Fatigue resistance of electrical vehicle motor core

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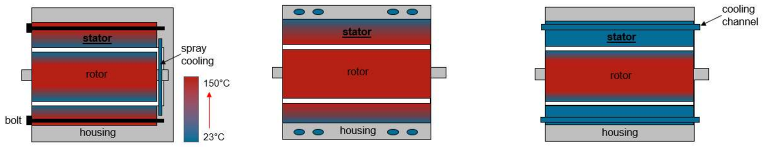
Introduction

- Cooling of laminated stators in electric motors allow for increased power density and more efficient mechanical energy conversion
- Diverse cooling methods and designs are commercially available
- Effect of cooling agents on long-term durability of laminates electrical steel stacks still to be determined
- ➢ Evaluate the effect of service-near boundary conditions on the delamination behavior of electrical steel laminates on specimen level



Case 1
Ford Mach-E

- oil spray cooling into stator/rotor gap
- delamination: high temperature

Case 2
Mercedes Benz EQS

- cooling jacket over stator (poor contact)
- delamination: high temperature

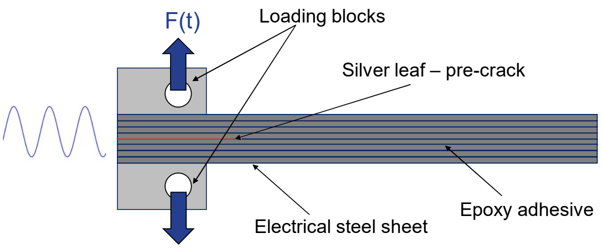
Case 3
Tesla Model S & Y

- cooling channels across stacked stator
- delamination: water/oil based HCF in close contact with laminates

Experimental

Materials & Specimen

- Double cantilever beam specimen (DCB)
- Substrate: Pre- and un-treated electrical steel substrates
- Adhesives: untreated epoxy varnish (< 10 µm) & pre-treated: epoxy varnish + pre-treatment and catalyst
- Artificial crack: by silver leaf, initial length 45 mm
- Curing parameters: 130°C, 1 MPa, 4 hours



Analytical characterization, fracture mechanical testing and fractography

- Dynamic mechanical analysis in torsional mode,
- Fatigue testing: Displacement controlled: δ = 2 mm, f = 5 Hz (air, oil and water-based heat carrier fluid - HCF)
- Crack length determination: elastic embedded beam

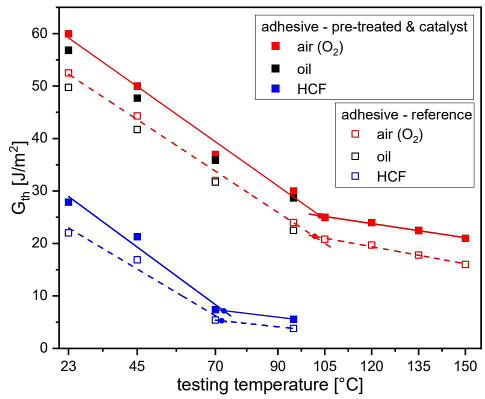
$$C = \frac{4\beta + 8\beta^2 a + 8\beta^3 a^2 + \frac{8}{3}\beta^4 a^3}{k} \qquad \beta = \left(\frac{k}{4EI}\right)^{\frac{1}{4}}$$

Erdman, 2000

- Strain energy release rate (focus on threshold value G_{th})

$$G = \frac{P^2}{2b}\frac{dC}{da}$$

- Laser confocal microscopy



Results & Discussion

Thermo-mechanical properties

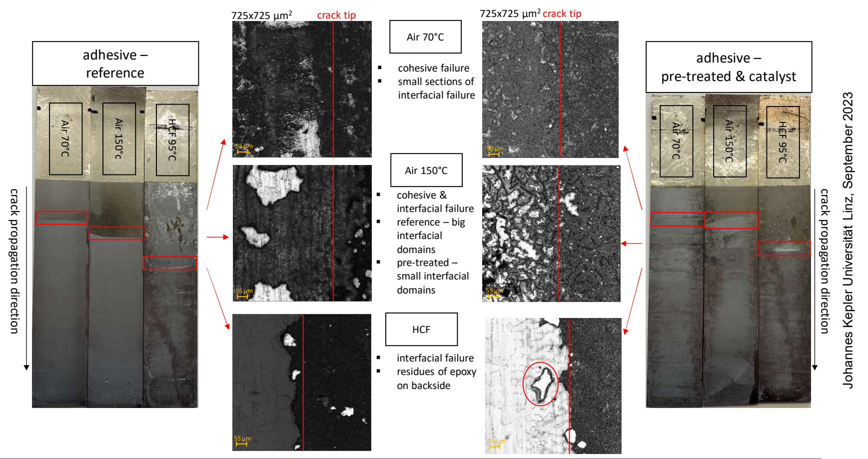
- Pre-treatment and catalyst rose T_g from 88 up to 98°C compared to untreated laminates

Delamination kinetics

- G_{th} ranging from 5 to 64 J/m² dependent on investigated substrate and testing environment
- Significant reduction of crack growth resistance in water (plasticization effect) → oil and air are more suitable

Failure mechanism

- Highly dependent on environment:
  - Water-based HCF: Cohesive failure at high propagation rates followed by interfacial failure in threshold regime
  - Oil and air: Cohesive failure with an inversed C-shaped crack tip



Conclusions

- Significant reduction of crack growth resistance in water-based HCF but no significant differences between oil and air on delamination kinetics
- Oil is the most suitable cooling method for laminated stators in electric motors

Acknowledgement

The financial support by the Austrian Federal Ministry for Digital and Economic Affairs, the National Foundation for Research, Technology and Development and the Christian Doppler Research Association is gratefully acknowledged.

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Johannes Kepler Universität Linz, September 2023