Mechanical study and optimization of a multi-material rotor in a high speed synchronous reluctance machine

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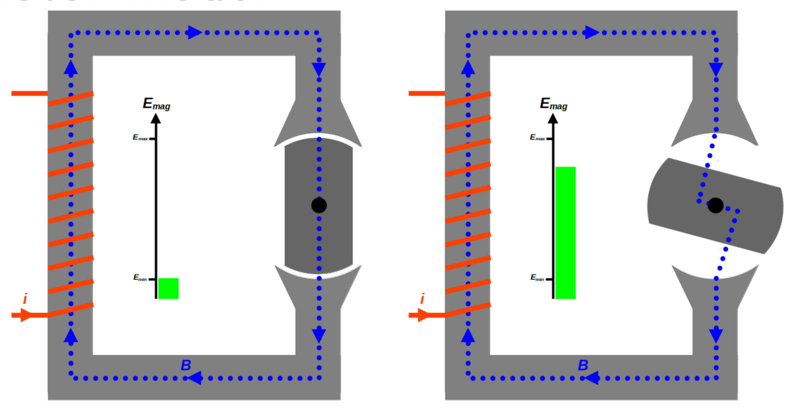
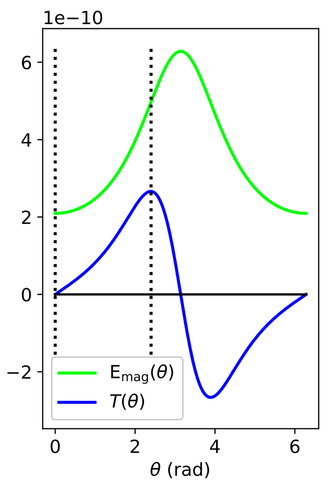
SynRm principle

- **Simplified** switched reluctance motor model

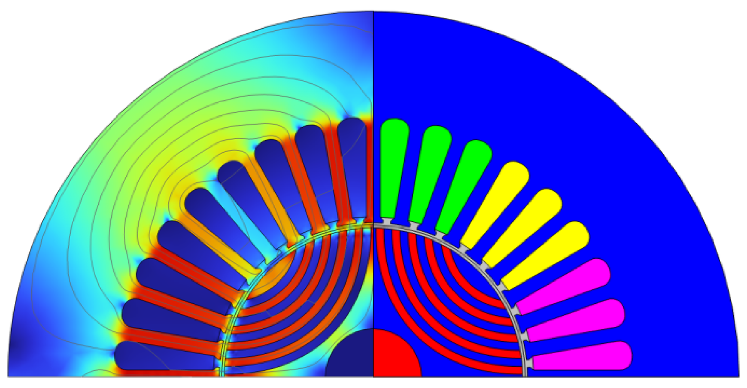


- Torque evolution:

$$T(\theta) = \frac{\partial \mathrm{E_{mag}}}{\partial \theta}$$



- **Realistic** COMSOL F.E. model



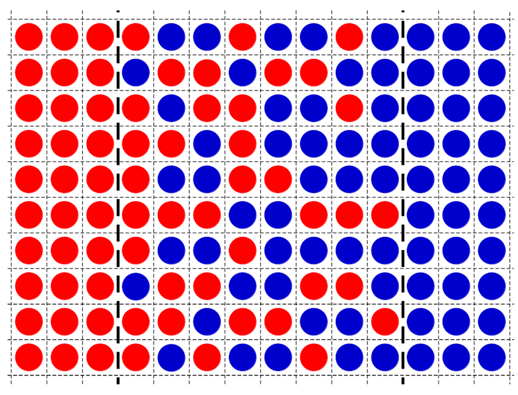
B field / Domains

Objectives

- **Mechanical study** of a 2 material rotor bonded through diffusion bonding
- Optimizing the the rotor shape to obtain **better performance**

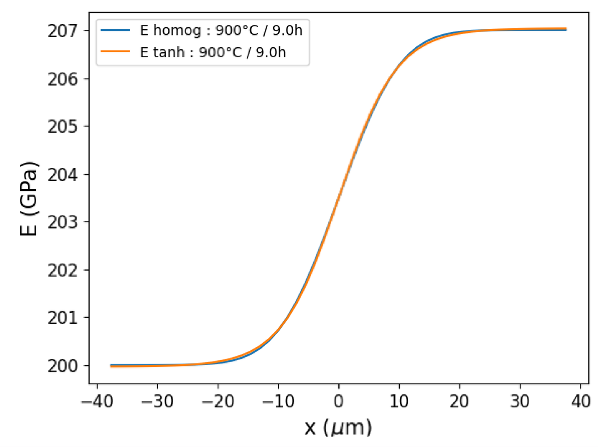
Diffusion bonding

- Diffusion law: $\frac{\partial C}{\partial t} - D(T^{\circ})\Delta C = 0$



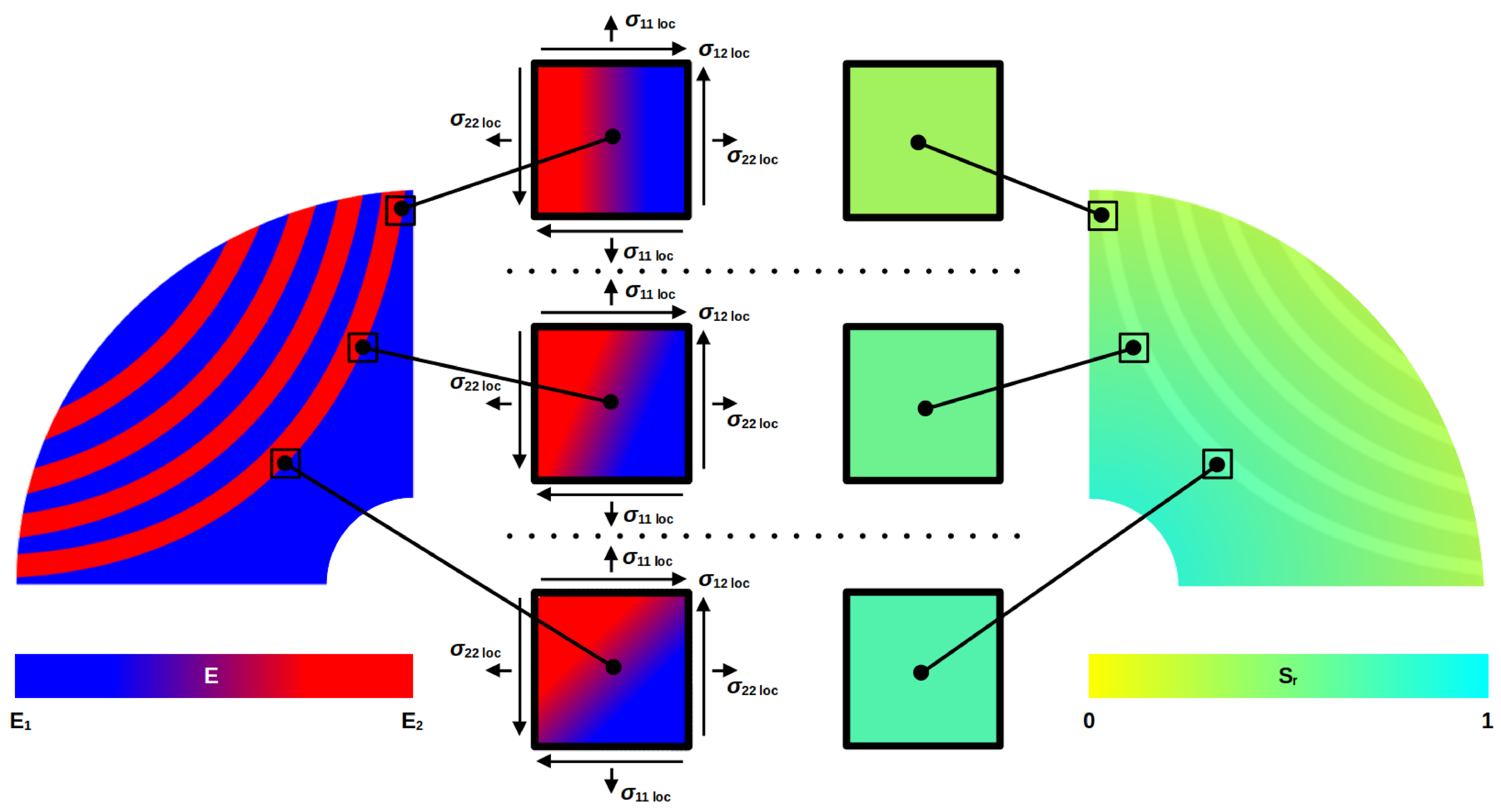
- Obtaining material characteristics using self-consistent homogenization:

$$\sum_i f_i \left(\mathbb{I} + \mathbb{S}_i^E : \tilde{\mathbb{C}}^{-1} : (\mathbb{C}_i - \tilde{\mathbb{C}})\right)^{-1} = \mathbb{I}$$



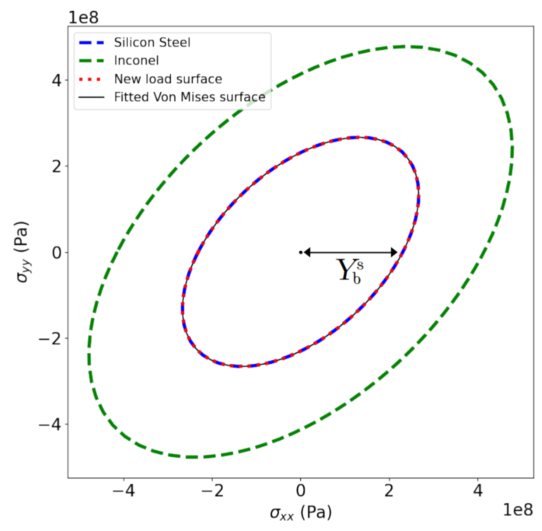
Elastic domain criteria

- **Dual scale** method to use the bond material characteristics on parts 1000 times bigger than the characteristic bond size

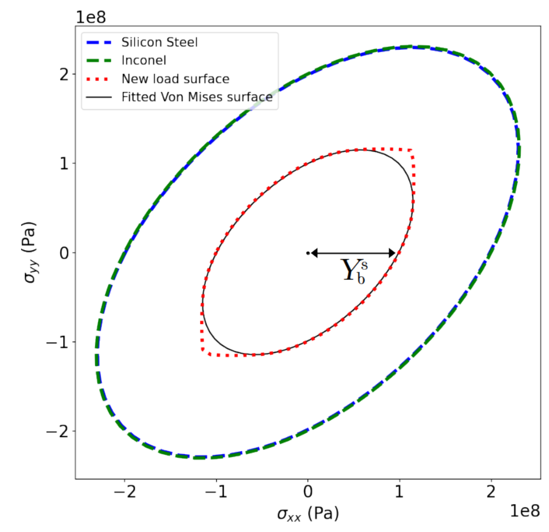


- **Generalizing** for all load and orientation cases using a load surface

$\mathrm{E_1}$ =200 GPa
$\mathrm{E_2}$ =207 GPa
μ_1 =0.32 s.u.
μ_2 =0.28 s.u.
$\mathrm{Y_1^s}$ =207 MPa
$\mathrm{Y_2^s}$ =414 MPa



$\mathrm{E_1}$ =200 GPa
$\mathrm{E_2}$ =100 GPa
μ_1 =0.3 s.u.
μ_2 =0.3 s.u.
$\mathrm{Y_1^s}$ =200 MPa
$\mathrm{Y_2^s}$ =200 MPa

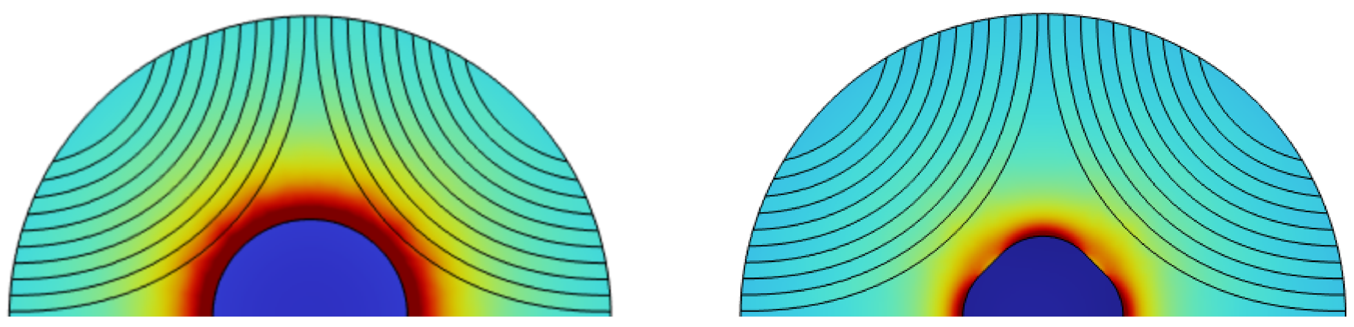


- Definition of the **safety ratio**: $S_r = \frac{\sigma_{\mathrm{vm}}}{Y_{\mathrm{b}}^{\mathrm{s}}}$

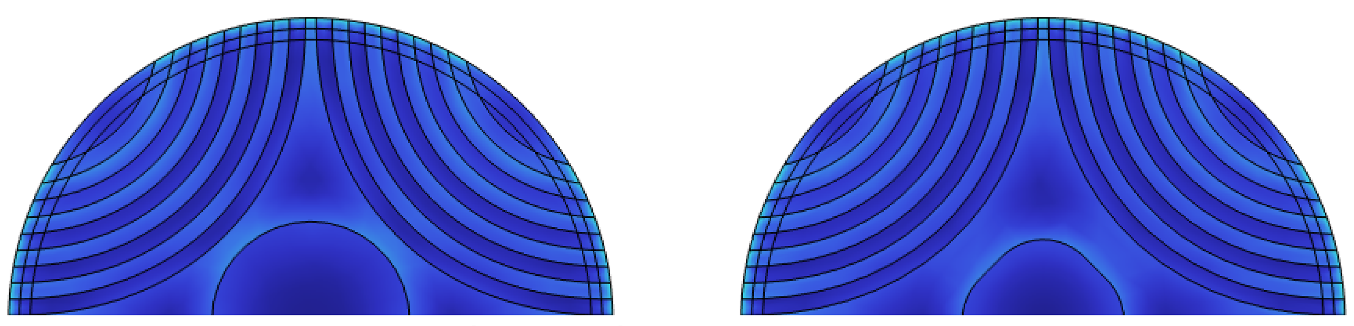
Simulation for high speed applications

- **Application** of the safety ratio for two different shaft shapes and different load cases

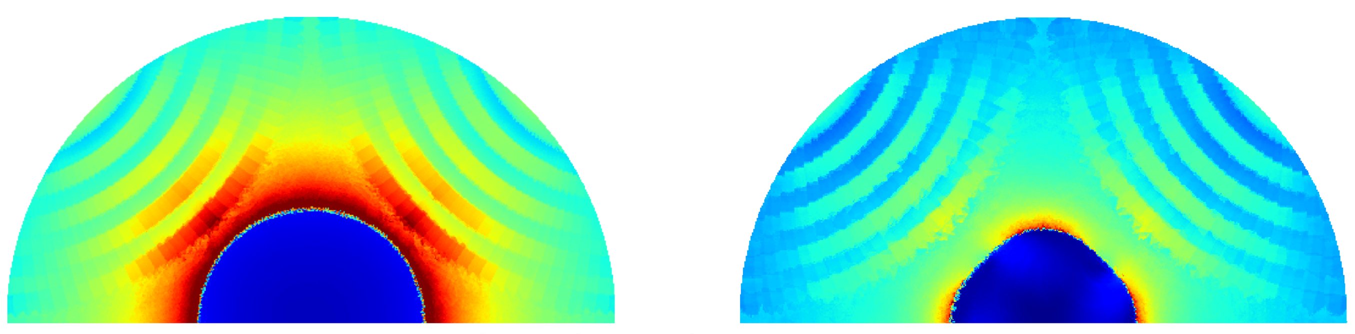
Round shaft | Double oval shaft



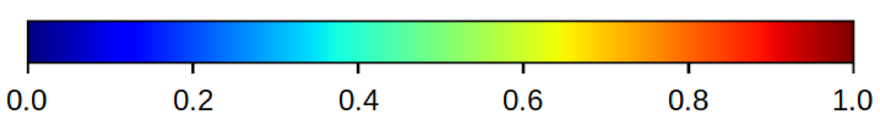
Rotational and torque transmission stresses



Thermal stress at t^{∞}



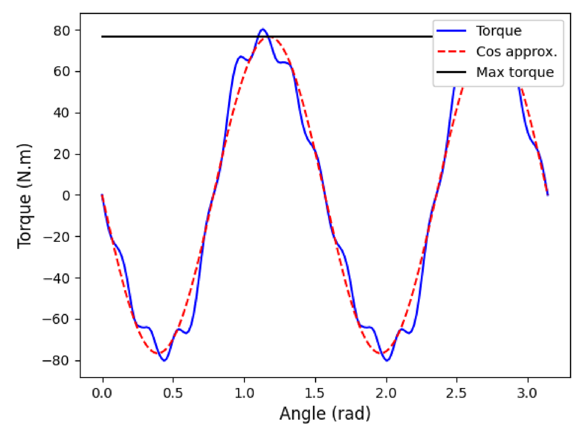
Combined stresses

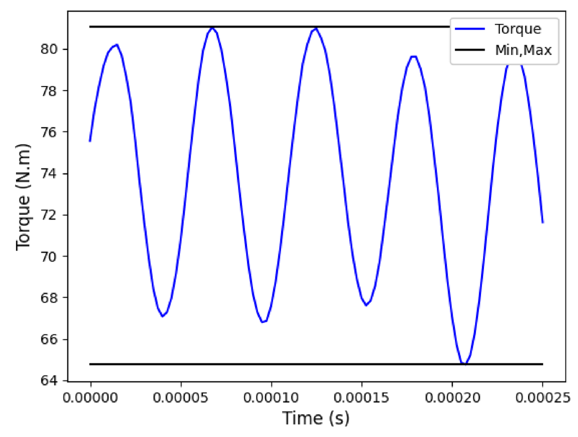


no stress **Safety ratio** plasticity

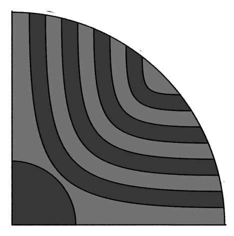
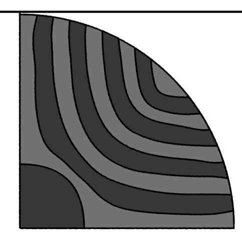
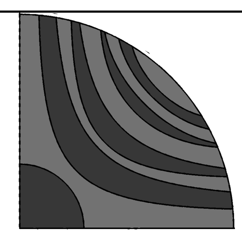
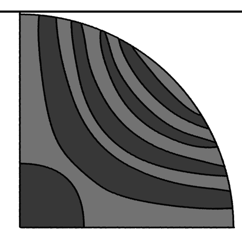
Rotor shape optimization

- Simulation results used at each optimization step to determine **maximum torque** and maximum **torque variation**





- **Cost function**: $C = \max(T(\theta)) - \beta(\max(T(t)) - \min(T(t)))$

Reference Shape		End cost: 14.6 Max torque: 78.2 N.m Ripple: 40.6 % $\eta_{\%}$: 98.0 % $\cos\phi$: 0.47
Topology optimization		End cost: 16.0 Max torque: 81.2 N.m Ripple: 40.0 % $\eta_{\%}$: 98.4 % $\cos\phi$: 0.50
Parametric optimization		End cost: 79.4 Max torque: 86.0 N.m Ripple: 3.9 % $\eta_{\%}$: 98.6 % $\cos\phi$: 0.51
Parametric **and** topology optimization		End cost: 79.7 Max torque: 87.4 N.m Ripple: 4.4 % $\eta_{\%}$: 98.6 % $\cos\phi$: 0.53

Conclusion

- **Simplified model** for multi-material parts made using powder manufacturing and post-processed using **hot isostatic pressuring**
- Designing the **non-cylindrical** shape of the shaft for **high speed** applications to reduce shrink fitting stresses
- **Global** parametric optimization with a high number of independent variables using Bayesian optimization
- **Multiple step optimization** to obtain near ideal shape with topology optimization

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