Effect of epoxy-metal interphase development on debonding kinetics of advanced laminates

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Hybrid metal laminates are of high relevance for renewable energy technologies such as wind power generators, electric engines or transformers. Especially for electrical steel stacks, waterborne epoxy coatings cured with the latent curing agent dicyandiamide (DICY) are well-established. As evidenced in previous studies for electrical steel laminates, chemical interactions take place already during coating of waterborne epoxy varnishes onto the metal substrate. The main objective of this study was to evaluate waterborne epoxy/metal interactions on a fundamental and more comprehensive level. Pure metals such as Sn, Ti, Fe, Al, Zn or Mg with oxide or hydroxide passsivation layers differing in their isoelectric point (IEP) were considered. While Sn is chracterized by a rather acidic oxide, MgOH is classified as alkaline. First, the pure metal sheets were immersed in a boiling solution of DICY in water. The lower the IEP, the higher was the amount of protonated amine at the surface. Vice versa, high IEP metals revealed an pronounced formation of imine species. Second, epoxy coated metal sheets were investigated. The coated metal was cryo-ultra-low-angle-microtomed (cryo-ULAM) and characterized by XPS. At the epoxy/metal interface, reaction products were detected which were in agreement with the immersion test. Moreover, it was confirmed that especially alkaline metal oxides are prone to release metal ions migrating into the epoxy coating. Metal complexes were discrnible within the bulk, but also on the surface of the few microns thin epoxy coating. Finally, the effect of the IEP of the substrate on the crack growth kinetics of bonded laminates was assessed by cyclic fatigue tests on double cantilever beam specimen. The higher the IEP of the metal substrate, the slower was the crack growth rate in the stable crack growth regime and the higher was the strain energy release rate in the threshold regime. Overall, this study clearly confirmed that chemical interactions are taking place during manufacturing of waterborne epoxy/metal laminates, which have a significant impact on the adherence and the crack growth resistance [1].

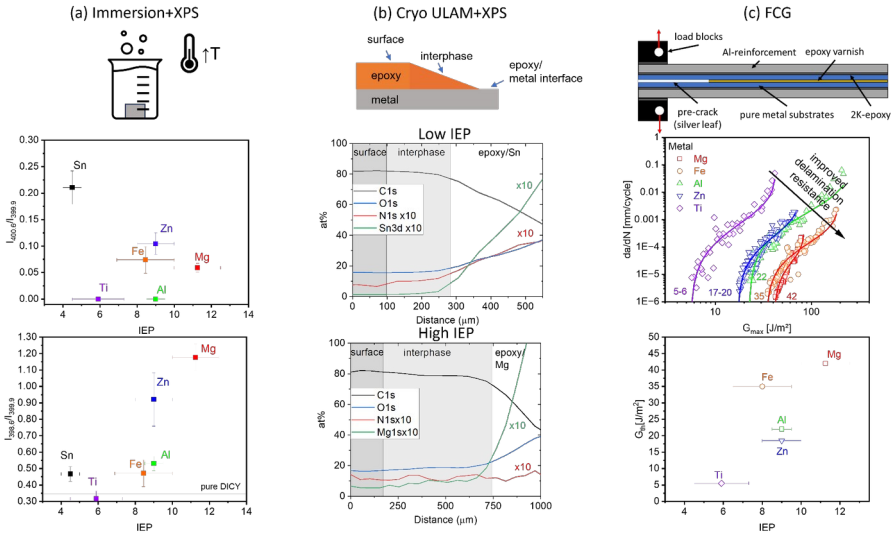

Fig. 1: **Effect of the isoelectric point of a metal oxide on the formation of DICY reaction products (a) after immersion in a solution of DICY in water, and (b) in epoxy coatings on metal substrates, and (c) on the fatigue debonding kinetics of epxy/metal laminates.**

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Reference

[1] Säckl, G., Riedl, G., Duchoslav, J., Marchfelder, C., Aufray, M., Stifter, D., Wallner, G.M., (2025). Metal laminates based on waterborne epoxy varnishes - chemical inter-actions and effect on fatigue crack growth kinetics, Progress in Organic Coatings, 200, 109104.