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

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Abstract content

Electrical steel sheets are of high relevance for magnetic cores and rotors of electrical machines. Electrical steel stacks allow for reduced eddy current losses and narrow hysteresis loops. To further increase efficiency, such sheets are frequently isolated. Adhesively bonded stacks are based on lamination of pre-coated electrical steel. Hence, high latency adhesive systems granting for pre-coating and subsequent lamination are required. The main objective of this paper work was to evaluate the effect of processing conditions (i.e., curing time) on crack growth kinetics of electrical steel/epoxy laminates on specimen level at ambient and elevated temperatures. Therefore, a linear elastic fracture mechanical method suitable for mode I and cyclic fatigue was employed. Furthermore, fractography was performed on fractured surfaces. Threshold strain energy release rate values were correlated to the glass transition of the adhesive examined by dynamic mechanical analysis.

Model electrical steel sheets were double sided coated using an epoxy-based adhesive and pre-cured at set temperature and exposure time. DCB specimens were manufactured by stacking and laminating 6 plies. These laminates went through final curing for up to 30 minutes. A separation film was inserted prior to lamination to ensure a well-defined initial crack.

The crack growth resistance of the laminates at ambient and elevated temperatures was dependent on curing time. At higher curing times the glass transition temperature (Tg) leveled off at 95°C. Accordingly, the threshold strain energy release rate values (Gth), which were ranging from 7 to 57 J/m2 and were about a factor of two lower at testing temperature well above Tg, revealed a non-linear correlation to the glass transition temperature of the epoxy adhesive (s. Fig. 1). Hence, the degree of crosslinking of the epoxy is significantly affecting fatigue crack initiation and growth. Optimized processing windows should be determined for specific materials combinations and component geometries. Fractographic investigations revealed predominantly cohesive failure within the coating at ambient temperatures, but mainly interfacial failure at temperatures well above Tg.

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Gth over Tg of the epoxy adhesive at 23°C