Effect of curing time on fatigue crack growth kinetics of model electrical steel laminates

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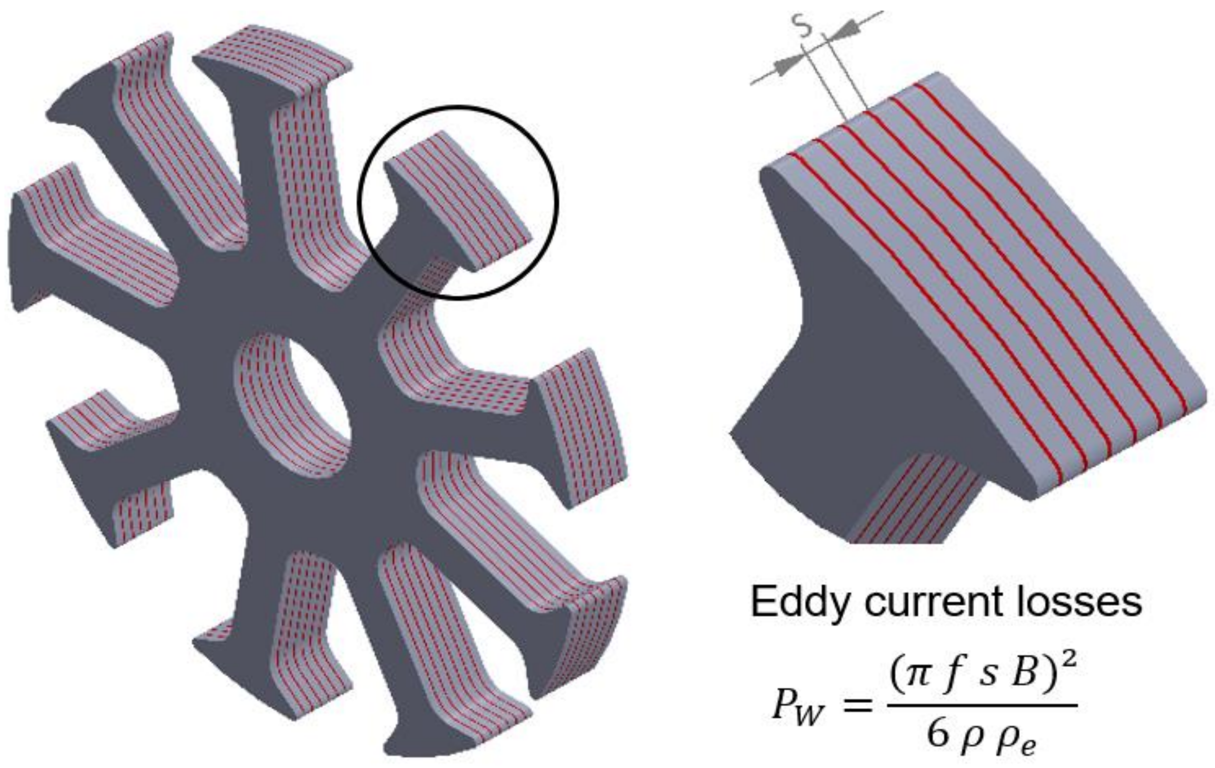
Introduction

- electrical steel laminates with polymeric adhesive allow for reduced core losses in rotors and magnetic cores of electrical machines
- complex, superimposed loading conditions in service
- multiple processing steps from the varnish (A-stage), via the coated electrical steel (B-stage) to the cured laminate (C-stage)

➢ evaluate the effect of processing conditions (curing time) on specimen level



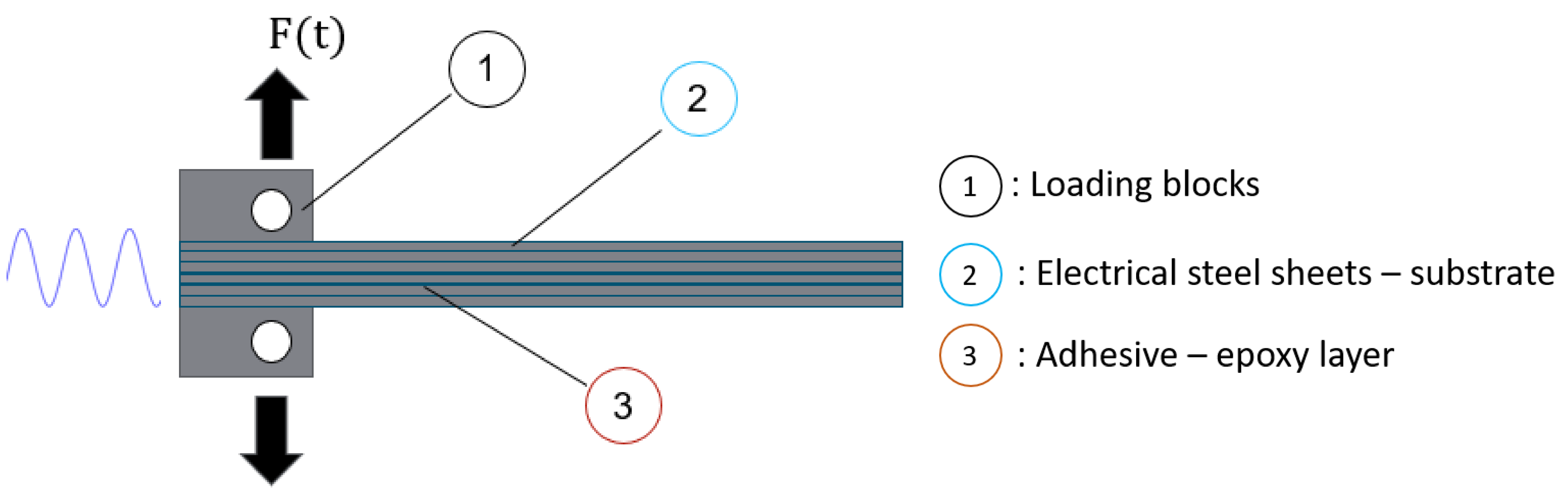
Eddy current losses

$$P_W = \frac{(\pi f s B)^2}{6 \rho \rho_e}$$

Experimental

Materials & Specimen

- double cantilever beam specimen (DCB)
- substrate: electrical steel sheets
- varnish: water-borne epoxy (< 10µm)
- artificial crack: silver leaf, initial length 45 mm
- curing parameters at 190°C:
  - curing time: 1 up to 30 minutes
  - pressure: 2.8 MPa



Analytical characterization, fracture mechanical testing and fractography

- dynamic mechanical analysis in torsional mode
- displacement controlled fatigue testing at 23°C and 150°C, f = 5 Hz
- compliance based (C) crack length (a) evaluation: 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, 2009

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

$$G = \frac{P^2}{2b}\frac{dC}{da} \qquad P \ldots \text{applied load}, b \ldots \text{specimen width}$$

- laser confocal microscopy and IR spectroscopy

Results & Discussion

Thermo-mechanical properties

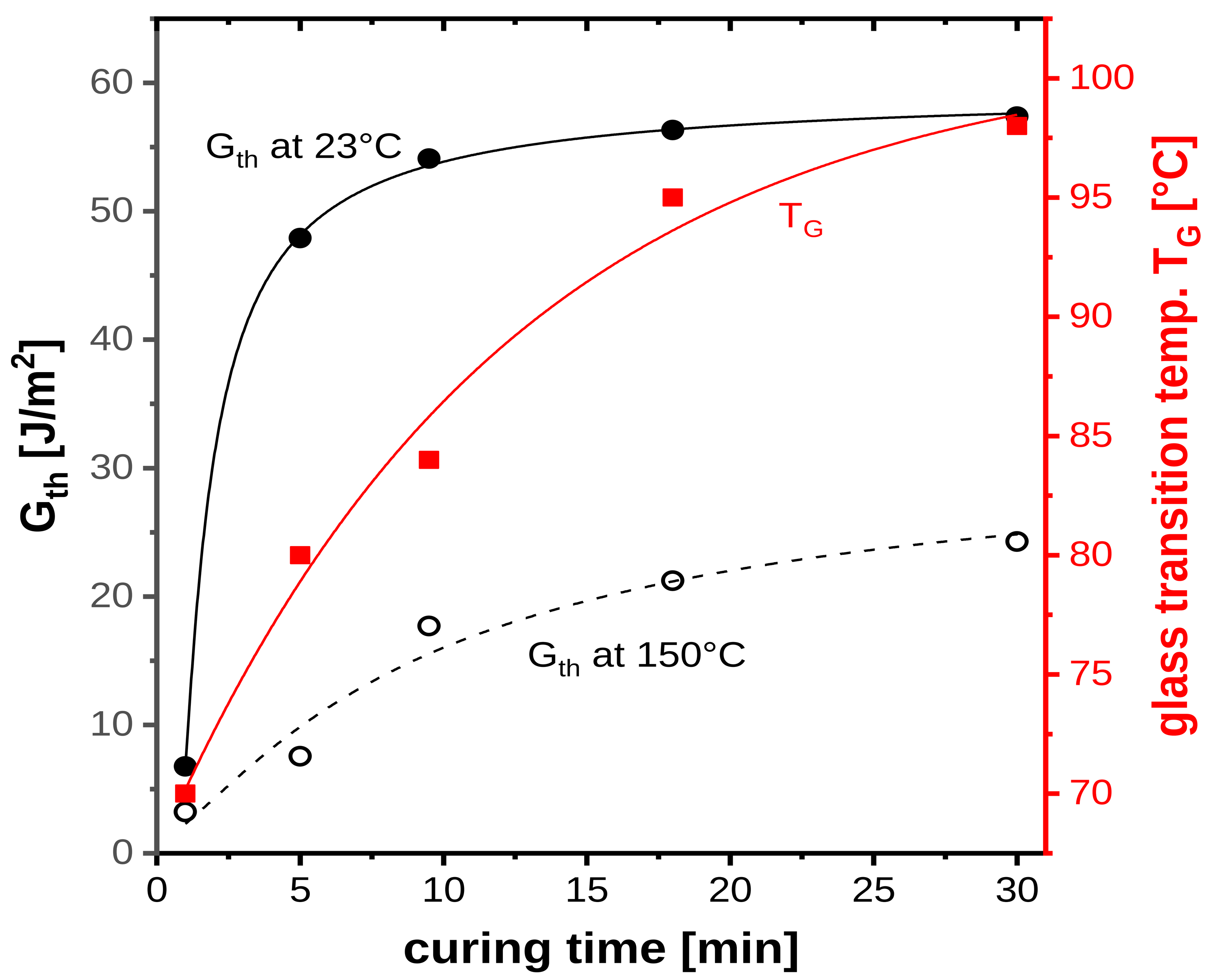
- increasing glass transition temperature T_G indicates enhanced crosslinking density

Fatigue crack growth (FCG)

- improved crack growth resistance with increasing curing time at 23 and 150°C
- reduction of G_{th} by a factor of 2 at 150°C compared to 23°C
- higher degree of crosslinking is essential for FCG at 150°C

Failure mechanism

- cohesive and interfacial failure at 23 and 150°C, respectively
- local ageing and degradation effects at 150°C



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Conclusions

- fatigue behaviour of electrical steel laminates depends significantly on lamination time and degree of cure of epoxy layer
- more critical fatigue behaviour at T > T_G (150°C) associated with interfacial failure

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