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Functionally graded adhesive joints fabricated via multi-material additive manufacturing

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This study investigates an advanced strategy to enhance the performance of adhesively bonded joints through functionally graded curing enabled by multi-material additive manufacturing. Conventional thermal curing of adhesives in complex geometries is often limited by heat conduction and material distribution, leading to suboptimal mechanical performance. In this work, spatially controlled temperature gradients are generated across the adhesive layer using embedded, additively manufactured resistive heating elements fabricated from conductive filaments and placed at the adherend–adhesive interfaces. This approach enables programmable, gradient thermal curing along the overlap region and through the adherend thickness, promoting precise curing, reduced residual stresses, and improved load distribution. Mechanical testing is conducted to evaluate the strength and failure behavior of the graded joints, and the results are compared with those of conventional homogeneous adhesive joints. The results demonstrate that functionally graded adhesive joints produced using embedded 3D-printed heating elements exhibit progressive failure mechanisms and a load-bearing capacity improved by up to 170%. The proposed methodology provides a scalable platform for tailoring local adhesive properties and for designing functionally graded adhesive joints, offering new opportunities to optimize stiffness distribution and mechanical performance in advanced structural applications.

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