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Tyler Hudson AERoBOND Project Summary 4/24/20

Under NASA's Convergent Aeronautics Solutions (CAS) project, the Adhesive-Free Bonding of Complex Composites (AERoBOND) project investigated off-stoichiometric epoxy polymers for fast, reliable assembly of epoxy matrix composite structures. The project goal was to demonstrate feasibility of the AERoBOND joining method by demonstrating mechanical properties greater than 80% of conventional co-cured materials while reducing structure weight by 1%. The project consisted of three convergent research areas: material and process development, systems analysis, and material and process modeling. Material and process development was the largest component of AERoBOND with approximately 6 FTE and 1 WYE of support to formulate and characterize new resins, prepare carbon fiber prepregs, fabricate laminates, measure mechanical properties, analyze failure results, and select material and process improvements. The systems analysis activity estimated the potential reduction in part count and aircraft weight by comparing models of composite wing boxes with no fasteners (co-cured structure), fasteners in major joints (co-cured stringers), and fasteners in all joints. The materials and process modeling activity included a molecular model of the AERoBOND materials system to predict mechanical properties of resins with offset stoichiometry and a process model to predict the effect of resin formulation and processing conditions on the extent of mixing and degree of cure in a finished joint.

As the number of airline passenger trips doubles in the next 20 years (IATA/Tourism Economics Air Passenger Forecasts, April 2019), the increased demand for new commercial aircraft is now the single greatest technical challenge to the airframe manufacturing industry. To meet efficiency requirements, new aircraft must be fabricated primarily from high performance structural composites, but manufacturing processes are inherently slow with the largest bottleneck attributed to assembly and installation of fasteners (NASA/TM–2019-220428). Manufactures of commercial transport aircraft are compelled to install more than 100,000 redundant fasteners into bonded joints to prevent failures due to unpredictable weak bonds. In structural adhesive bonds, the interface between adherend and adhesive is nearly two-dimensional making it susceptible to minute quantities of contamination, which can cause weak bonds. Currently, bond strength assessment is only possible through destructive testing (i.e., breaking the joint). For these reasons, regulatory organizations such as the Federal Aviation Administration (FAA) often require redundant load paths in secondary-bonded, primary-structures to alleviate concerns with bond performance. The AERoBOND process enables reflow of matrix resin during assembly to eliminate the material discontinuity at the interface, thereby eliminating the dependence of mechanical performance on interfacial adhesion. The AERoBOND joint is equivalent to the interlaminar region obtained during a co-cure process, so joint performance depends on the cohesive properties of the matrix resin. Conventional co-cured structures, although too costly and complex for large-scale manufacturing, are trusted by manufacturers and regulators, and are certified for flight with few or no redundant fasteners.

Systems analysis performed on a composite wing model at the scale of a single-aisle commercial transport aircraft indicated that >20,000 redundant fasteners per wing could be eliminated by implementing the AERoBOND joining method. A total weight reduction of 15% was predicted in a wing box by eliminating fasteners and thinning components that must no longer support localized fastener loads and accommodate fastener dimensions. Interlaminar shear fracture toughness measured by the end-notched flexure test was greater than 1 kJ/m^2 (nearly 140% of the co-cured benchmark property), which is greatly in excess of the project goals for mechanical properties. Testing was planned to measure interlaminar tensile fracture toughness as well as interlaminar tensile and shear strengths using the same AERoBOND configuration, but was delayed due to closure of LaRC facilities during the COVID-19 pandemic. The AERoBOND process model is partially validated and available for experimental use. It allows the user to input AERoBOND process parameters such as material composition, laminate configuration, and cure cycle to predict the final cure state of the AERoBOND joint. A preliminary, multi-scale material model was developed to predict AERoBOND joint mechanical properties (stiffness and strength) based on the cure state of the joint provided by the process model.

The timing for transition of this technology within NASA is excellent as NASA initiates new enduring projects to address composites manufacturing rate challenges. AERoBOND technology is well suited to AAVP/AATT objectives for rapid manufacturing of a composite wing. A minimal effort (1 FTE/$15k procurement/0 WYE) is proposed in FY21 to continue a minor mechanical testing effort and maintain a SAA with ASX composites to develop commercial quality prepreg material. An RFI with the composites industry is suggested to quantify the technology gap between the current TRL and the TRL needed for transition to industry. A moderate effort [3-4 FTE/$150k/1 WYE (~$115k)] is proposed in FY22 for the "high rate composites manufacturing" project currently in planning. The partnership with ASX Composites will be expanded to produce material for sub-element/element-scale "panel-off" activities. Industry partnerships with airframe manufacturers is an expected component to explore damage tolerance and environmental stability. Further development of multi-scale modeling tools (process model, meso-scale model, and molecular model) is planned to enhance and deliver tools for rapid manufacturing infusion.