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Non-deterministic characterization of the damage tolerance of metal/composite structure

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Layered fiber reinforced composite overlays (patches) co-cured to a metal substrate, called composite/metal hybrid structure, have been proven to effectively restore the load carrying capacity to fatigue-cracked or corrosion-damaged parts and reinforce under-designed regions. Application of the composite overlay has been demonstrated to reinforce or repair metallic structures in engineering fields such as aerospace, automotive, infrastructure, and marine. Even with the many advantages offered by composite/metal hybrids, a serious concern comes with the evaluation of their non-visible damage. Non-visible damage, occurring internally and potentially unidentifiable prior to complete failure, occurs within the composite overlay during designed loads or overloads such as from bending and low-velocity impact. This non-visible damage can progress as matrix cracking, fiber breakage (fracture or buckling), delamination within the composite, or disbond at the composite/metal interface. Previous studies have demonstrated that the damage within the composite patch can substantially reduce the performance of the repair or reinforcement [1, 2]. Therefore, it is necessary to capture multiple damage mechanisms and progressive failure to model and predict damage initiation and propagation in these hybrid structures.

This study uses a validated, high fidelity finite element model that includes the relevant damage mechanisms in the composite, interface, and metal to addresses several challenges in the prediction and understanding of composite overlay performance with respect to damage tolerance. The large number of model inputs encompassing material selection significantly increases the difficulty in identifying the most influential inputs on the damage tolerance, as developing a validated surrogate model and performing sensitivity analysis becomes prohibitive for non-linear, highly dimensional parameter spaces. This challenge is compounded by the likelihood that, during preliminary design and evaluation, many of the parameters may be defined by sparse data, average values, or estimates based on the behavior of similar materials. A systematic, non-deterministic approach encompassing damage tolerance characterization, sensitivity analysis, and uncertainty quantification was applied to (1) evaluate the effects of data quality on damage prediction, (2) formulate a reduced order surrogate model created using artificial neural network, and (3) map damage tolerance subspaces to enable rapid exploration of a large material property parameter space.

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