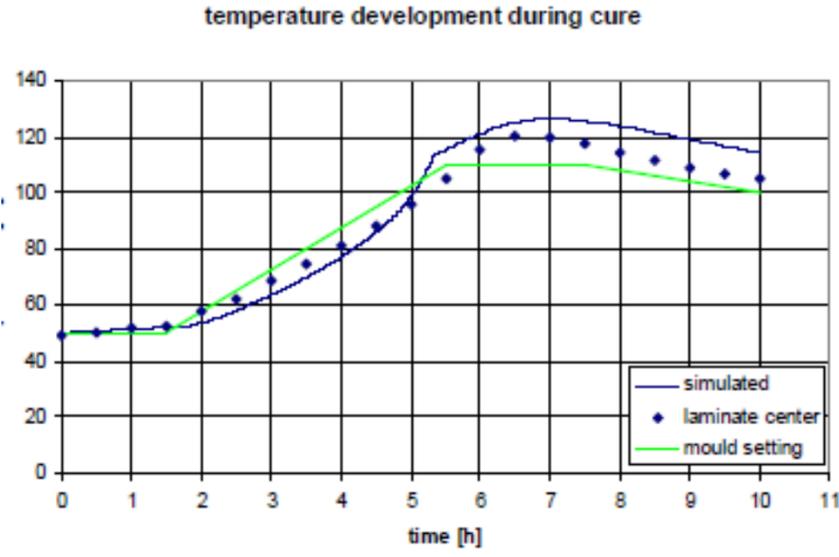
Expertise facilitates to relate customer unmet needs into properties

Expressed unmet need	Corresponding material property	Simulation result
Crack resistant in temperature shock test e.g. - 40 to 180°C	K_{1C} ; G_{1C}	Minimum G_{1C} to stay below a certain crack probability
Need to withstand 1000 thermos cycles	K_{1C} ; G_{1C}	
Need a robust process	K_{1C} ; G_{1C}	
Temperature in operation to stay below a certain max.	λ	Minimum thermal conductivity and required coolant flow rate

Modelling tool enables fast simulation of critical process and material properties

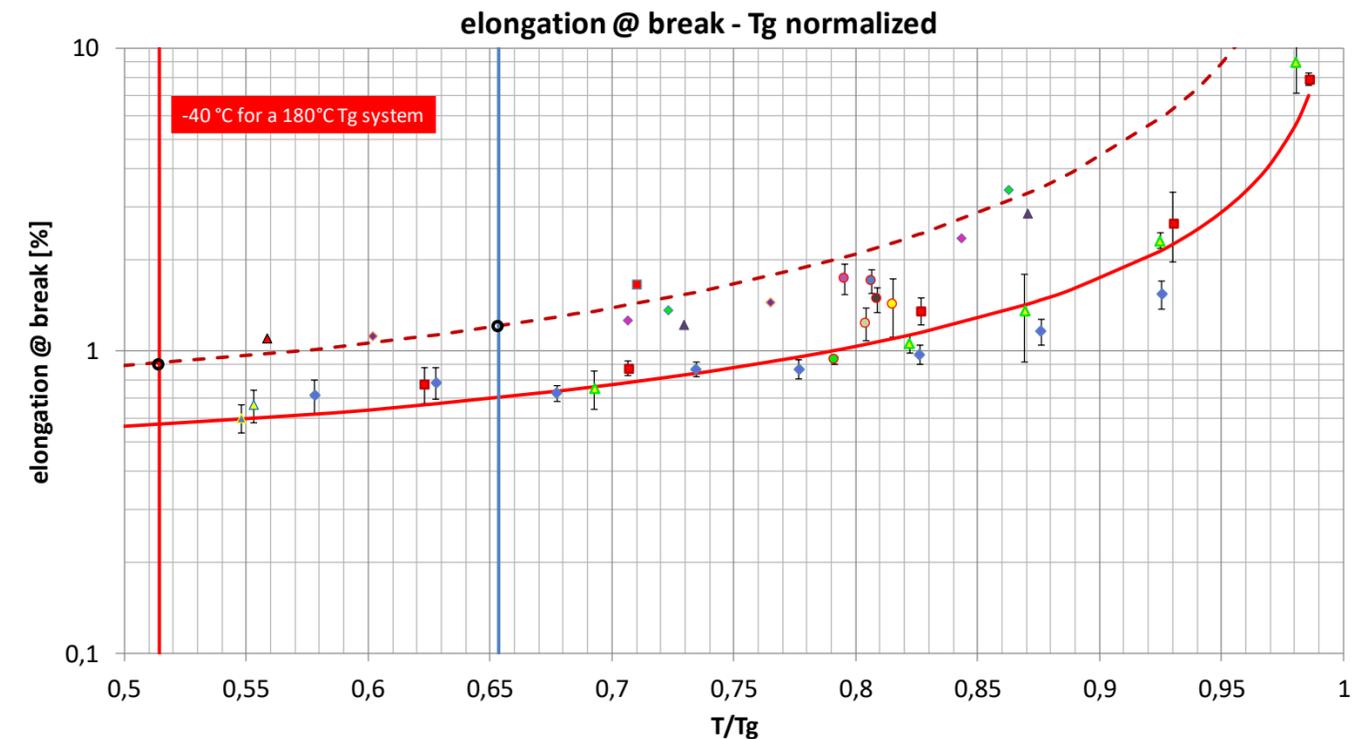
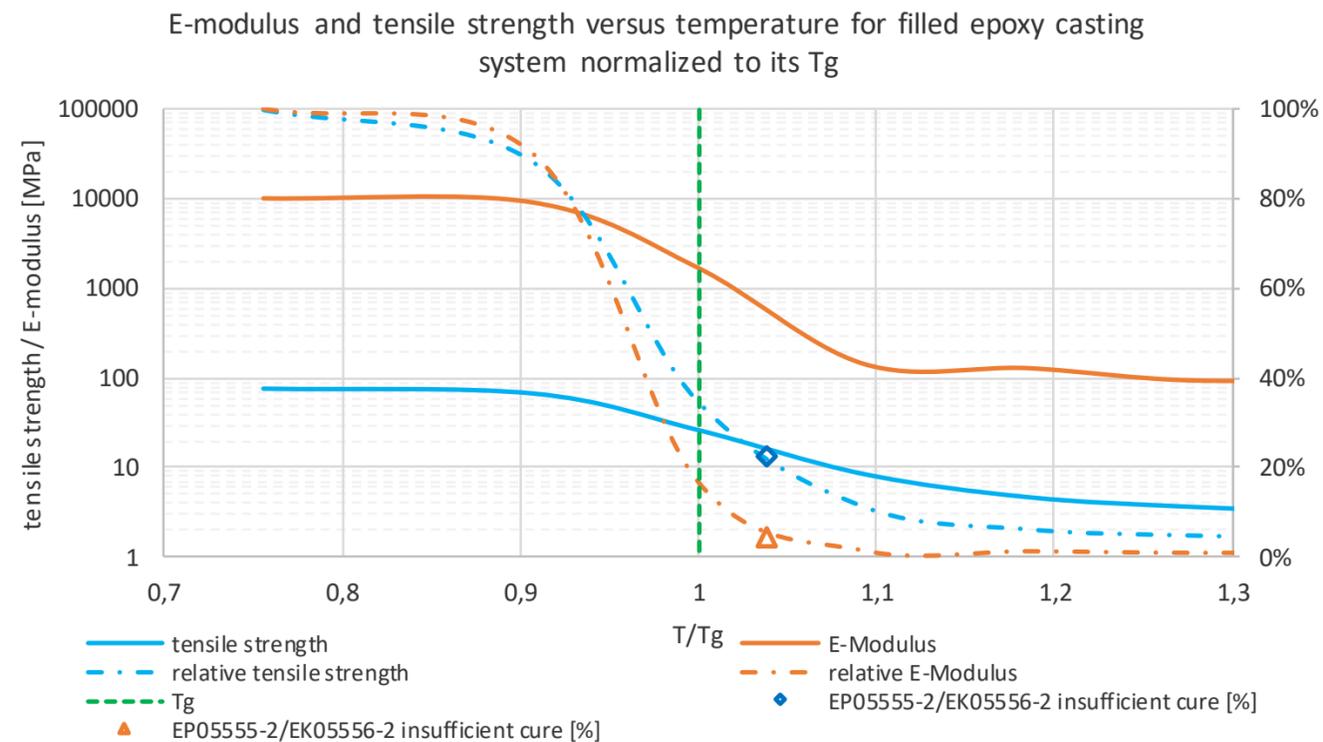
- Hexion used process modeling capabilities to transform customer requirements and unmet needs into targeted epoxy material properties (CTQ's)
- An own developed modeling tool not only simulates the temperature development during cure, it also delivers strain levels.
- The tool was developed and constantly optimized over the last 20 years.
- It was often successfully used to solve application issues as well as process cycle time reduction efforts.
- Model set up for customer application and simulating various boundary conditions can be done in less than a week.

Process modeling demonstrates an excellent fit between computed and measured data



EPIKOTE™ 05555 / EPIKURE™ 05556 secures performance at high operating temperatures

- The EPIKOTE™ Resin 05555 / EPIKURE™ Curing Agent 05556 casting system provides sufficient crack resistance at -40°C, and enables an operational temperature of 180°C, while maintaining full impregnation capabilities.



EPIKOTE™ 05555 / EPIKURE™ 05556 encapsulation for demanding rotor applications

- Rare earth free motor technology accessible
- Very high mechanical properties, capable of withstanding elevated operating temperature up to 200°C, enable higher power density motors
- High engine reliability through a high crack resistance of the insulation over a full temperature range, down to -40°C
- Excellent gap filling capabilities usable for PM rotor and Hairpin stator encapsulation
- Excellent thermal conductivity contributes to an improved thermal management of the engine, and reducing efficiency losses
- Short cycle times reduce the investments for casting lines and post-curing ovens, while achieving high build-rates

Elaphe customer testimony

- A good example where we intensively used the afore described capabilities is the ELAPHE in-wheel motor our project partner enabled us to present here.
- More about ELAPHE can be found here: <http://in-wheel.com/>

S400			
M700			
M1100			
L1500			
Marine			
LEV			
COSIVU			

M700

An in-wheel motor with a wide range of possible applications, from exiting platform conversion and hybridization to new concepts of EVs and light commercial electric vehicles.

Made with the Smart car original OEM brake and bearing, it's as close as it gets to plug and play electrification.

Weight	23 kg
Peak torque	700 Nm
Top speed	1500 rpm
Peak power	75 kW
Continuous power	50 kW (liquid cooling)



Conclusion - Hexion's capabilities enable to fastly develop encapsulation materials for demanding E-motor applications

- No matter which drive technology, Hexion provides high end casting systems to support
 - Heat release
 - Extended life time
 - Centrifugal force management
 - Drive efficiency
- Our simulation capabilities support our R&D efforts to shorten time to market as well as on-site technical support for manufacturing process optimization

Thank you

Christoph Scheuer

Global Market Segment Leader Electrical Casting

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